A Spectral Representation of the Phillips Curve in Australia

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Abstract

We present the Phillips curve in Australia in the frequency domain and document an evolving pattern in its slope at low frequencies 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 lagged unemployment during the first period but led during the second period. The Phillips curve at business-cycle frequencies is downward sloping in all periods. The flattened Phillips curve is 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. Notwithstanding similar level of economic development and monetary policy adopted by central banks, Australia can be distinguished from other economies by its economic structures and labor market relations. Australia 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 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 also coincided with the first oil price shock. There were also agreements between the Australian Labour Party and Australian Council of Trade Unions from mid-1980s to mid-1990s on nominal wage setting to control inflation. Changes in the monetary policy regimes and wage setting behaviors in the labor market may have contributed differently to the inflation-unemployment relationship at different points in time and across frequencies, and justify an independent investigation for Australia.

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

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[1] The business-cycle Phillips curve is also referred to the short-run Phillips curve. In this article, business-cycle Phillips curve is defined over the business cycle frequencies; high frequency components in the data have been discarded.

over time depending on the sample period studied. 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 1954-92. 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 observe a flattened long-run Phillips curve at low inflation in Australia.[3] There are studies that document the Phillips curve in Australia for different periods (discussed in Section 2), but 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 two major respects. The first is to document 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 about the long-run Phillips curve from estimation of (time varying) the equilibrium unemployment rate (non-accelerating inflation rate of unemployment (NAIRU)) rather than directly estimating it. The second main departure is to employ the spectral method to document the relationship. The spectral method investigates the inflation-unemployment relationship without relying on any identifying restrictions on it. In contrast, in the time domain,

[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 (2015) have also observed similar in the case of Sweden.

the long-run relationship depends on the short-run identifying restrictions.[4] The spectral method is able to estimate the relationship at each frequency, while the estimated coefficient in the time domain can be thought of an average of the coefficients across frequencies within the relevant frequency band. For example, regression using the band-pass (or low-pass) filtered series estimates a coefficient that is the average of the regression coefficients over the business-cycle (long-run) frequencies, such as 6 to 32 quarters (or 32 quarters and above). Cointegration, in contrast, estimates the long-run relationship at zero frequency. The spectral method also allows to investigate the lead or lag in the relationship (direction of causality) within the same framework.

We first identify the periods over which the patterns in the long-run relationship between the CPI inflation and unemployment are qualitatively different.[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 filtering in which filter weights are derived based on the Baxter-King (1999) band-pass filter. We observe the first break during 1974-76 and a second sharp break in 1993. The timing of these breaks coincide with the adoption of aggregate monetary targeting in 1976 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 that also coincided with the oil price shock may also have contributed to the first break. In the pre-1977 period, the long-run Phillips curve is upward sloping; however, it becomes very steep (almost vertical) if the sample period is shortened to the

[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 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) have 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 the CPI inflation and unemployment.

pre-1974 period. 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-cycle Philips curve, drawn using the band-pass filtered data, is downward sloping in all periods 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 inflation on unemployment 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 the appropriate filter. The squared coherence is analogous to the *R*-square in a two-variable regression. 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 low 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 the series to be stationary. 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 specification can be regarded as the reduced form expectations-augmented Phillips curve that examines how the inflation deviates from its expected level at different frequencies when the 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 quarters range-medium-run frequencies), while it is significant at all long-run frequencies (32 quarters and above) in the 1977-1993 period. 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 this downward sloping long-run Phillips curve. However, if the first period is shortened to pre-1974, the significance of the gain narrows down to 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 entire 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 lagged unemployment in the pre-1977 period but led 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 first two periods. This latter can be seen from the significance of the gain (and squared coherence) at some but not all business-cycle frequencies; however, the gain fluctuates enormously across frequencies in all periods.

We finally document that the inflation-unemployment relationship observed in Australia in the post-inflation targeting period is not unique but resemble several other countries that adopted inflation targeting, such as Canada, Sweden, New Zealand and the UK. But the pre-inflation targeting relationship varies across countries.

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

The organization of the paper is 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 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 are explained in Section 6. Section 7 graphically presents the Phillips curve in the frequency domain. Explanations for the evolving patterns in the long-run relationship are also discussed in this section. In Section 8, inflation-unemployment relationship in several inflation-targeting countries is compared with that observed in Australia. Finally, Section 9 concludes.

2. A brief review of the Phillips curve studies 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, especially in 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. 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 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 historical perspective

In this section, we discuss milestones in the history of Australian monetary policy and their possible effects on the long-run inflation-unemployment relationship. 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

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

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 wage 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 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 based on different monetary policy regimes can be identified over which inflationary behavior is expected to be different: i) pre-1977, ii) 1977-1993, and iii) post-1993. In the following, we observe that these are indeed the break points in the long-run inflation-unemployment relationship. However, the first break point is not as clear as the second one since the former also coincided with the real wage and/or oil price shocks; we therefore additionally estimate for the pre-1974 period as an alternative to the first episode.

4. Inflation-unemployed relationship in the time domain

To complement our analysis in the frequency domain, we first document the long-run and business-cycle inflation-unemployment relationship in the time domain using the filtered data. These results provide useful insights about the relationship.

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, not reported, also support).

[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 series from the original CPI series (ID: A2325846C) as $[(CPI_t - CPI_{t-4})/CPI_{t-4}]*100$; the two series differ only by 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

The long-run or low frequency values (calculated by the low-pass filter following Baxter-King (1999)) 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) 1959:3-mid-1970s ii) mid-1970s-1993:3, and iii) 1994:1-2012:4, that are consistent with policy changes and shocks discussed earlier. During the 1959-1974 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 very steep (near vertical) long-run Phillips curve and thus almost no trade-off between inflation and unemployment as can also be seen from the linear fit. If the first period is extended to 1976 following the adoption of monetary targeting, the fit becomes slightly flatter. Inflation slowly and gradually declined and unemployment secularly increased 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-2 (A-D) display the Baxter-King (1999) 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 1994:1-2012:4 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.

Insert Figures 1-3 here

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

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October 31, 2014). The series (Series ID: AUSGDPDEFQISMEI) is seasonally adjusted quarterly inflation, so we multiply it by 4.

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 reproduce the above relationship using the percentage change in the implicit GDP deflator. These are displayed in Figures 3A-3F. Figure-3A displays the CPI and GDP deflator inflation. Both series 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-3 (C-F). In all cases, there is a negative relationship as in Figures-2 (A-D) although the slopes differ in magnitude for the two inflation measures. Therefore, the relationship using the two series suggests the same conclusion; we use CPI inflation for further analysis.

5. The Phillips curve model

In the following, we discuss the Phillips curve model that we estimate in the frequency domain. We also relate this specification to alternative specifications with micro-foundations. 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 New Classical (NCPC) and New Keynesian Phillips curve (NKPC). For example, it becomes 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 the 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:

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

where $\hat{\pi}_t = \pi_t - \pi_t^e$ and $\hat{u}_t = u_t - u_t^N$. The main challenge is to extract unobservables, 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, say, u_t (unemployment), the UC is defined as:

$$u_t = u_t^N + \varepsilon_t \;,\; \varepsilon_t \sim NID\left(0, \sigma_\varepsilon^2\right),$$

where u_t^N is the NAIRU and is modeled as

$$u_t^N = u_{t=1}^N + \eta_t \text{ , with } \eta_t \sim NID\left(0, \sigma_\eta^2\right).$$

The disturbances, ε_t and η_t are serially and mutually uncorrelated, and normally and independently distributed (*NID*) with mean zero and variance σ_ε^2 and σ_η^2, respectively. The inflation is modeled similarly. 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 ($\hat{\pi}$ and $\hat{u}$) are stationary processes, and therefore equation (2) can be estimated in the frequency domain. Our specification examines how inflation deviates from its expected (trend) level at different frequencies when

[9] Figure-1B provides support for such modelling. Cogley, Primiceri and Thomas (2010) and Harvey (2011) also model the trend inflation as a driftless random walk for the USA. On the other hand, King and Morley (2007) estimate NAIRU in a SVAR model.

unemployment deviates from its natural rate.[10] Svensson (2015, equation (7)) also estimates a variant of equation (2) by adding lag 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 gaps. Frequency domain method estimates parameter at each frequency without specifying lag structures.[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.

[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.

[11] McCallum (1984) criticizes the tests for the long-run Phillips curve by the 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 (equation (2)) is immune to this critique.

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 $\hat{\gamma}_{yx}^{j}=\frac{1}{T}\sum_{t=j+1}^{T}(y_t-\overline{y})(x_{t-j}-\overline{x})$. 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 part is called quadrature spectrum. We write these two as $\hat{c}(\omega)=\hat{\gamma}_{yx}^{0}+\sum_{j=1}^{T-1}\left(\hat{\gamma}_{yx}^{j}+\hat{\gamma}_{yx}^{-j}\right)\cos(\omega j)$ 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.[12]

To estimate a 95% confidence interval of the coherence, 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

[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.

(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 $\tanh z_1 \le C(\omega) \le \tanh z_2$, where z_1 and z_2 are $\text{arctanh}\hat{C}(\omega) \pm \left(1.96g / \sqrt{2}\right) = (1/2)\ln\left\{\left(1+\hat{C}(\omega)\right)/\left(1-\hat{C}(\omega)\right)\right\} \pm \left(1.96g / \sqrt{2}\right)$. 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: $\hat{G}(\omega) \pm \hat{G}(\omega)\left\{\left[\hat{\sigma}^2 \big/ \left(1+2\hat{\sigma}^2\right)\right] 2F_{2,2n-2}\right\}^{1/2}$, 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, 4.3 and 4.4).

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 the 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. The Phillips curve in the frequency domain

The long-run and business-cycle Phillips curves are presented in terms of the gain, squared coherence and phase spectrum. As mentioned earlier, the gain is analogous to the absolute value of the regression coefficient in a regression of inflation on unemployment. We supplement the sign of the gain by the linear fit of inflation on unemployment in the time domain transforming the data by appropriate filtering discussed in the previous section. We suggest a strong relationship if the lower 95% confidence line of the gain exceeds zero at all frequencies in the relevant range. 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.[13]

7.1 The long-run Phillips curve

In the following, we present the long-run relationship in the $[0,\ \omega_1 = 0.196]$ frequency range separately for three distinct sub-periods.[14]

The results for the 1959:3-1976:4 period are presented in Figures 4 (A-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. However, it is statistically significant (lower confidence line lying above zero) only at relatively higher frequencies $[0.113,\ \omega_1]$ (implying a periodicity ranging between 32 and 56 quarters). These two observations suggest a weak long-run Phillips curve; more specifically, a Phillips curve at higher frequency component of the long-run or alternatively 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 $[0.113,\ \omega_1]$ frequency range (Panel C). Since the gain (and squared coherence) is significant only 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 sample period is shortened to 1959:3-1973:4 based on the real wage and oil price shocks (Figures-5 (A-D)), the long-run frequency range over which the gain is significant becomes even narrower at the higher frequency component

[13] For a discussion on the direction of causality in terms of the phase, see Hause (1971).

[14] The sample size becomes small for separate analysis of the sub-periods. However, this is a problem in any time series analysis even in the time domain.

$[0.15,\ \omega_1]$ (or equivalently, 32-42 quarters, which are close to the business-cycle frequencies). This clearly suggests an absence of the long-run Phillips curve. No definite lead or lag in the relationship between inflation and unemployment can be established as the phase is insignificant at all frequencies.

The relationship for the 1977:1-1993:4 period is shown in Figures-6 (A-D). The gain, displayed in Panel A, secularly increases along long-run frequencies and range between 0.32 and 0.58, and is significant at all frequencies. Combining with the fit in Figure-1D, a long-run downward sloping Phillips curve is suggested for 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 $[0.025,\ \omega_1]$ frequency range but now positive implying that inflation leads unemployment (direction of causality from inflation to unemployment). This direction of causality may seem opposite to that suggested by the standard Phillips curve model. However, 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 for the period aftermath of real wage and oil shocks, but additional factors may be at work, such as the changing labor relations that we discuss in next section.

In the 1994:1-2012:4 period, gain, squared coherence and phase are insignificant at all frequencies suggesting no long-run Phillips curve (Figures-7 (A-C)). This 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; inflation in this period remains persistently low with very little variations over time.

Insert Figures 4-7 here

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

Our explanations of different slopes of the long-run Phillips curve in different periods 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, short-run supply curve shifts so that output moves back to its natural level (unemployment also 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 shifting the short-run supply curve. For Australia this shock is the real wage shock in 1974 caused by labor union (the oil shock in 1973-74 may not have much impact, discussed in Section 3). Our results are consistent with the above argument in that there is no long-run Phillips curve (near vertical slope) for the 1959-1974 period, but it flattens to become positively sloped if the period is extended to 1976 (shortly after realization of the shock that increased unemployment) indicating a medium-run rather than long-run relationship.[15] 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)[16] estimate (retrieve) time-varying wage rigidity for Australia. The wage rigidity remained almost unchanged until the mid-1970s

[15] Berentsen, Menzio and Wright (2011) provide an alternative argument for upward sloping long-run Phillips curve. They develop a model appropriate for the low frequency with explicit 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 (but not the entire sample period), so our results are consistent with the supply shock argument of Gordon (2013).

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

and gradually increased since then that continued till 1993. The variations (increase) in wage rigidity are the result of changes in labor market regulation and institutions rather than the new monetary policy.

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 and the wage share returned to its pre-shock level (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). 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) 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 limiting 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 Reserve Bank of Australia 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). Paradiso and Rao (2012) argue for a lower inflation target to be the reason for flattening Phillips curve in Australia. Anchored inflation expectations has been offered as an explanation for the flattened (downward sloping) long-run Phillips curve by Fuhrer (2011) and Benigno and Ricci (2011) in the case of the USA and by Svensson (2015) in the case of Sweden.[17]

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

[17] 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 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 (2014) 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. Svensson (2015) argues that if inflation expectations become firmly anchored at the inflation target even when average inflation deviates from the target, the long-run Phillips curve becomes nonvertical.

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 range suggesting a weak relationship. The squared coherence is significant in the similar frequency range. The phase is also significant in the similar range and is negative implying inflation as the lagging variable (Figure-8C).

Figures-9 (A-C) display the business-cycle relationship for 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] range which is even narrower compared to the previous period. This again 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. The business-cycle relationship for 1994:1-2012:4 period is displayed in Figure-10 (A-C). The gain fluctuates between 0.467 and 1.759 but is significant at all frequencies suggesting a strong relationship in this period. 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 but negative at the frequencies in-between.

Combining with the information of the linear fits in Figures-2 (A-C), we suggest downward sloping Phillips curves at the business-cycle frequencies in all periods, but the relationship is strong only in the post-1993 period.

Insert Figures 8-10 here

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.[18] The dates for their announcement of inflation targeting are 1991, 1993, 1990 and 1992, respectively (Roger, 2010).

[18] Inflation data have been obtained from OECD http://data.oecd.org/price/inflation-cpi.htm (Accessed on 19 February 2015). Unemployment data have also been obtained from the same source

Insert Figures 11-15 here

The long-run and business-cycle inflation-unemployment relationship drawn from the low- and band-pass filtered series using the Baxter-King (1999) filter are displayed in Figures 11-14. The figures show enormous similarity in the long-run relationship among these countries in the post-inflation targeting period and also with Australia. In all countries, the long-run Phillips curve is flat (horizontal) since they adopted inflation targeting.

The patterns of the long-run Phillips curve in the pre-inflation targeting period differ across countries and cannot be generalized. For example, for the UK (Figure-12A) and New Zealand (Figure-14A),[19] it is downward sloping and is very similar to that for Australia. For the UK, the downward slope is more pronounced for the 1975-1984 period. In the case Canada (Figure-11A), the slope in the 1975-1990 period appears to be negative at first glance; however, careful consideration reveals a different pattern. For the 1984-1990 period, the long-run Phillips curve is also flat (horizontal) as in the post-inflation targeting period. In the pre-1975 period, the long-run Phillips curve is vertical. In the case of Sweden (Figure-13A), the long-run Phillips curve is downward sloping, but there is no pattern if the sample period is shortened to 1990 (excluding only 3 years of data from 1991 to 1993).

Recently, some commentators (e.g., Beyer and Farmer, 2007; Russell and Banerjee, 2008; Berentsen, Menzio and Wright, 2011; Haug and King, 2014) have argued for an upward sloping long-run Phillips curve in the USA. It is important to note that although the US Fed

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http://data.oecd.org/unemp/unemployment-rate.htm (Accessed on 19 February 2015). However, for the UK and Sweden, the unemployment data span shorter period of time. For the UK, unemployment data starts from 1999:Q2; data for the 1971:Q1-1999:Q1 period have been obtained from the Office for National Statistics (Seasonally adjusted monthly data; lfs8df series). For Sweden unemployment data starts from 2001:Q1; data for the 1976:Q1-2000:Q4 period have been obtained from the labour statistics database of the International Labour Organization (ILO).

[19] The results for New Zealand should be treated with caution because the data date back only to 1986.

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, 2015). 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 inflation targeting. The long-run Phillips curve is indeed upward sloping if the entire period is considered (Figure-15A), but this examination masks the changing patterns in its shape over time. A similar upward sloping long-run Phillips curve can also be visualized for the 1983-1999 period (Figure-15C); however, the slope is downward sloping for the 1975-82 period (after the oil shock to the Volker recession) (Figure-15B). On the other hand, for the post-2000 (post-inflation targeting) period, the long-run Phillips curve has flattened (Figure-15D).

These findings suggest that there is striking similarities among inflation-targeting countries in their inflation-unemployment relationship—a persistently low inflation since inflation targeting leading to flattened long-run Phillips curve. It is likely that the same explanation of the anchored inflation expectations due to inflation targeting may be at work for all countries. On the other hand, the relationship in the pre-inflation targeting period varied across countries. The effect of oil price shock in 1973-74 that was common to all countries cannot be generalized for an explanation for the shape of the long-run Phillips curve. Each country may have its own unique reasons, such as the labor market developments in the case of Australia. The business-cycle Phillips curve, on the other hand, is always negatively sloped for all countries and sub-periods with varying slopes.

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 in Australia can be distinguished in three distinct periods based on the monetary policy regimes: 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, which is complemented by the linear fits in the time domain. In the first period, a positive relationship between inflation and unemployment exists at the high frequency components of the long-run, or more specifically, in the medium-run (periodicity of 32-56 quarters). However, if the sample period is shortened to pre-1974 based on real wage and oil price shocks, the relationship weakens being significant at even higher frequency components of the long-run (periodicity of 32-42 quarters).[20] 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 regulations and institutions as the reason for the downward sloping long-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 post-1993 period. In this period, inflation is persistently low with almost no variations due to anchored inflation expectations resulting from inflation targeting by the RBA. There is a negative relationship between unemployment and inflation at the 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 in the post-1993 period is not unique in the case of Australia but also hold in the case of several other 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 unemployment cost of deflation is very large at low inflation (Svensson, 2015).[21] However, 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 over the business-cycle frequencies. This result has important implications for the conduction of monetary policy.

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[20] The result of the medium-run Phillips curve in the first period based on the statistical significance of the gain at larger frequencies in the long-run range is not captured in the time domain regression.

[21] Disinflation did not occur in the USA during the Great Recession. Coibion and Gorodnichenko (2015) explain the missing disinflation by the rise in the households' inflation expectations during 2009-2011.

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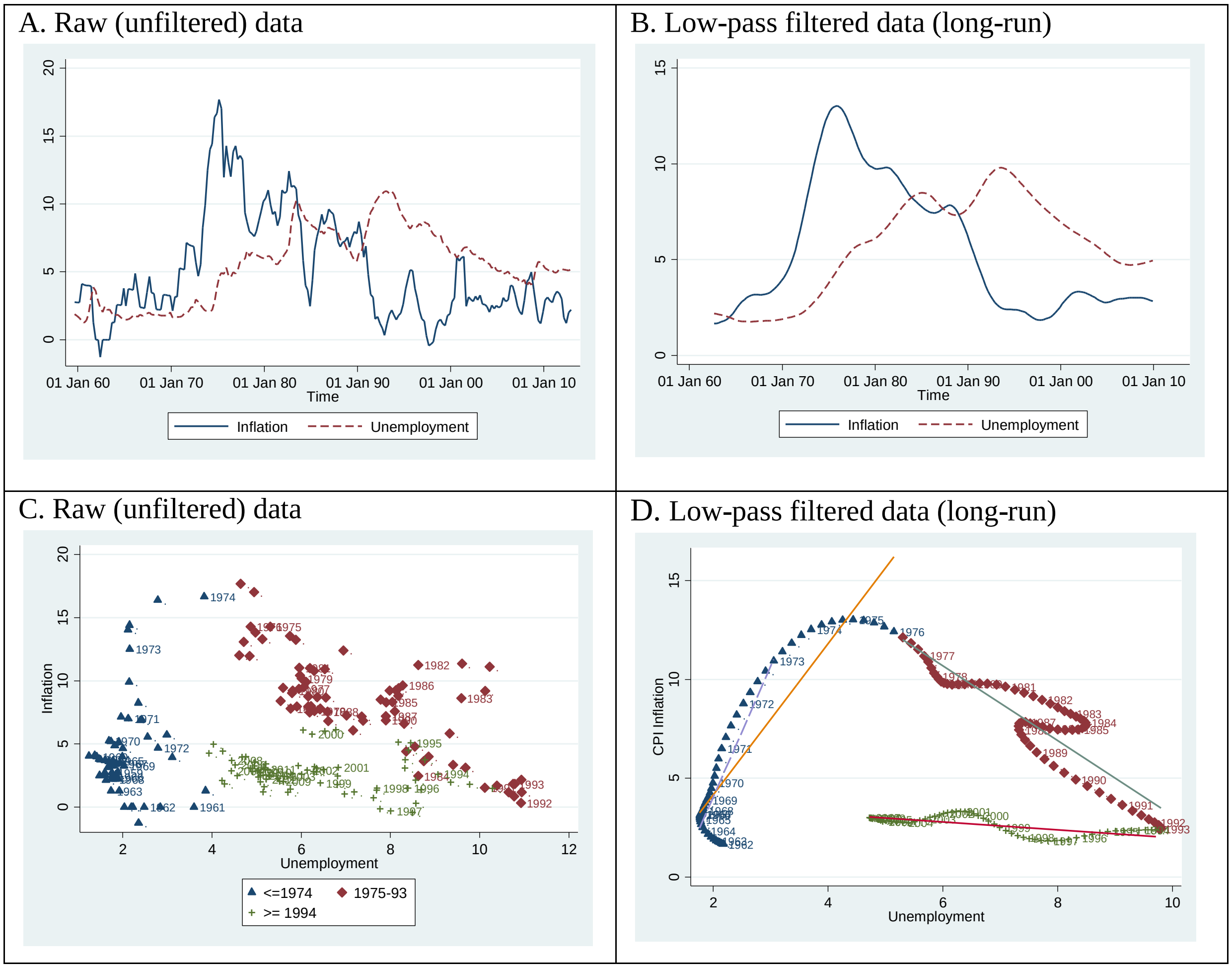
Figures

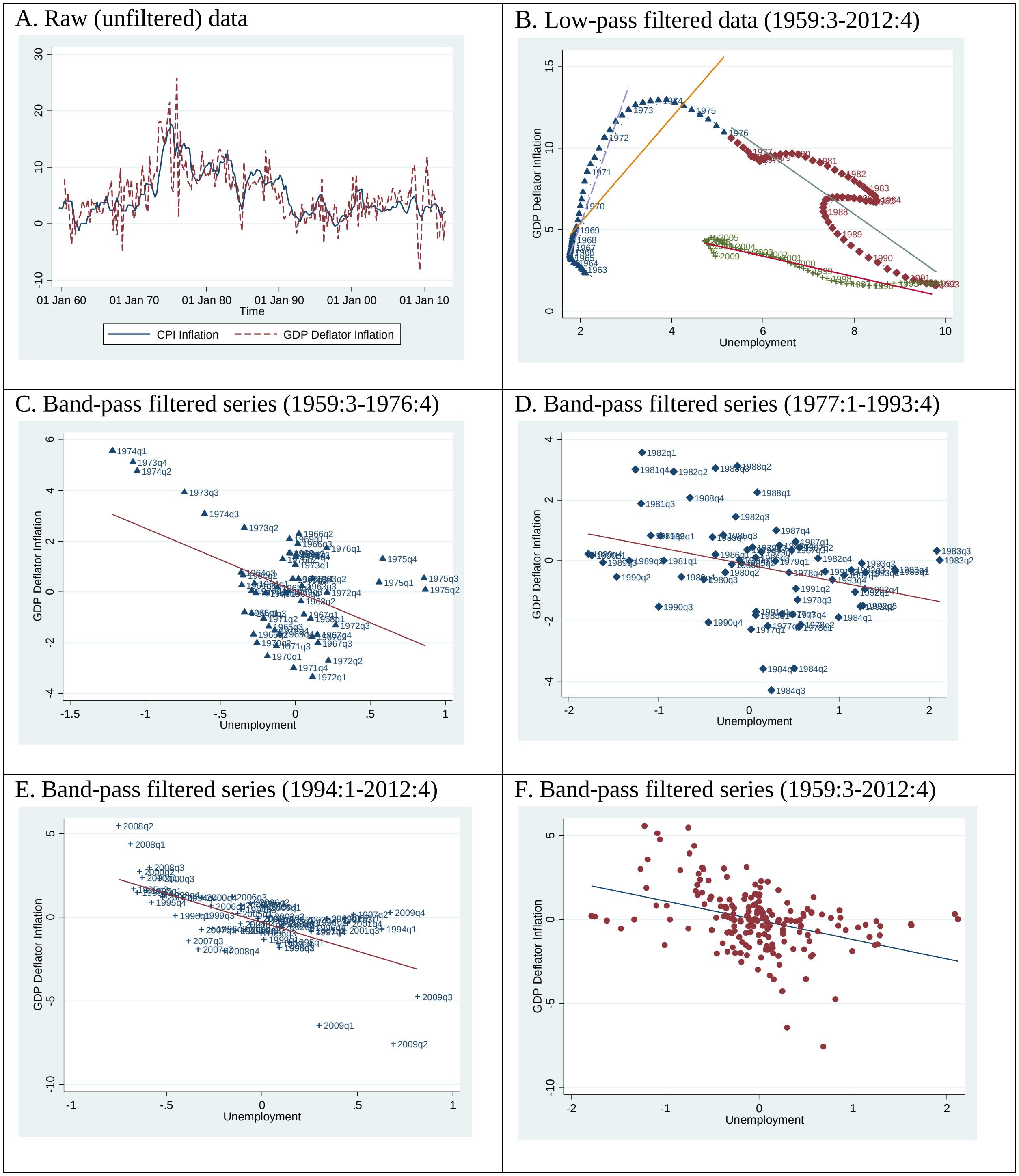
Figure-1: Inflation-unemployment relationship over different frequency ranges for the 1959:3-2012:4 period



Note for Figure-1D: The broken upward sloping straight line 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 the business-cycle frequency ranges for different periods

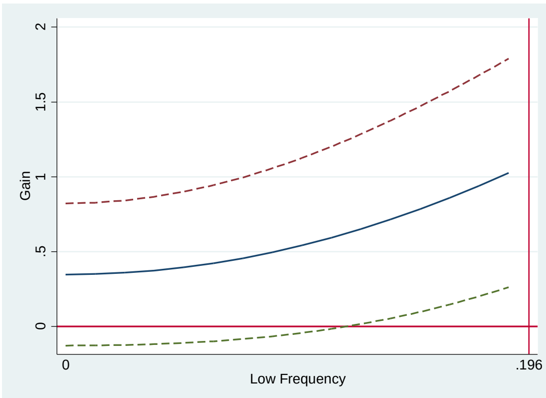
Figure-3: Inflation-unemployment relationship: Inflation measured as the change in the GDP deflator



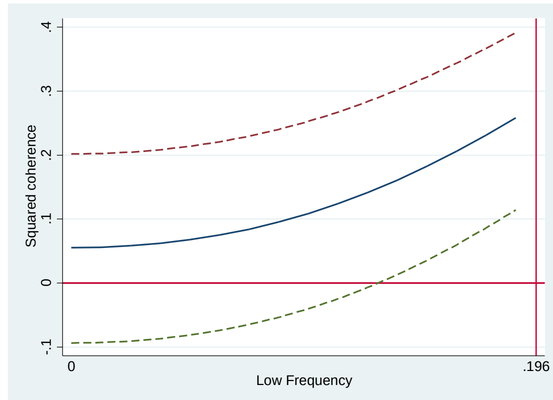
Note for Figure-3B: The broken upward sloping straight line is the linear fit for the 1959:3-1973:4 period. The solid upward sloping straight line is the linear fit for the 1959:3-1976:4 period.

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

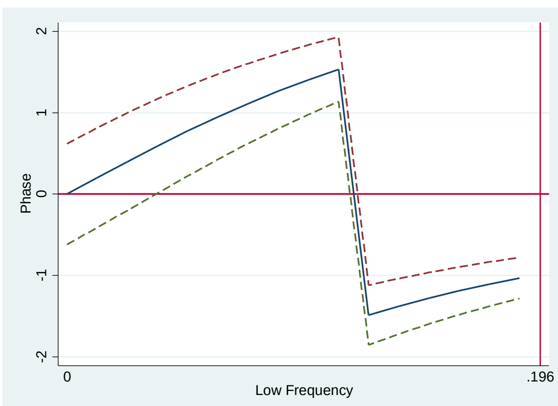
A. Gain



B. Squared coherence



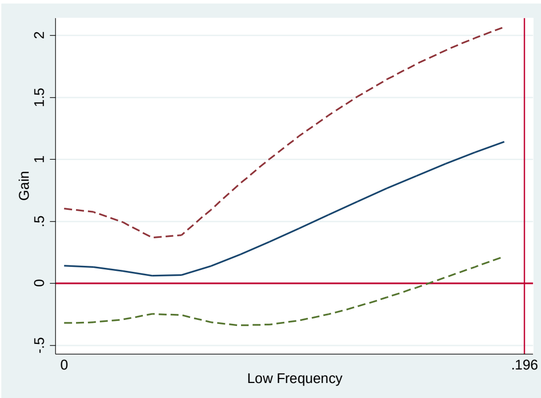
C. Phase



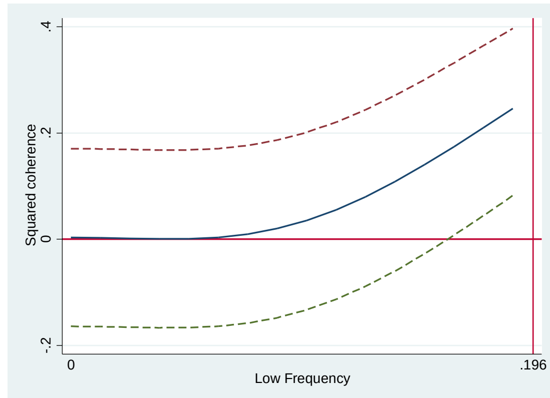
Note: Dotted lines represent the 95% confidence intervals.

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

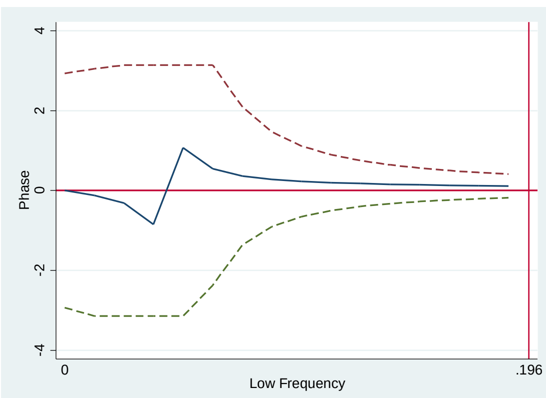
A. Gain



B. Squared coherence

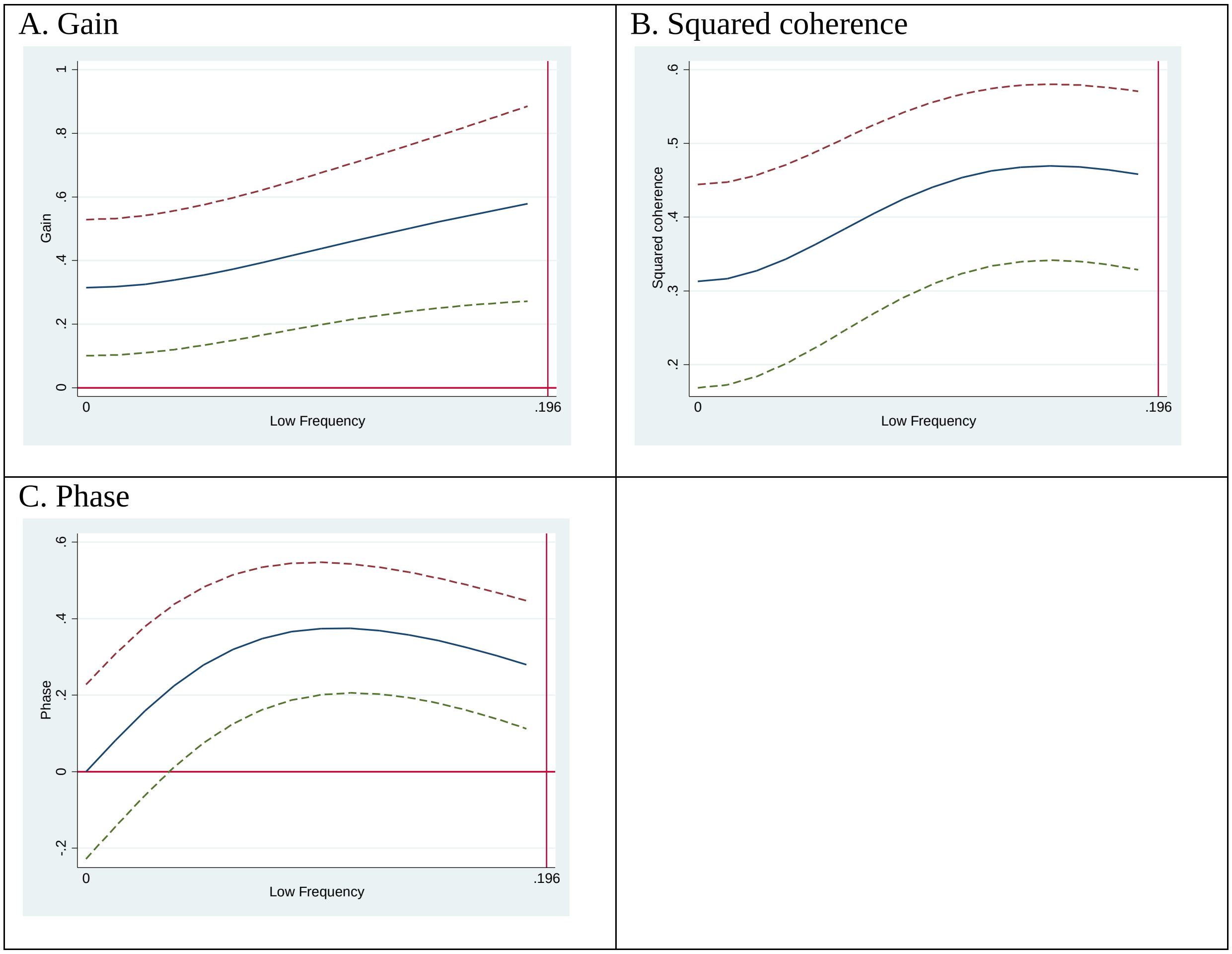


C. Phase



Note: Dotted lines represent the 95% confidence intervals.

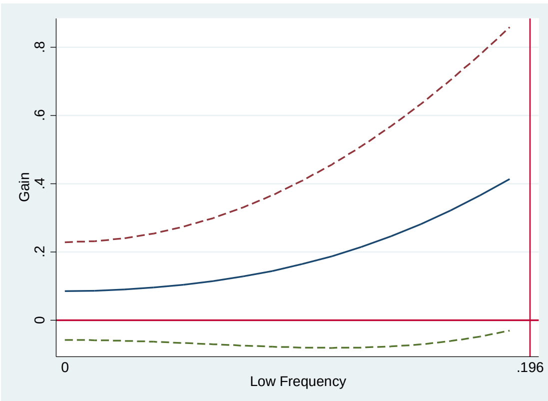
Figure 6: Long-run relationship (0-0.196 frequency range) for the 1977:1-1993:4 period



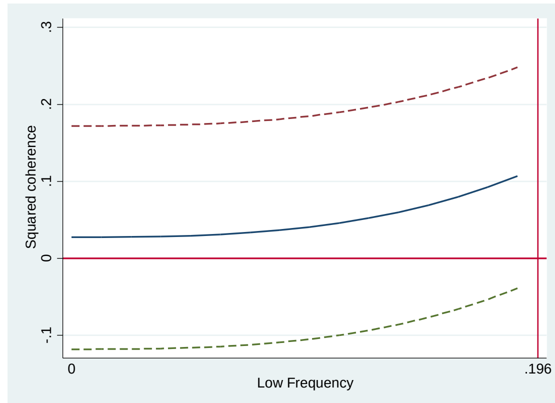
Note: Dotted lines represent the 95% confidence intervals.

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

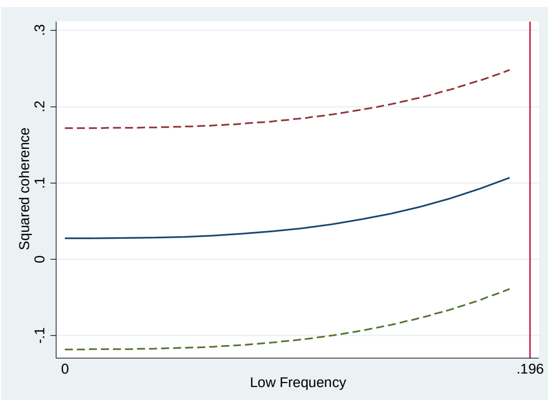
A. Gain



B. Squared coherence



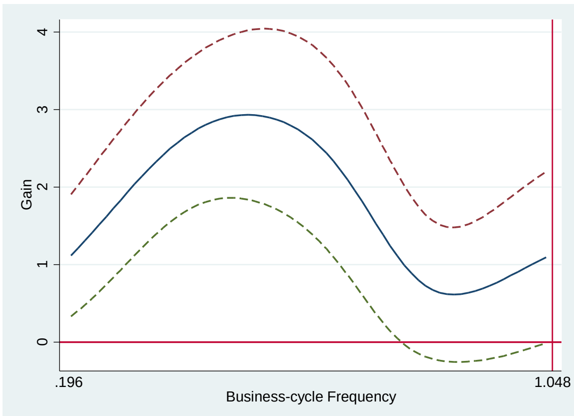
C. Phase



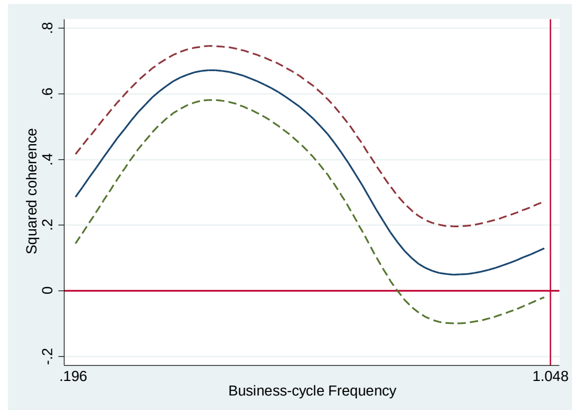
Note: Dotted lines represent the 95% confidence intervals.

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

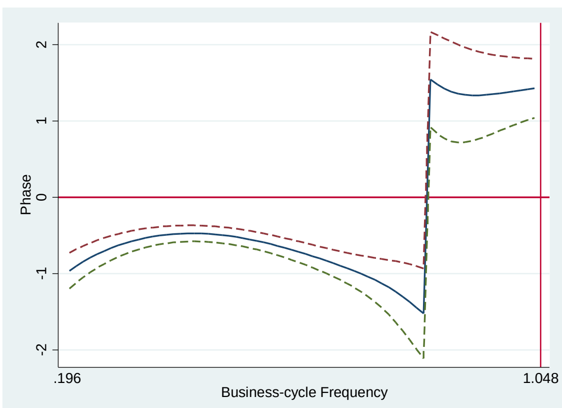
A. Gain



B. Squared coherence



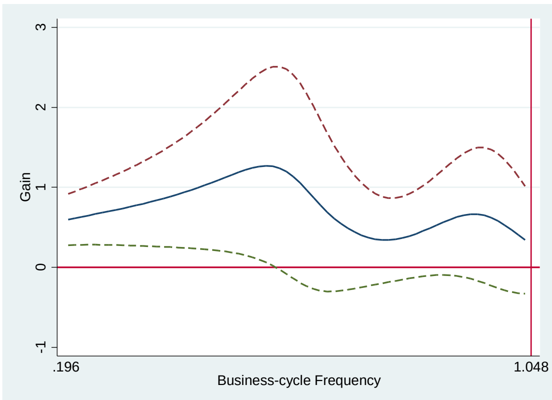
C. Phase



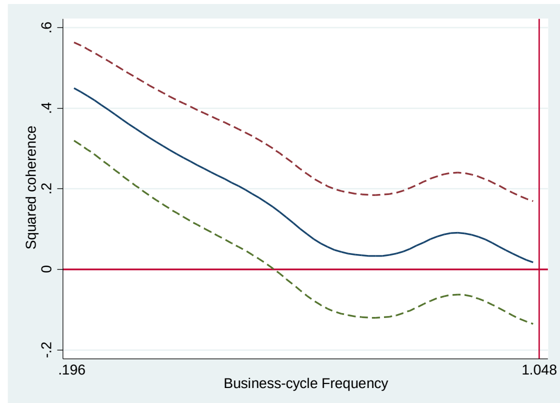
Note: Dotted lines represent the 95% confidence intervals.

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

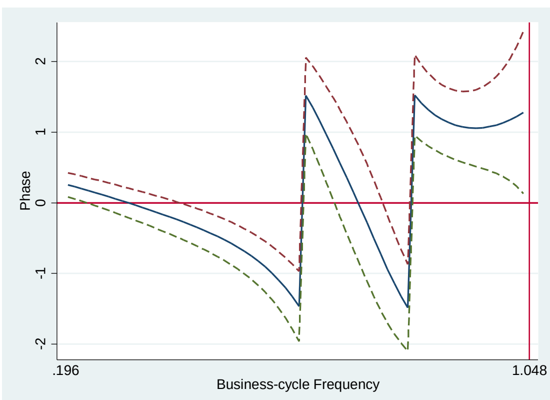
A. Gain



B. Squared coherence



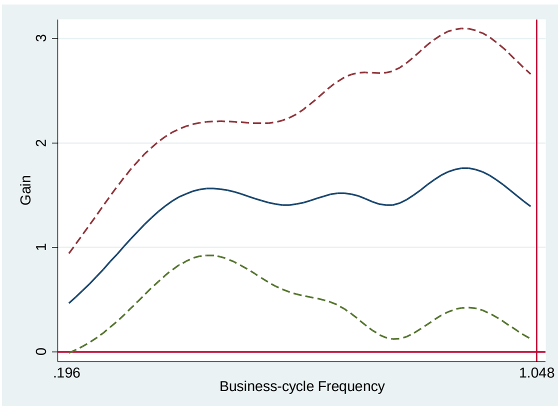
C. Phase



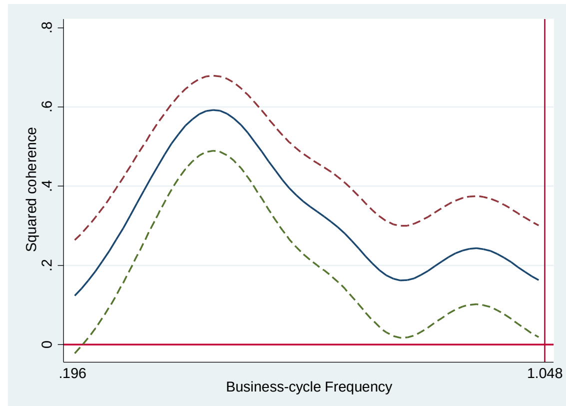
Note: Dotted lines represent the 95% confidence intervals.

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

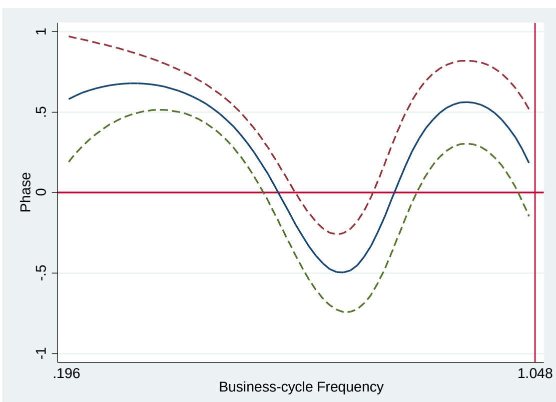
A. Gain



B. Squared coherence



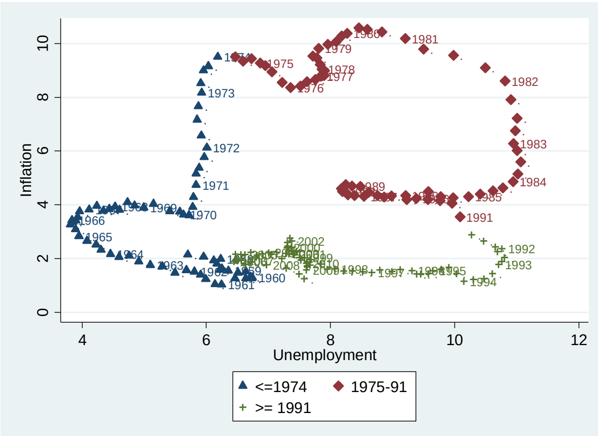
C. Phase



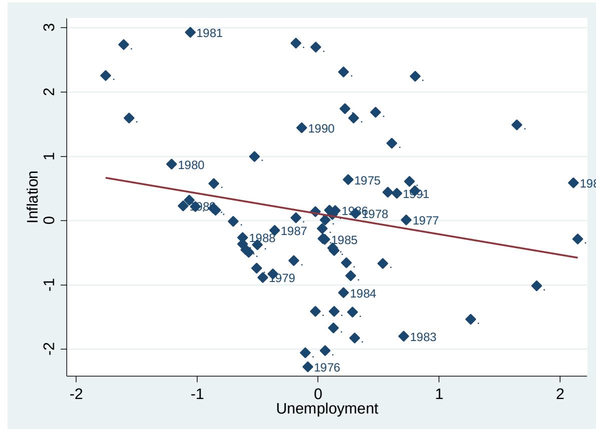
Note: Dotted lines represent the 95% confidence intervals.

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

A. Low-pass filtered data



B. Band-pass filtered data: 1975-1991 period



C. Band-pass filtered data: post-1992 period

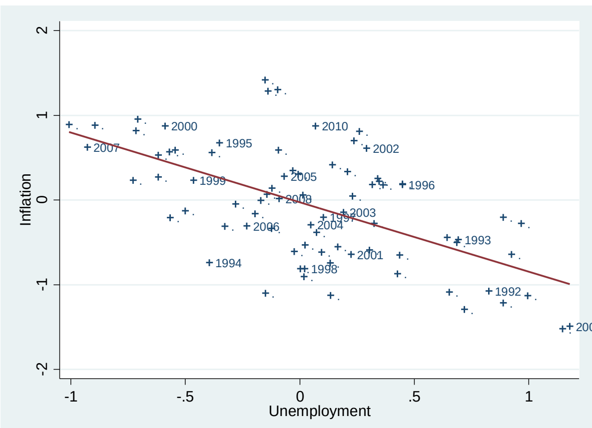
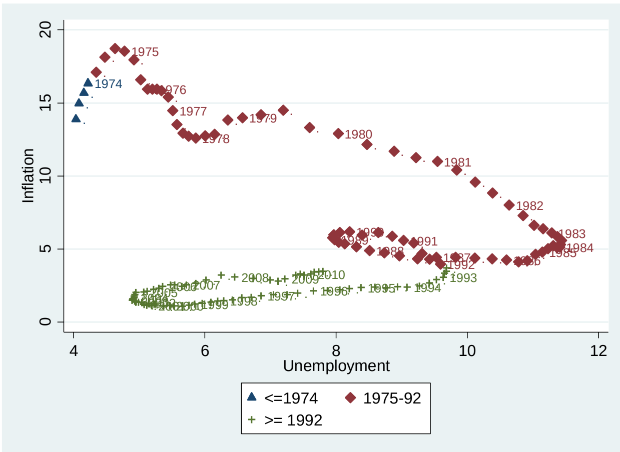
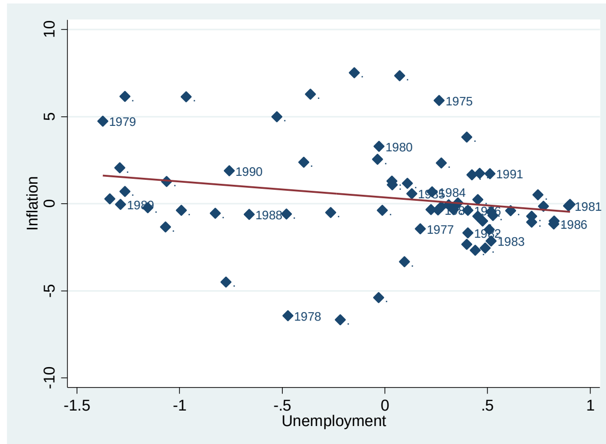


Figure-12: Inflation-unemployment relationship over different frequency ranges for the UK (Inflation targeting in 1992)

A. Low-pass filtered data



B. Band-pass filtered data: 1975-1992 period



C. Band-pass filtered data: post-1993 period

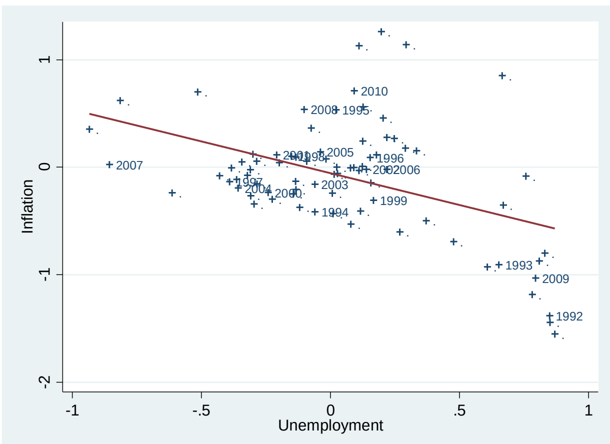
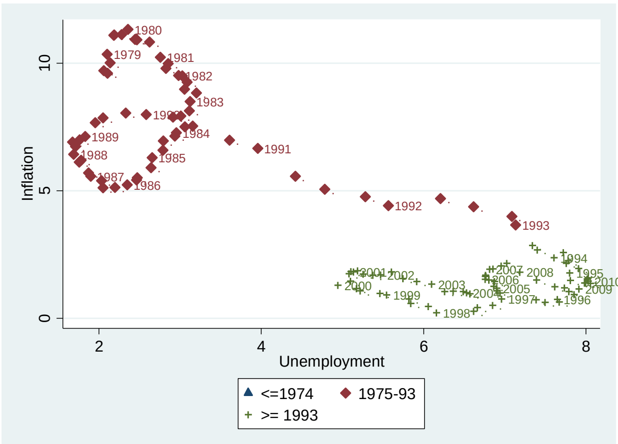
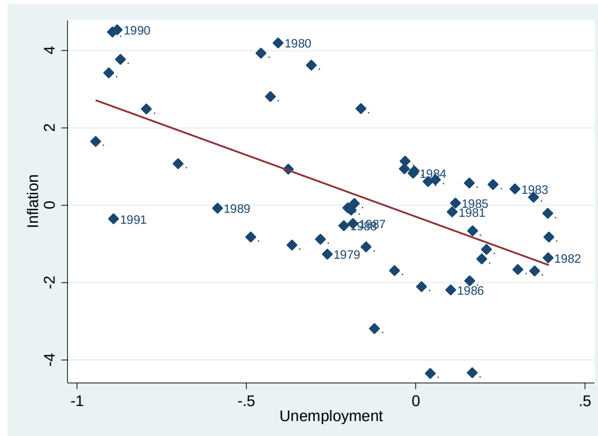


Figure-13: Inflation-unemployment relationship over different frequency ranges for Sweden (Inflation targeting in 1993)

A. Low-pass filtered data



B. Band-pass filtered data: 1975-1993 period



C. Band-pass filtered data: post-1994 period

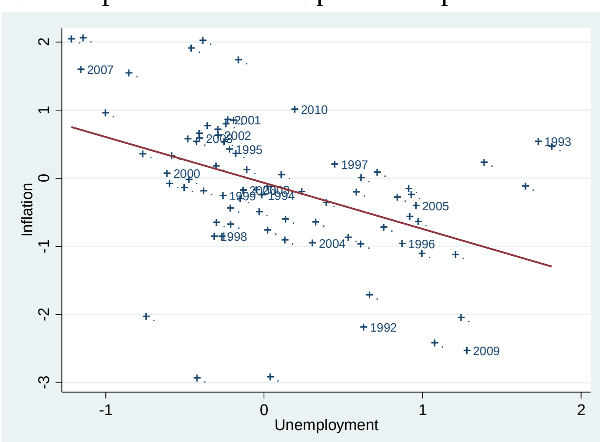
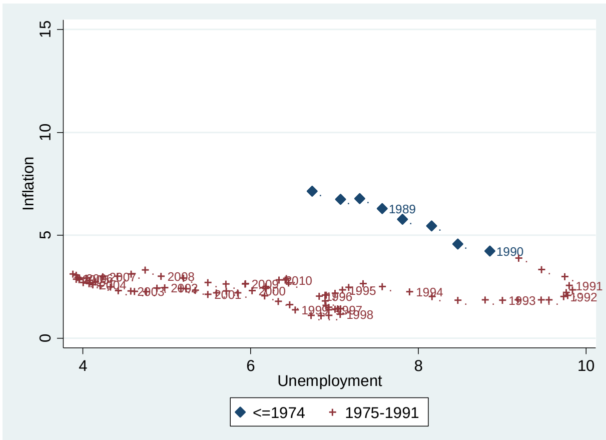
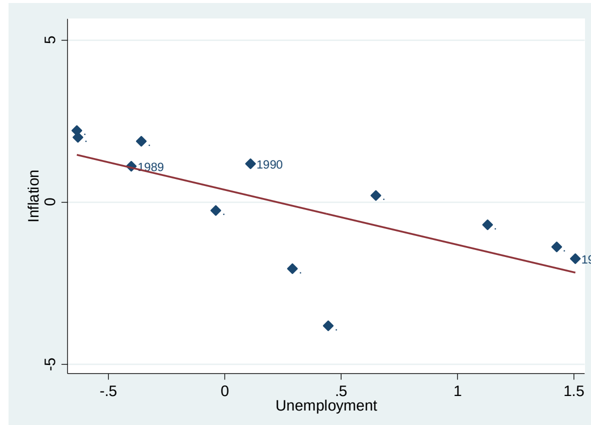


Figure-14: Inflation-unemployment relationship over different frequency ranges for New Zealand (Inflation targeting in 1990)

A. Low-pass filtered data



B. Band-pass filtered data: 1975-1990



C. Band-pass filtered data: post-1991 period

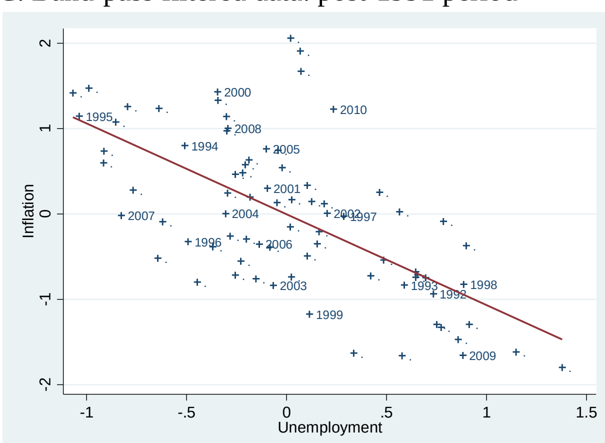


Figure-15: Inflation-unemployment relationship over different frequency ranges for the USA (No explicit inflation targeting; Volcker recession in 1982)