Policy Regimes and the Shape of the Phillips Curve in Australia

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Abstract

We document an evolving pattern in the slope of the Phillips curve in Australia at different frequencies under different monetary policy regimes and labor market regulations. Our estimation strategy relies on the frequency domain estimation but is also complemented by the time domain estimation. We document an upward sloping medium-run Phillips curve in the pre-1977 period, a downward sloping long-run Phillips curve from 1977 to 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. We explain our results in terms of the monetary targeting in 1976 and the inflation targeting in 1993 by the RBA, respectively, and important changes in labor relations from the mid-1980s to the mid-1990s. The flattened Phillips curve is also observed in several industrialized countries since their adoption of 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 the inflation-unemployment relationship in Australia for different periods characterized by monetary policy regimes and development in labor market relations. More specifically, we document how the shape of the Phillips curve has changed at different frequencies over time. Our estimation strategy relies mainly on frequency domain analysis but is also complemented by time domain analysis. We emphasize the relationship at the long/medium-run and business-cycle horizons that correspond to low[1] and business-cycle[2] frequencies, respectively.

Notwithstanding similar levels 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 into the world economy that did not suffer from the recent global financial crises. Recently, 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 labor unions 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 the mid-1980s to the 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 dynamics at different points in time and across frequencies, and justify an independent investigation for Australia.

[1] We use long-run and low frequency interchangeably throughout the paper.

[2] The business-cycle Phillips curve is also referred to the short-run Phillips curve in the literature.

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. Recent empirical evidence, however, suggests a non-vertical long-run Phillips curve and a changing slope over time depending on the sample period studied. For example, in the case of the USA, whose inflation-unemployment relationship has been most extensively studied, King and Watson (1994; 1997) documented a strong negative correlation at low frequencies from 1954 to 1969, and no consistent relationship from 1970 to 1987, but an overall positive correlation from 1954 to 1992. Berentsen, Menzio and Wright (2011), using data for longer periods from 1955 to 2005, document a strong positive correlation at low frequencies.[3] In contrast, several recent commentators have documented a flattened downward sloping long-run Phillips curve as a result 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. Conversely, the business-cycle Phillips curve remains downward sloping although the degree of the 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.[4] There are studies that document the Phillips curve in Australia for different periods (discussed in Section 2), but whether and how the long-run and business-cycle Phillips curves have evolved over time is not well-understood. This paper is also intended to fill this gap.

This paper departs from the extant literature in some important respects. We document the Phillips curve for Australia at all frequencies using the recent data. We employ a combination of frequency and time domain methods; in our specific context, the frequency domain (spectral) method estimates the relationship at each frequency except at zero (see Section 5), which is

[3] 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.

[4] Lundborg and Sacklén (2006) and Svensson (2015) have made similar observations in the case of Sweden.

complemented by the cointegration method in the time domain at zero frequency. It is important to note that most studies in the context of Australia infer about 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. Their approach provides information only about the zero frequency, ignoring other frequencies containing information about the long-run. Conversely, regression using the low-pass (or band-pass) filtered series estimates a coefficient that is the average of the regression coefficients over the long-run (business-cycle) frequencies. The frequency domain method, unlike its time domain counterpart, allows us to investigate the inflation-unemployment relationship without relying on any identifying restrictions on the relationship.[5] The frequency domain method also allows us 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.[6] 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 the 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 coincides with the adoption of aggregate monetary targeting in 1976 and inflation targeting in 1993 by the RBA, respectively. Based on these observations, the three distinct periods are defined as i) pre-1977, ii) 1977-1993, and iii) post-1993. The real wage shock due to

[5] 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 identifications in the context of the European and G7 countries, respectively.

[6] The original Phillips (1958) curve stated the relationship between nominal wage change and unemployment; however, it has become standard to express the Phillips curve in terms of the CPI inflation and unemployment.

union pressure and the oil price shock, both in 1974, just preceded the adoption of monetary targeting and may have contributed to the first break. In the pre-1977 period, the long-run Phillips curve is upward sloping and very steep. In the 1977-1993 period, a clear long-run trade-off (downward sloping long-run Phillips curve) emerges, and 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, visualized from the band-pass filtered data, is downward sloping in all periods although the magnitude of the slope differs across periods.

We then proceed to analyzing the inflation-unemployment relationship in the frequency domain for each period. Our analysis is based on the gain 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 with the slope of the linear fit in the time domain after transforming the series by the appropriate filter. 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.

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. In contrast, application of the spectral method requires the series to be stationary. Our statistical tests also suggest that the inflation and unemployment series are nonstationary (except the inflation in the post-1993 period). 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 by employing the Unobserved Component Model. It is worth mentioning that the application of the UCM in the unemployment and inflation series removes information only at the zero frequency, and our frequency domain analysis therefore estimates the relationship at all but the zero frequency. 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 assume business-cycle periodicities of 6-32 quarters. Given that zero frequency contains important information about the long-run, we complement our frequency domain analysis by employing the ARDL cointegration test to determine the relationship at the zero frequency.

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); it is also significant in most of the business cycle frequencies, including around the cut-off at 0.196. In contrast, the gain is significant at all long-run frequencies (32 quarters and above) in the 1977-1993 period; it is also significant at the lower range in the business cycle frequencies. In the first period, the fit estimated in the time domain using the low-pass filtered series (in the (0+, 0.196) frequency range) 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-/medium-run negatively sloped Phillips curve in the 1977-1993 period. We suggest that important changes in labor market relations rather than monetary targeting in 1976 was responsible for this downward sloping long-run Phillips curve. The fit using the band-pass filtered series is negative in both periods, suggesting a downward sloping business-cycle Phillips curve. For the post-1993 period, the gain is insignificant in the entire low frequency range. The cointegration test suggests an absence of relationship at the zero frequency in all three periods. The phase indicates that inflation lagged unemployment in the pre-1977 period but led in the 1977-1993 period.[7] The causality changes sharply over the business-cycle frequencies, especially

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

in the 1977-1993 period, suggesting instability in the relationship (shifting the business-cycle Phillips curve).

The results in the frequency domain highlight several important patterns that are not apparent in the time domain. There is enormous fluctuation in the relationship (gain) even within a particular frequency band in terms of both the magnitude and statistical significance. For example, in the 1977-1993 period, in addition to large fluctuations, the gain is significant only at lower frequencies in the business-cycle frequency band (close to the medium-run frequency band), and in the pre-1997 period, it is significant only at the higher frequencies in the lower frequency band. Similar fluctuations in the direction of causality are also observed across frequencies.

We finally document that the inflation-unemployment relationship in several other countries such as Canada, Sweden, New Zealand and the UK is similar to Australia since they adopted inflation targeting, but the relationship in the pre-inflation-targeting period varies among these countries.

The remainder of the paper is organized as follows. Section 2 briefly reviews the literature on the Phillips curve in Australia. Section 3 provides a brief history of monetary policy in Australia. Section 4 describes the long-run and business-cycle relationship in the time domain. Section 5 discusses the Phillips curve model that we estimate in the frequency domain. The frequency domain estimation method, which includes the gain and phase spectrum, is explained in Section 6. Section 7 graphically presents the Phillips curve in the frequency domain. This section also presents the time domain results at the zero frequency. Explanations for the evolving patterns in the long-run relationship are also discussed in this section. In Section 8, the inflation-unemployment relationship in several inflation-targeting countries is compared with that observed in Australia. Finally, Section 9 concludes.

2. A brief review of Phillips curve studies in Australia

In this section, we provide a brief summary of the studies on the Phillips curve in Australia; a detailed account can be found in Gruen, Pagan and Thompson (1999) and Borland and McDonald (2000, especially 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 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 a similar time period. Parkin also noted a weak short-run trade-off. Although several studies also investigated the Phillips curve, there is scant research that focuses on both the short- and long-run. Gruen, Pagan and Thompson (1999) correctly note that the central issue for estimating Australian Phillips curves is 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 has 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 from 1960:Q1 to 2008:Q4, allowing for a 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 approximately 2% until the early 1970s. At that point, it began to drift upwards, a trend that continued until the mid-1990s. It 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 the flattened Phillips curve observed recently in Australia, arguing that a positive output gap would be less inflationary but with a greater 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.[8]

Since the Bretton-Woods agreement, Australian currency was fixed with US dollar, which did not allow the 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 the 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 increasingly became 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 increases in inflation in Australia overtook those in the USA. The role of the 1973 oil shock was probably not important as inflation in Australia had already reached double-digit rates before the shock. Rather, the real wage shock of 1974 pushed by labor unions was key. It is important to mention that after the parity with US dollar was broken, there was effectively no clearly enunciated guiding principle behind Australian monetary policy until the introduction of monetary targeting in 1976. Monetary targeting was based on an annual target for M3. This 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).

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[8] The following discussions are drawn from the speeches of the contemporaneous RBA governor, Mr. I. J. Macfarlane, in 1997 and 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. Below, we observe that these are indeed the break points in the long-run inflation-unemployment relationship. The first break point, however, is not as sharp as the second one as the former also coincided with the real wage and/or oil price shocks.

4. Inflation-unemployment relationship in the time 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 and complement the results in the frequency domain.

The raw inflation and employment series are plotted against time in Figure-1A.[9] Both series are non-stationary and follow random walk except the inflation in the post-1993 period (Appendix Table-I). 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 (32 quarters and above). 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 the policy changes and shocks discussed above. During the 1959-1974 period, the long-run value of inflation gradually increased from less than 2% to more than 12% with unemployment ranging from 1.7% to 3.7%. This indicates a very steep (near vertical) long-run

[9] 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 the decimal. Hence, 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 the decimal. The implicit GDP deflator inflation series is obtained from the St. Louis Federal Reserve (http://research.stlouisfed.org/fred2/series/AUSGDPDEFQISMEI; accessed on October 31, 2014). The series (Series ID: AUSGDPDEFQISMEI) is seasonally adjusted quarterly inflation, so we multiply it by 4. The data are quarterly and the time period is 1959:Q4-2012:Q4.

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 from 1976 to 1993, with the unemployment rate staying 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 a flattening of the long-run Phillips curve. Figures-2 (A-D) display the Baxter-King (1999) band-pass filtered series (6-32 quarters) for the above three distinct 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-2D) than the previous two periods, suggesting a 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 closed economy. Therefore, it is argued that change in the implicit GDP deflator captures economic activity better than the CPI inflation. Imports of goods and services as a percentage of GDP in Australia are close to that in the USA, however, and much smaller than that in similar small, open economies. 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, which exhibits the same relationship using the CPI inflation. The business-cycle relationships for different 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, both inflation series suggest 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 the 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. However, it becomes the reduced-form NKPC if $\pi_t^e = E_t\left\{\pi_{t+1}\right\}$ with its coefficient being one. From the empirical perspective (2SLS estimation that accounts for the endogeneity of expected future inflation using lagged variables as instruments), however, 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 by employing the univariate Unobserved Component Model (UCM) by modeling both expected (trend) inflation and NAIRU as driftless random walk processes. For a series, say, u_t (unemployment), the UC is defined as:

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

where ψ_t is the cyclical component, and 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 processes in a bivariate UCM.[10] Debelle and Vickery (1998) use a Phillips curve framework to estimate the NAIRU as a unit-root process using the Kalman filter. After subtracting the trend components, both the inflation and output gaps ($\hat{\pi}$ and $\hat{u}$) become stationary processes, and equation (2) can therefore 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.[11] 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 deeper lags of inflation and unemployment gaps in equation (2). Frequency domain method estimates parameter at each frequency without specifying lag structures.[12]

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

[11] Zhu (2005) transform the data using the Hodrick-Prescott and Baxter-King filters to estimate the 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.

[12] 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

It is imperative to mention that subtracting the trend components from the inflation and unemployment series removes only the zero frequency components in the data. The remaining low frequency components are used for estimating the long-run relationship; however, zero frequency components also contain important information about the long-run. We test the relationship at the zero frequency in the time domain using the Pesaran-Shin-Smith (2001) ARDL cointegration test. The reason for employing both the frequency and time domain methods is that the series must be nonstationary to have any long-run relationship, but the application of the spectral method requires a stationary series.

6. Estimation method in the frequency domain

In this section, we discuss the estimation of the gain, squared coherence and phase spectrum that we use to analyze the 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:

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

unanticipated fluctuations of inflation that is crucial for accurately characterizing the inflation-unemployment relationship in a dynamic model. Our specification (equation (2)) is immune to this critique.

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.[13]

To estimate a 95% confidence interval of the coherence, we need its variance. The variance of $\hat{C}(\omega)$, however, 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,

[13] 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.

p. 224). In our case, no such weight or tapering is relevant, but because we use a Bartlett window, g involves a correction term ($2M/3T$) 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 $\operatorname{arctanh}\hat{C}(\omega) \pm \left(1.96g/\sqrt{2}\right) = (1/2)\ln\left\{\left(1+\hat{C}(\omega)\right)/\left(1-\hat{C}(\omega)\right)\right\} \pm \left(1.96g/\sqrt{2}\right)$. 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 at different frequencies

The long-run and business-cycle Phillips curves are presented in terms of the gain and phase spectrum. As mentioned above, the gain is analogous to the absolute value of the regression coefficient in a regression of unemployment on inflation. We supplement the sign of the gain by the linear fit of unemployment on inflation in the time domain transforming the data by appropriate filtering. We suggest a significant 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.[14]

7.1 The Phillips curve in the frequency domain

In the following, we present the relationship in the (0+, 1.048) frequency range separately for three distinct periods.[15] The (0+, 0.196) is the low frequency range and (0.196, 1.048) is the business-cycle frequency range. It must be emphasized, however, that the selection of 0.196 as the cut-off frequency, although standard in the business cycle literature, is arbitrary; thus, separating the relationship between the long-run and business-cycle frequencies is quite difficult. We therefore refer to the frequencies at around this cut-off (both left and right) as medium-run frequencies.

The results for the 1959:3-1976:4 period are presented in Figures 4 (A-C). Panel A displays the gain along with its 95% confidence intervals (CIs). The gain secularly increases along frequencies from 0.35 to 2.93 and then declines to 0.61 before increasing again; however, it is statistically significant (lower confidence line lying above zero) only at the (0.125, 0.775) frequency range (implying a periodicity ranging between 8 and 50 quarters).[16] The maximum value of gain is attained at frequency 0.513 (12 quarters). The observation that the gain is insignificant at lower frequencies suggests an absence of the long-run Phillips curve, or at best, a weak long-run relationship. Given, however, that the gain is significant at the higher frequencies in the long-run range and also at the lower frequencies in the business-cycle range (both left and right of the cut-off), we can infer a medium-run Phillips curve. Finally, the significance of the gain over most of the business-cycle frequencies (except at the very high frequencies) suggests a

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

[15] The sample size becomes small for separate analysis of the sub-periods; however, this is a problem in any time series analysis.

[16] The squared coherence, displayed in Panel C, also follows the same pattern as the gain. We do not discuss it because it contains similar information as the gain.

business-cycle Phillips curve. As the gain is positive by definition, we rely on the time domain fit to determine the actual sign. It is positive but statistically insignificant in the long-run and negatively significant over the business cycles, suggesting no long-run relationship and an inflation-unemployment trade-off over the business cycles.[17] The phase fluctuates and changes sign along frequencies. For example, it is positive and significant at the very low and very high frequencies—(0+, 0.113) and (0.775, 1.048) ranges, but it is negative and significant in the range over which the gain is significant. Therefore, we conclude that inflation lags unemployment in the medium run and over the business cycles; in other words, the causality runs from unemployment to inflation.[18]

The relationship for the 1977:1-1993:4 period is shown in Figures-5 (A-C). The gain, displayed in Panel A, secularly increases from 0.32 to 1.27 before decreasing; it is significant at all frequencies in the long-run range and also significant in the lower frequencies in the business-cycle range (0.196, 0.575). Combined with the fit in the time domain, we suggest a long-run downward sloping Phillips curve and a weak downward sloping business-cycle Phillips curve for this period. The phase is significant only in the higher frequencies in the long-run range (0.125,

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[17] The coefficient (Newey-West standard error) of the regression of unemployment on inflation using the data filtered at the (0+, 0.196) frequency range is 0.186 (0.247) for the pre-1977 period. For the 1977-1993 and post-1993 periods, these are -0.321 (0.039) and -0.044 (0.069), respectively. These fits are different from the fits displayed in Figures 1D and 3B that also included the zero frequency. The coefficients (Newey-West standard errors) using the data filtered at the business-cycle frequency range (0.196, 1.048) are -2.317 (0.213), -0.774 (0.140) and -1.109 (0.117) for the pre-1973, 1977-1993 and post-1993 periods, respectively.

[18] If the sample period is shortened to 1959:3-1973:4 based on the real wage (and oil price) shocks, the long-run frequency range over which the gain is significant becomes even narrower at the (0.15, 0.196) range (or equivalently, 32-42 quarters) (Appendix Figures-I (A-C)). This clearly suggests an absence of the long-run Phillips curve. The gain in the business-cycle frequency range follows a similar pattern to that for the 1959-1976 period, suggesting a medium-run and business-cycle Phillips curve. No definite lead or lag in the relationship between inflation and unemployment can be established as the phase is now insignificant in the medium-run. The phase is negative and significant at higher frequencies in the business-cycle range, suggesting that the causality running from unemployment to inflation.

0.196), but it is 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. Gordon (2013) argues that inflation leads unemployment from the mid-1970s to early 1980s because of adverse supply shocks during this period. This argument may also apply to Australia for the period following the real wage and oil shocks, but additional factors may be at work, such as the changing labor relations that we will discuss in next section. This argument is strengthened by an examination of the changing sign of the phase at the business-cycle frequencies. This suggests an unstable relationship, shifting the Phillips curve over the business-cycle frequencies.

In the 1994:1-2012:4 period, both the gain and phase are insignificant at all frequencies in the long-run frequency range, suggesting no long-run Phillips curve (Figures-6 (A-B)). 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 variation over time. Conversely, the gain is significant at all business-cycle frequencies and combined with the fit in the time domain, we suggest a downward sloping business-cycle Phillips curve. The phase fluctuates across frequencies; it is positive at the lower and higher frequencies in the range, while it is negative in the middle of the range. A definitive causality cannot be established; rather, shifting the business-cycle Phillips curve can be a plausible explanation.

To summarize, there is a weak long-run or more appropriately a medium-run upward sloping Phillips curve in the 1959-1976 period, a downward sloping long-run Phillips curve in the 1977-1993 period, and no long-run Phillips curve in the post-1993 period. The business-cycle Phillips curve is downward sloping and the magnitude of the inflation-unemployment trade-off varies across periods.

Insert Figures 4-6 here

7.2 Cointegrating relationship at the zero frequency

Our previous analysis of the long-run in the frequency domain concerns low frequencies except at zero. The reason, as mentioned above, is that spectral analysis requires stationary series. Therefore, we discarded the zero frequency components from the inflation and unemployment series by the UCM. Although there is no general consensus on the definition of the long-run (whether it is only at zero frequency or over a frequency range from 0 to a specific cut-off), analysis of long-run would be incomplete without analyzing the zero frequency components of the data. In the following, we examine the Phillips curve at zero frequency by the cointegration method.

We employ the Pesaran-Shin-Simith (2001) Autoregressive Distributed Lag (ARDL) bound analysis to test the cointegrating relationship, which is robust to small sample size. The relationship is tested by comparing the F-statistic with the lower and upper bounds. If the F statistic is above the upper bound, the null hypothesis of no cointegration is rejected. If it is below the lower bound, the null hypothesis of no cointegration cannot be rejected. If the statistic lies between the two bounds, the test is inconclusive. An optimal lag length is chosen based on the SIC. The results are presented in Table-1. The results show that the F-statistic is smaller than the lower bound for all periods, thus suggesting no cointegration. The same result also holds if the full sample is considered. This result at the zero frequency is consistent with the results in the frequency domain that there is no long-run relationship in the pre-1977 and post-1993 periods. The results also suggest that the long-run negative relationship in the 1977-1993 period holds at all but zero frequency.

Insert Table-1 here

7.3 Explanation of varying slopes of the Phillips curve at low frequencies

The following explanations for different slopes of the long-run Phillips curve in different periods are only suggestive because they are not empirically tested.

In the short-run, the upward sloping aggregate supply curve (alternatively, the 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 also shifts to its natural rate), and the 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 unions. 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 the realization of the shock that increased unemployment), indicating a medium-run rather than long-run relationship.[19]

The sticky wage assumption actually implies that wages are adjusted slowly. But if the adjustment process becomes slower over time, then the upward sloping aggregate supply curve can also persist over the long-run; 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)[20] estimate (retrieve) time-varying wage rigidity for Australia. The wage rigidity remained almost unchanged until the mid-1970s and gradually increased since then until 1993. The variations (increase) in wage rigidity are the result of changes in labor market regulations and institutions rather than the new monetary policy.

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[19] Berentsen, Menzio and Wright (2011) provide an alternative argument for an 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 the cash-intensive goods market, which reduces profit and employment. The initial impact of a change in the 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).

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

The increase in real wages relative to productivity following the 1974 wage shocks lasted approximately 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 consequently abandoned in 1985. In contrast, developments in labor market relations were more important for controlling inflation. There were successive agreements (known as *Accords*) between the Australian Labour Party (ALP) and the Australian Council of Trade Unions (ACTU) during 1983–1996. Chapman (1998) documents that until 1993, the emphasis was on limiting nominal wage increases with the aim of achieving sustained decreases in inflation without an increase in unemployment. Pressure on limiting the nominal wage increase also slowed any real wage increase (Dyster and Meredith, 2012).

Prior to the *Accords*, the international economic environment and domestic policies also caused a slowdown of the economy. Inflation was quite 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 the Australian economy through declining demand for Australian commodities. To rein in 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 the budget deficit. The 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. Unfortunately, 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 adopted a policy of inflation targeting in 1993 and has been pursuing that policy since then. This policy changed 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 that the lower inflation target is the reason for the flattening Phillips curve in Australia. Anchored inflation expectations have 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.[21]

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

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[21] 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 the 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 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.

[22] 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 7-11 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 7-10. The figures show enormous similarity in the long-run relationship among these countries and Australia in the post-inflation targeting period. 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-8A) and New Zealand (Figure-10A),[23] it is downward sloping and very similar to that for Australia. For the UK, the downward slope is more pronounced for the 1975-1984 period. In the case of Canada (Figure-7A), 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-9A), 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 Federal Reserve announced a target of 2 percent inflation only in January 2012, a widely held perception

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http://data.oecd.org/unemp/unemployment-rate.htm (Accessed on 19 February 2015). For the UK and Sweden, the unemployment data span shorter period of time. For the UK, unemployment data start 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 start from 2001:Q1; data for the 1976:Q1-2000:Q4 period have been obtained from the labor statistics database of the International Labour Organization (ILO).

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

is that the Fed had long before (around 2000) set an unofficial target for core inflation of approximately 2 percent (Svensson, 2015). Another turning point for the USA may 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-11A), 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 period from 1983 to 1999 (Figure-11C); however, the slope is downward sloping for the 1975-82 period (after the oil shock to the Volker recession) (Figure-11B). Conversely, for the post-2000 (post-inflation targeting) period, the long-run Phillips curve has flattened (Figure-11D).

These findings suggest that there are striking similarities among inflation-targeting countries in their inflation-unemployment relationship—with persistently low inflation since inflation targeting leading to a 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. However, the relationship in the pre-inflation-targeting period varied across countries. The effect of the oil price shock in 1973-74 cannot be generalized to explain the shape of the long-run Phillips curve. Each country may have its own unique characteristics, such as the labor market developments in the case of Australia. In contrast, the business-cycle Phillips curve is negatively sloped in all countries and all periods with varying slopes.

9. Concluding remarks

In this paper, we document the inflation-unemployment relationship for Australia for different periods. Our approach to identifying both the long-run and business-cycle relationships relies mainly on frequency domain estimation, but is also complemented by the time domain estimation.

We first document that the long-run inflation-unemployment relationship in Australia can be divided into three distinct periods based on the monetary policy regimes: pre-1977, 1977-1993 and post-1993. 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. In the second period, there is a negative long-run relationship at all frequencies except at zero. We attribute the increase in wage rigidity as a result of changes in labor market regulations and institutions to 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 invariably a negative relationship between unemployment and inflation at the business-cycle frequencies, 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 holds in the cases of several other countries that adopted inflation targeting. The flattening of the Phillips curve has raised concerns about the efficacy of the conventional monetary policy of inflation targeting in output stabilization because the unemployment cost of deflation is quite high at low inflation (Svensson, 2015).[24] If the objective of monetary policy is to stabilize fluctuations over the business cycles, however, then its role has not been diminished because the Phillips curve remains downward sloping over the business-cycle frequencies. This result has important implications for the conduct of monetary policy.

[24] 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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Table

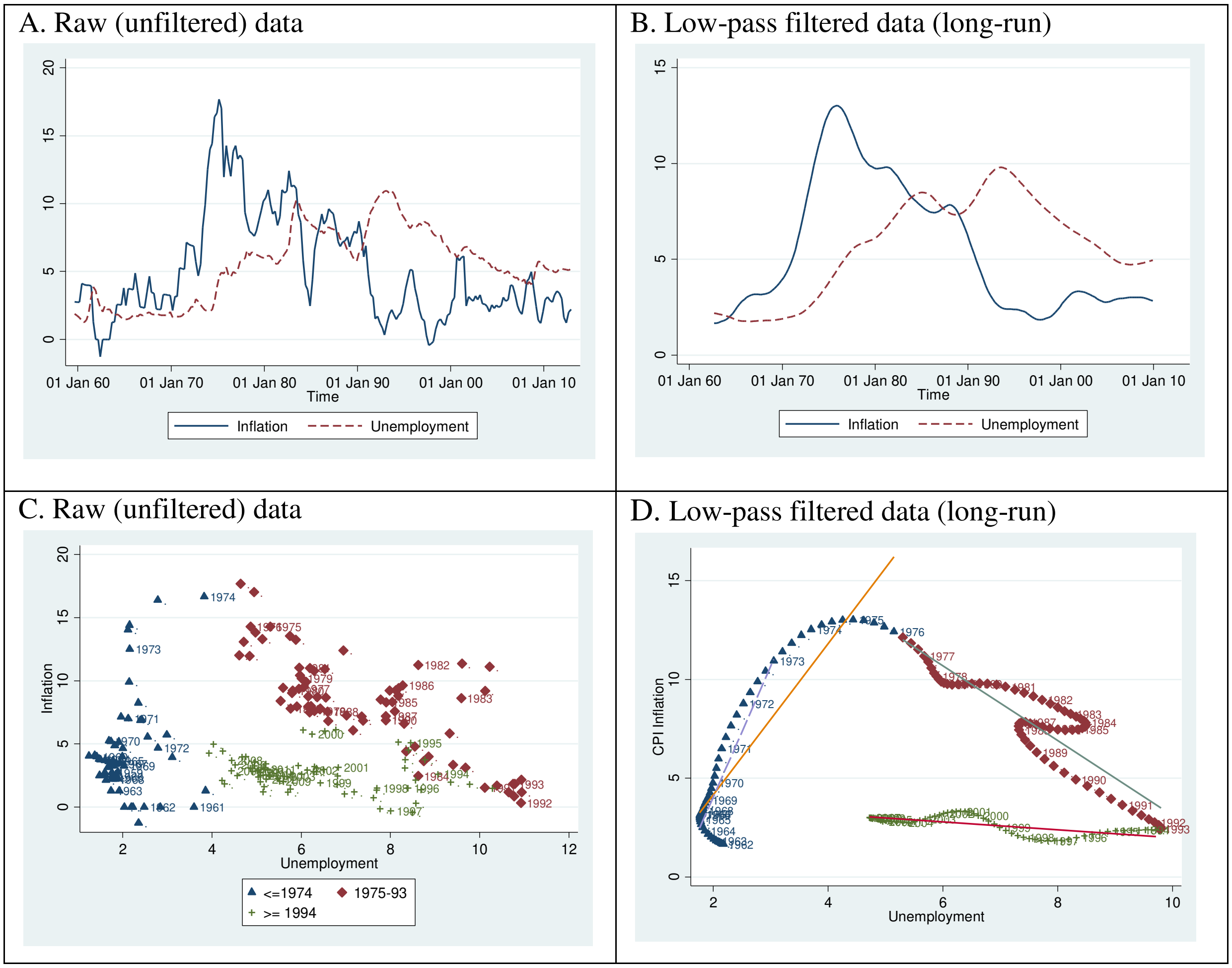
Table-1: Autoregressive Distributed Lag (ARDL) cointegration test

Period	F statistic	95% lower bound	95% upper bound	Optimal lag (inf, unemp)
1959:3-1976:4	1.1385	3.2348	4.2191	1,3
1977:1-1993:4	1.6872	3.2480	4.1681	2, 0
1994:1-2012:4	1.1289	3.2140	4.2594	1,1
1959:3-2012:4	.22665	3.0526	4.0888	1, 3

Note: Maximum lag length is 4. Optimal lag length is selected by the Schwarz Bayesian Criterion. The critical value bounds are computed by stochastic simulations using 20000 replications.

Figures

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

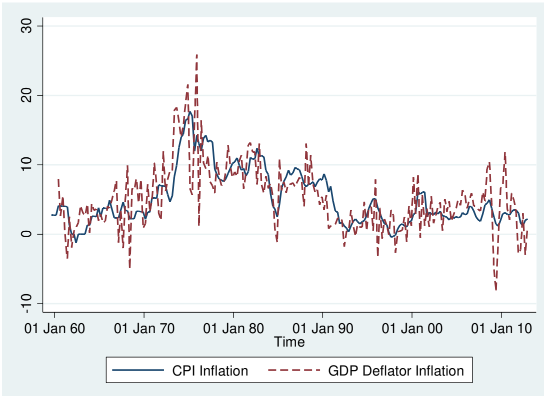


Note for Figure-1D: The broken upward sloping straight line is the linear fit for the 1959:3-1973:4 period. The solid upward sloping straight line is the linear fit for the 1959:3-1976:4 period.

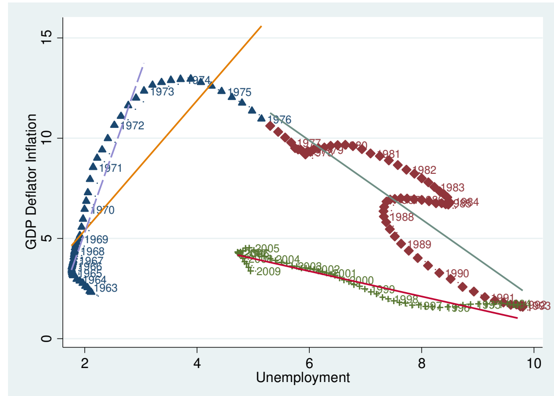
Figure-2: Inflation-unemployment relationship over the business-cycle frequency ranges for different periods

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

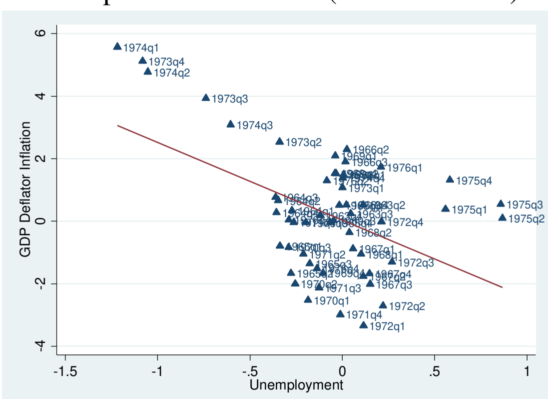
A. Raw (unfiltered) data



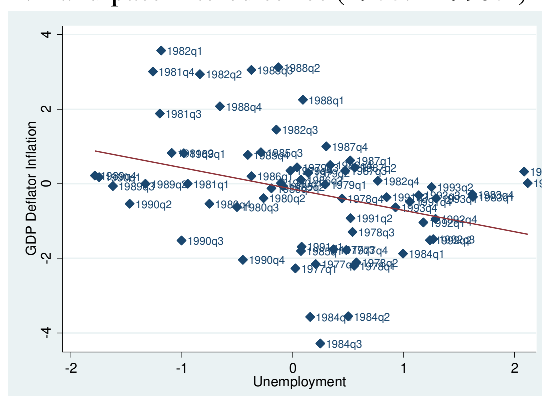
B. Low-pass filtered data (1959:3-2012:4)



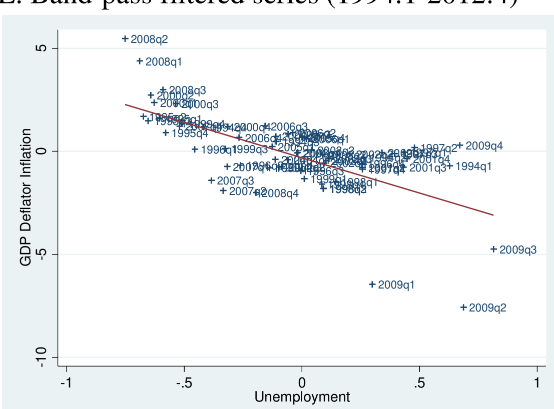
C. Band-pass filtered series (1959:3-1976:4)



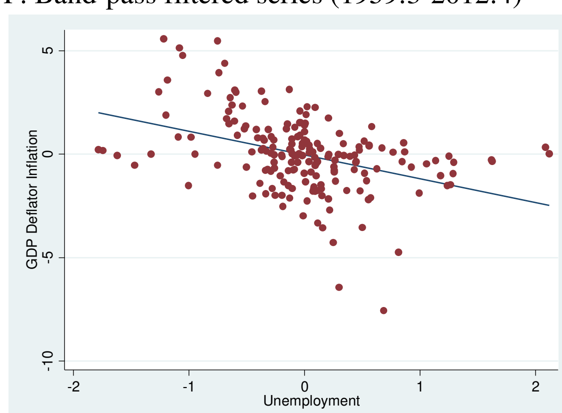
D. Band-pass filtered series (1977:1-1993:4)



E. Band-pass filtered series (1994:1-2012:4)



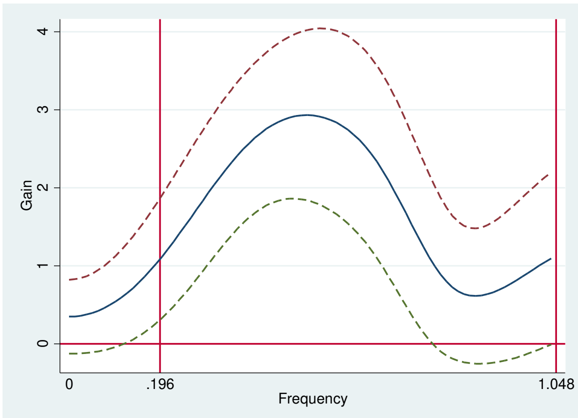
F. Band-pass filtered series (1959:3-2012:4)



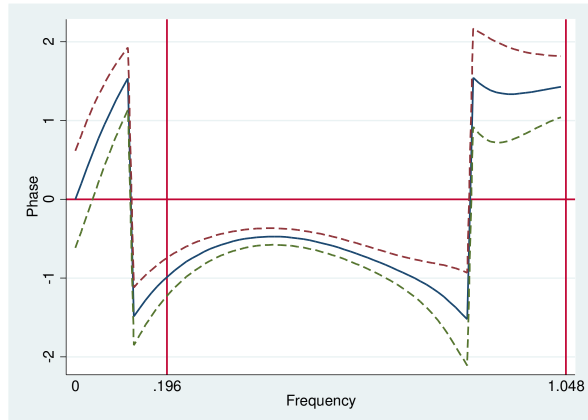
Note for Figure-3B: The broken upward sloping straight line is the linear fit for the 1959:3-1973:4 period. The solid upward sloping straight line is the linear fit for the 1959:3-1976:4 period.

Figure 4: Inflation-unemployment relationship at different frequencies for the 1959:3-1976:4 period

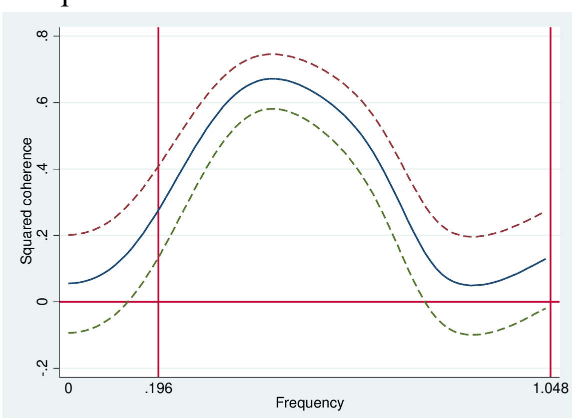
A. Gain



B. Phase

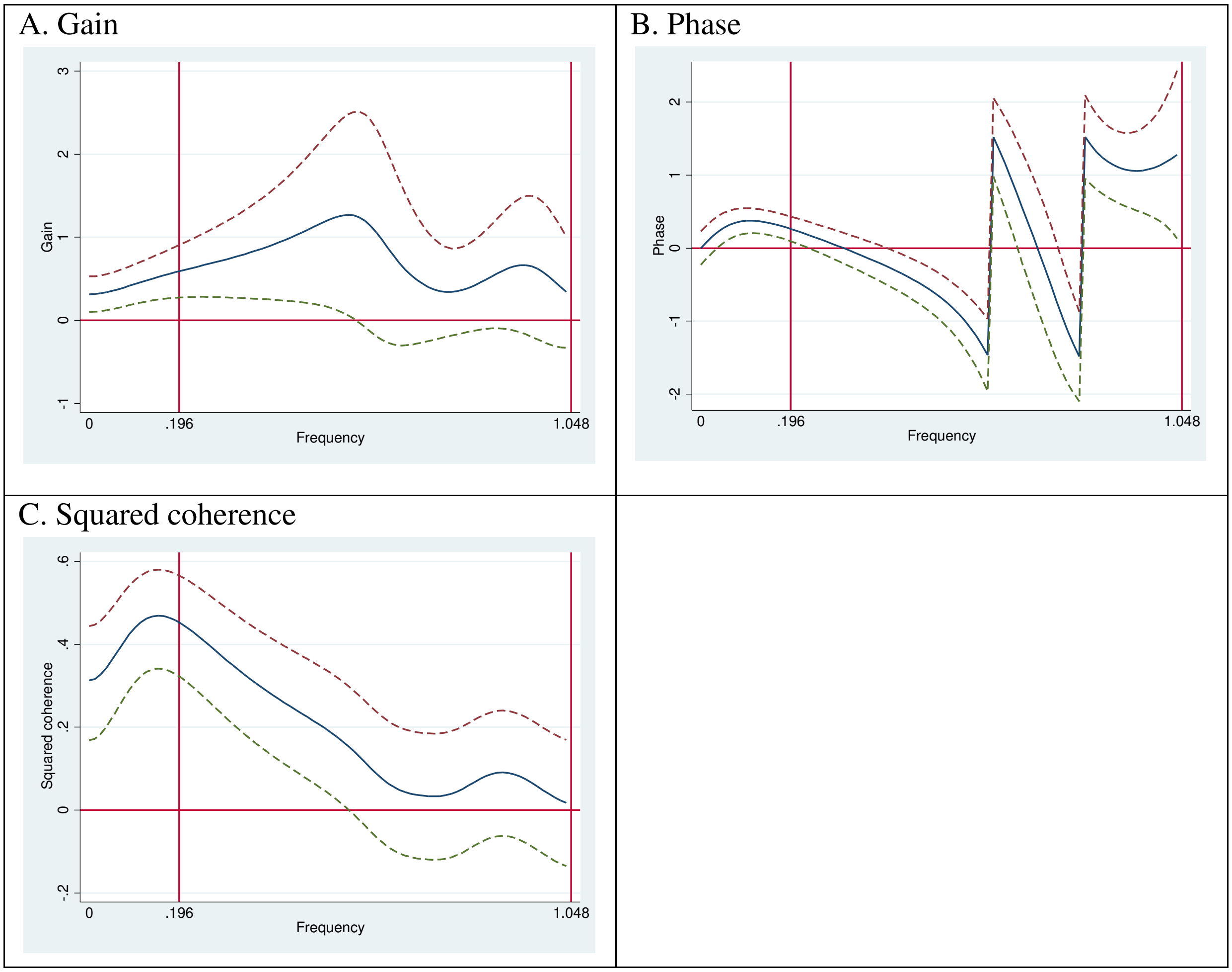


C. Squared coherence



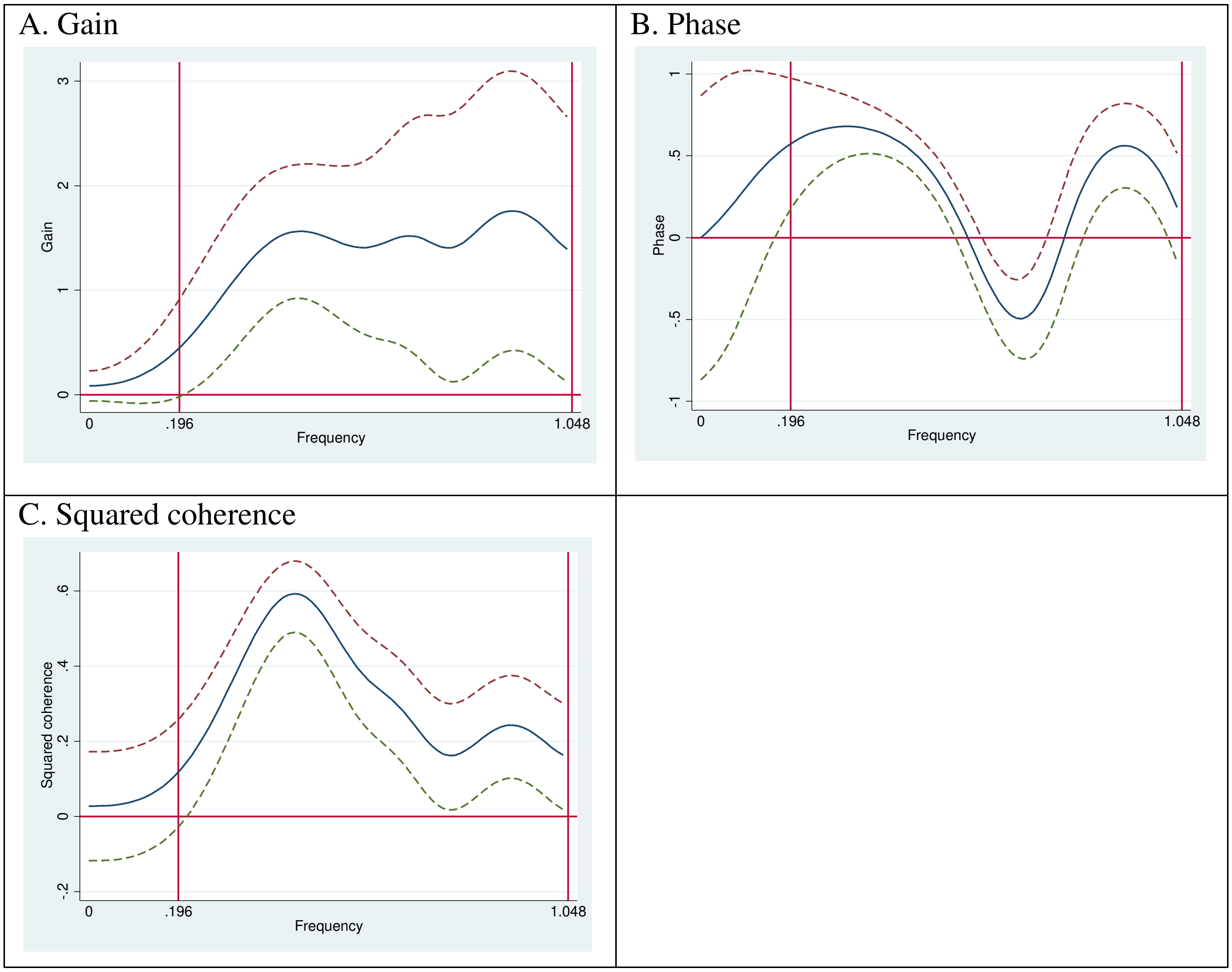
Note: Dotted lines represent the 95% confidence intervals.

Figure 5: Inflation-unemployment relationship at different frequencies for the 1977:1-1993:4 period



Note: Dotted lines represent the 95% confidence intervals.

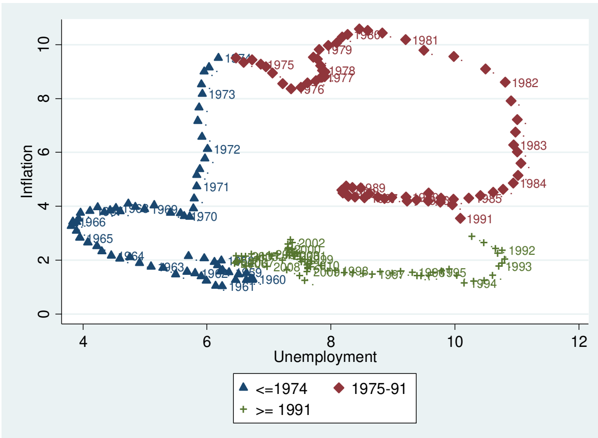
Figure 6: Inflation-unemployment relationship at different frequencies for the 1994:1-2012:4 period



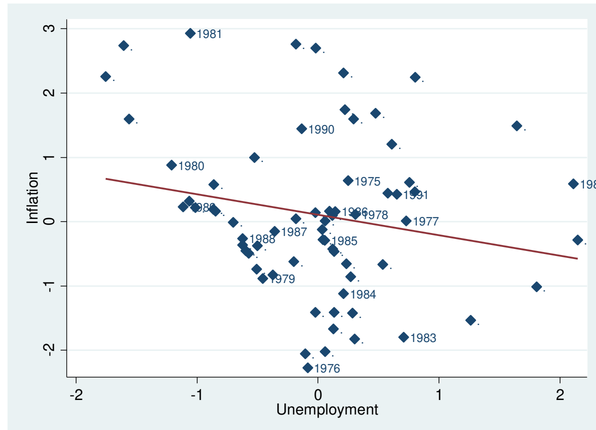
Note: Dotted lines represent the 95% confidence intervals.

Figure-7: 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

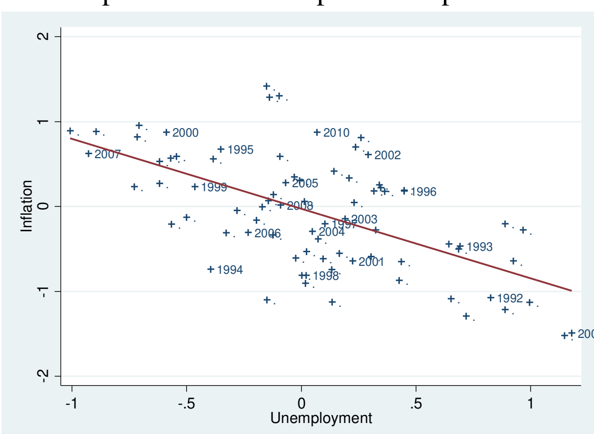


Figure-8: Inflation-unemployment relationship over different frequency ranges for the UK (Inflation targeting in 1992)

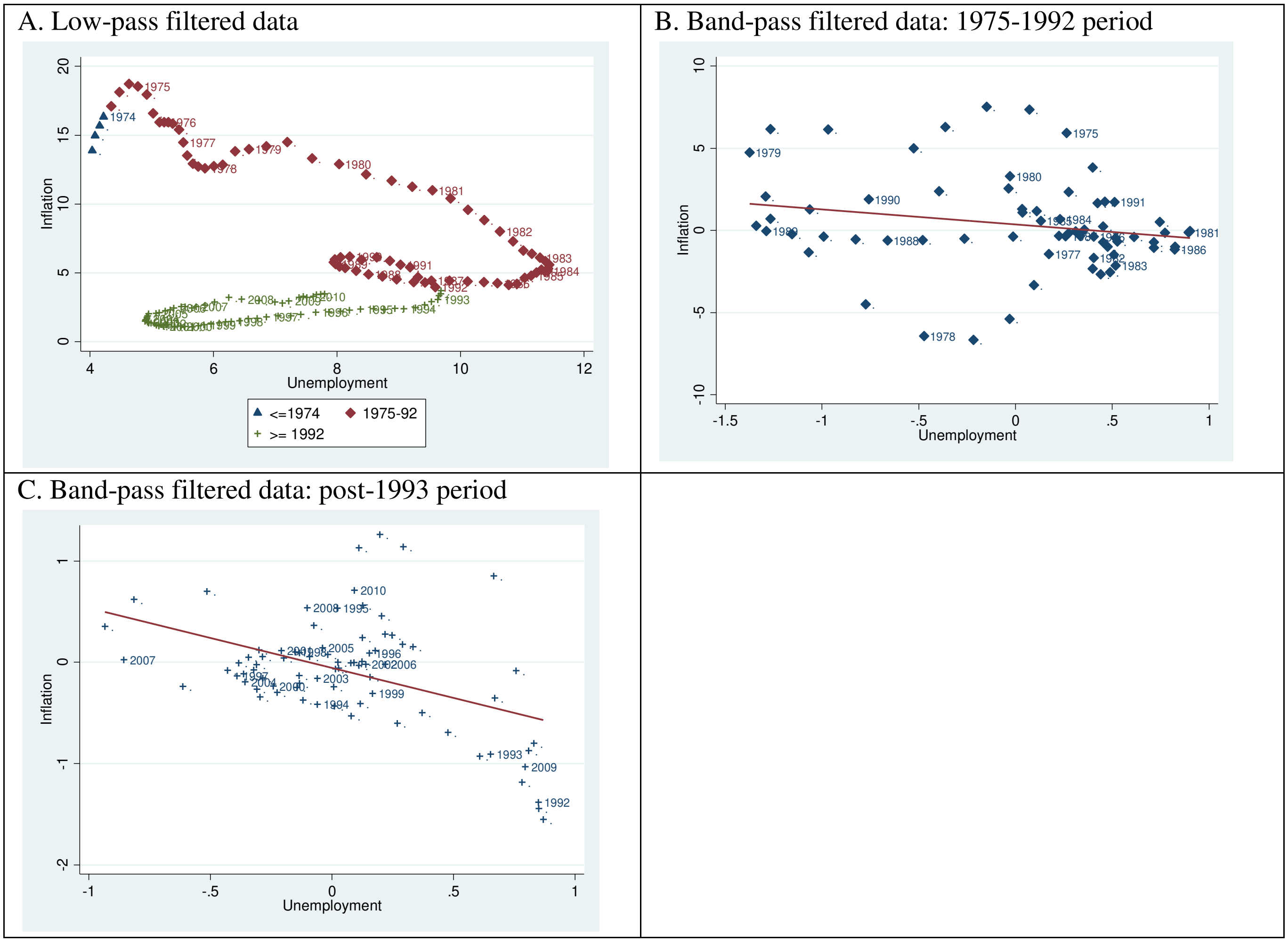
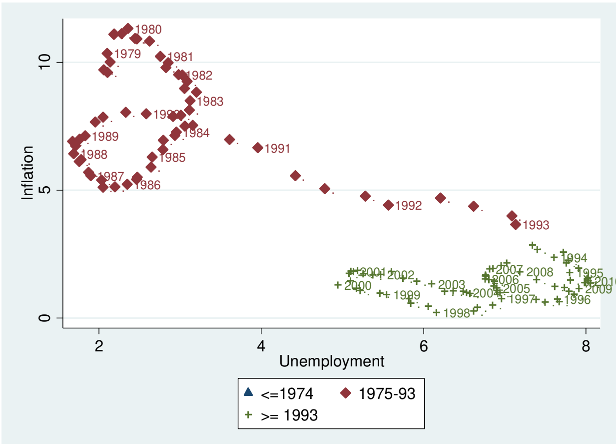
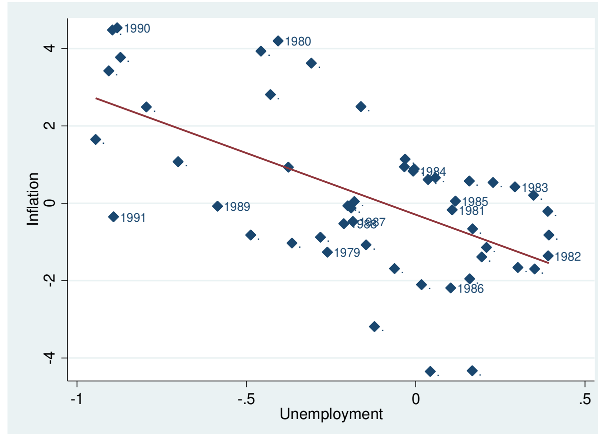


Figure-9: Inflation-unemployment relationship over different frequency ranges for Sweden (Inflation targeting in 1993)

A. Low-pass filtered data



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



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

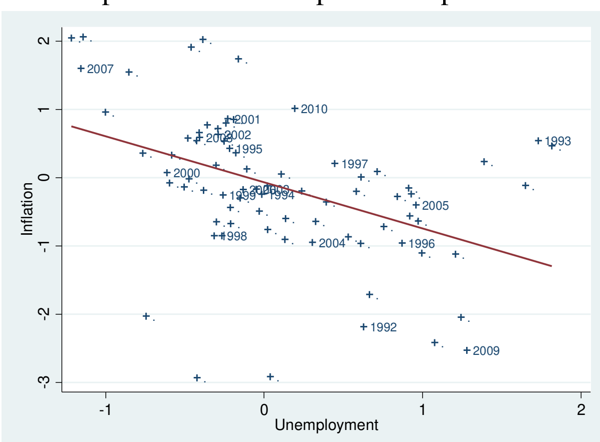
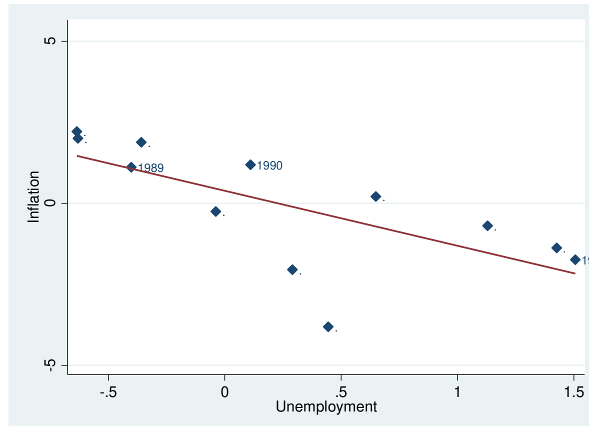


Figure-10: Inflation-unemployment relationship over different frequency ranges for New Zealand (Inflation targeting in 1990)

A. Low-pass filtered data

B. Band-pass filtered data: 1975-1990



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

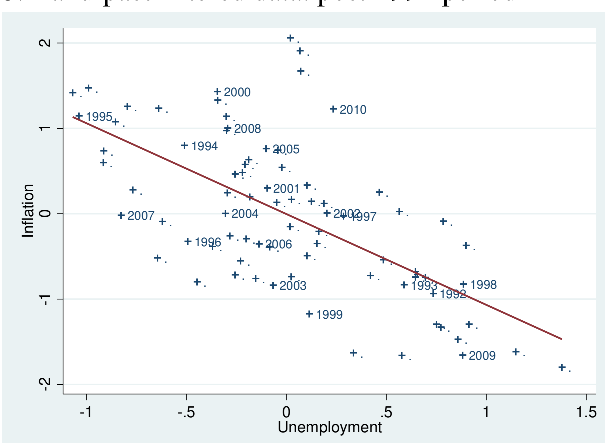
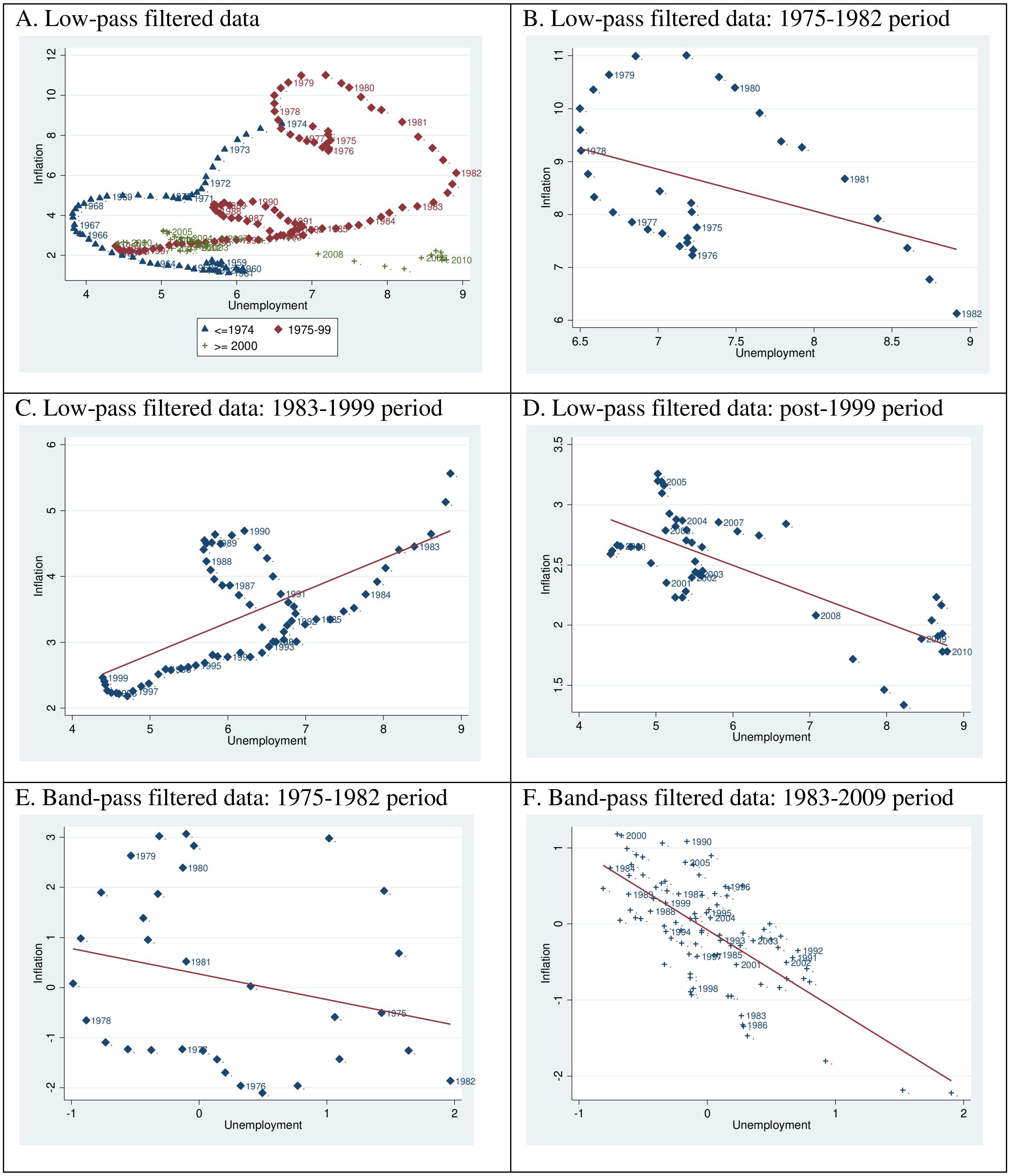


Figure-11: Inflation-unemployment relationship over different frequency ranges for the USA (no explicit inflation targeting; Volcker recession in 1982)



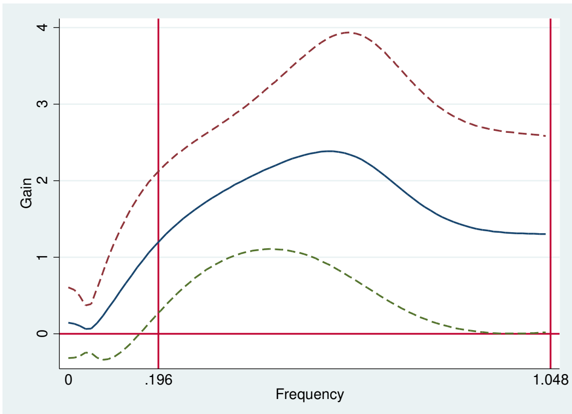
Appendix Table-I: Unit root tests

Variables	Unit root test		
	DF-GLS	PP	KPSS
1959:3—1976:4			
Inflation	-0.667 (-2.749)	-2.115 (-3.481)	0.201 (0.146)
Unemployment	-1.130 (-2.749)	-1.682 (-3.481)	0.205 (0.146)
1977:1—1993:4			
Inflation	-1.614 (-2.743)	-2.674 (-3.482)	0.0984* (0.146)
Unemployment	-2.125 (-2.743)	-1.884 (-3.482)	0.0881* (0.146)
1994:1—2012:4			
Inflation	-2.101* (-1.992)	-3.219* (-2.909)	0.0827* (0.463)
Unemployment	-0.607 (-2.721)	-2.273 (-3.474)	0.247 (0.146)
1959:3—2012:4			
Inflation	-1.807 (-2.804)	-2.526 (-3.435)	0.291 (0.146)
Unemployment	-1.032 (-2.804)	-1.378 (-3.435)	0.413 (0.146)

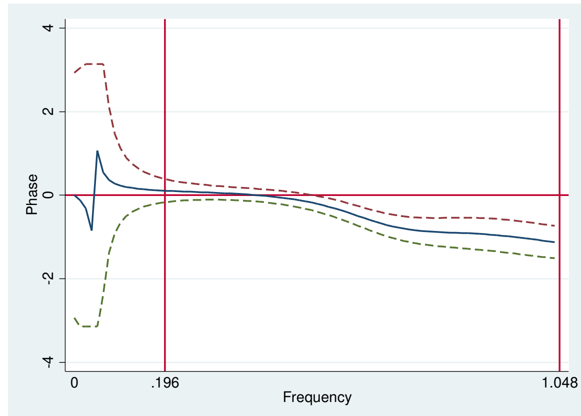
5% critical value in parentheses. * Significant at 5% level. For KPPS, the null is that the variable is stationary. For DF-GLS and PP, the null is that the series has a unit root. DF = Dickey-Fuller; PP = Phillips-Perron, KPSS = Kwiatkowski-Phillips-Schmidt-Shin.

Appendix Figure I: Inflation-unemployment relationship at different frequencies for the 1959:3-1973:4 period

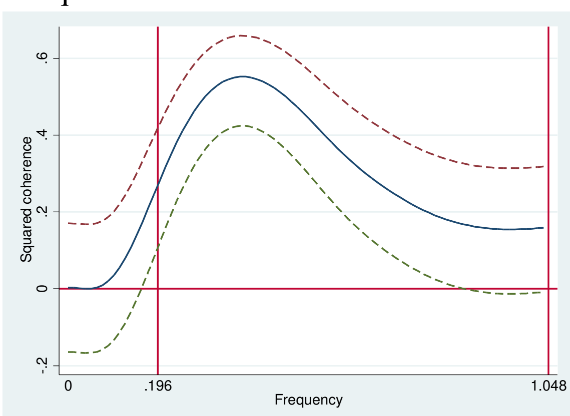
A. Gain



B. Phase



C. Squared coherence



Note: Dotted lines represent the 95% confidence intervals.