# **Revisiting Okun's law:** testing for asymmetric adjustment in Chile

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## Abstract

Okun’s law establishes how much of a country’s output is ‘lost’ when unemployment exceeds its natural or trend rate. Most studies assume a linear unemployment–output trade-off towards long-run equilibrium, which implies that economic expansions and recessions have a symmetric effect on unemployment. Nevertheless, this negative relationship may take a nonlinear form, in the sense that changes in output may cause asymmetric changes in unemployment. This paper therefore aims to test the linear assumption of Okun's law by deploying an asymmetric error correction model using seasonally adjusted quarterly data from Chile for the period 1996–2019 disaggregated by sex. The findings of the study confirm that unemployment in Chile adjusts asymmetrically across business cycles; to be precise, unemployment adjusts as expected during downturns in the business cycle but does not respond in the same way during upturns. Furthermore, the effect of economic growth on unemployment is almost twice as large for women as for men, but again only during recessions. The relevance of this research lies in the policy implications of misinterpreting the effects of business cycles on unemployment if asymmetry is ignored. For instance, the effectiveness and required ‘size’ of stabilisation policy on the real economy will depend on the ‘regime’ in which the Okun relationship is found. Similarly, economic growth policies should be accompanied by measures that address the gender gap, since the supply side tends to have incentives to penalise female employment.

## Keywords

Asymmetry, Chile, gender gap, Okun’s law, time series, unemployment

## JEL Codes

C22, E32, J64

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Santiago Chile cityscape from Canva Pro

## 1. Introduction

Okun's law – the relationship between unemployment and output – is one of the best-known empirical regularities in macroeconomics (Okun, 1962). It addresses the issue of how much of a country's output is 'lost' when unemployment exceeds its natural or trend rate, and provides a link between the labour and goods market over the business cycle. Moreover, it is a core part of many macroeconomic models, where the aggregate supply function is derived from combining Okun's law with the Phillips curve, which further links to policy trade-offs (Mankiw, 2015). Hence it has attracted the attention of economists, not only because it seems to be an empirical regularity but also because of its importance as a macroeconomic building block. The estimates of Okun's coefficient, which measures the responsiveness of unemployment to output growth, are essential insofar as they indicate the cost of unemployment in terms of output. Lastly, it is an important relationship because the way unemployment reacts to changes in output has implications for labour markets, monetary policies and forecasting.

One common and compelling criticism of Okun's relationship in the literature is the assumption of linearity. Since most specifications of Okun's law assume a symmetric relationship, expansions and contractions in output are assumed to have the same absolute effect on unemployment. Thus an essential aspect to consider – and one which is often forgotten – when measuring the effects of business cycles is whether there is evidence of asymmetric behaviour of the dependent variable throughout the business cycle, which could lead to an erroneous interpretation of the effects if ignored. Many studies instead suggest that the relationship is characterised by nonlinearities and asymmetries (see, for example, Virén, 2001; Crespo-Cuaresma, 2003; Silvapulle et al, 2004). A nonlinear asymmetric Okun's law would be a significant finding. For instance, it would suggest that any stabilisation policy's effectiveness (and required 'size') in the real economy would depend on the 'regime' in which Okun's relationship lies. Any nonlinearity in the relationship would also have implications for macroeconomic projections. Additionally, it might affect other recognised economic relationships, such as the price and wage Phillips curves.

The objective of this paper is to test Okun's law’s assumption of a symmetric relationship between changes in unemployment and output, in order to identify any asymmetric effects of business cycles on unemployment in Chile. The analysis disaggregates unemployment by sex, using Chile’s quarterly data (seasonally adjusted) from 1996:1 to 2019:4. For this purpose, the study mostly follows the methodology used by Harris and Silverstone (2001), which is based on the specification of an error-correction model (ECM). Although this approach is not the only one able to explore an asymmetric relationship and it does present some challenges in its implementation, it seems appropriate since its specification provides a flexible and straightforward econometric framework that accounts for both long-term and short-term asymmetries. Furthermore, the asymmetric ECM has the advantage of estimating coefficients for each business cycle regime without affecting the sample size; thus it overcomes the difficulties in determining a co-integrating vector between the variables.

This research contributes to the literature by being the first to establish a nonlinear Okun’s relationship using data from Chile, where previously there had been a significant gap for policy makers, since short-run output and unemployment adjustments to disequilibrium differ according to whether upturns or downturns in the business cycle are considered. Likewise, the paper incorporates for the first time an analysis of the relationship between unemployment and output disaggregated by sex. This could therefore lead to interest among economists in conducting analyses to identify asymmetries or determinants of asymmetry in the unemployment–output trade-off, since several countries in the region produce gender gaps that follow similar sociocultural patterns, significantly affecting development.

The paper is organised as follows. Section 2 presents the literature on the asymmetric unemployment–output relationship. Section 3 describes the econometric methods. Section 4 summarises the test results of the asymmetric effects of business cycles on unemployment based on the ECM. The final section concludes.

## 2. Asymmetry in Okun's law: evidence

Most studies on the nonlinear relationship between unemployment and output primarily focus on OECD countries, particularly the US, employing sophisticated econometric models. For instance, Altissimo and Violante (2001) found that propagated shocks during recession induce a nonlinear relationship between output and unemployment in the US because of the significantly larger impact of the shock on unemployment than on output in a nonlinear vector autoregressive (VAR) model. Crespo-Cuaresma (2003) constructed a regime-dependent specification of Okun's law to examine the asymmetric cyclical unemployment and cyclical output trade-off in the US, and found a significantly higher asymmetric contemporaneous effect of output on unemployment during economic recessions than in expansions. However, shocks to unemployment seemed to be more persistent in the expansionary regime.

Using a dynamic model, Silvapulle et al (2004) confirmed a negative nonlinear relationship between cyclical output and unemployment in the US and found that the contemporaneous effects of positive cyclical output on cyclical unemployment differed quantitatively from those of negative ones. Holmes and Silverstone (2006) used a Markov regime-switching model that captures asymmetries within and across regimes and found a significant inverse relationship between cyclical output and unemployment in the US during expansionary regimes.

Elsewhere, Lee (2000) studied the presence of an asymmetric Okun's relationship across 16 OECD countries utilising a static model that allows changes (negative and positive) in unemployment to determine output growth rate, and found a significantly higher Okun's coefficient for decreases (than for increases) in the unemployment rate for Finland, Japan and the US, while the opposite held true for Canada, France and the Netherlands. Virén (2001) introduced an error-correction asymmetric-based model – in which changes in unemployment are determined by positive and negative changes in output – to assess the asymmetric relationship among the variables across 20 OECD countries; the results obtained show that output growth exerts a more substantial impact on unemployment when it is low and output is high, and vice versa.

Harris and Silverstone (2001) tested for asymmetry in Okun's law in seven OECD countries using an asymmetric ECM (where Okun's coefficient is either above or below the long-run equilibrium) and found that unemployment reacted asymmetrically to contemporaneous changes in output contingent on upswings or downswings in the business cycle; they found asymmetry for Australia, Japan, New Zealand, the UK, US and Germany. However, Huang and Yeh (2013) found a highly significant unemployment–output trade-off for 53 OECD countries in the short and long run at both the state and country level, using panel autoregressive distributed lag (ARDL) model (with Pool Mean Group estimator) estimated from 1980 to 2005.

Furthermore, Shin et al (2014) found evidence of an asymmetric negative relationship between cyclical output and unemployment in the US, Canada and Japan, using the nonlinear autoregressive distributed lag (NARDL) model with monthly data spanning 1982 to 2003. More recently, Tang and Bethencourt (2017) considered the asymmetric unemployment–output trade-off across 17 countries in the Eurozone employing the NARDL, which showed evidence of long-run and short-run asymmetries in most of the countries considered, while labour markets responded quickly to changes in cyclical outputs in a short period. However, the adjustments towards a new equilibrium become weak in the long-run.

Despite the increasing interest, and implementation of new econometric techniques, in the study of the nonlinear asymmetric relationship between business cycles and unemployment rates, this is the first study that evaluates asymmetries in Okun's law for Chile. Only a handful of studies have investigated the symmetric version of Okun's law. Among these, Ball et al (2019) compared the performance of Okun's law in advanced and developing economies. They found that the cyclical relationship between jobs and growth is considerably weaker, on average, in developing than in advanced economies. Similarly, Bartolucci et al (2018) found a higher value of Okun coefficients for high-income economies than for low-income countries. Their results also show that the labour market problems in developing countries are mainly structural, since the sensitivity of unemployment to GDP changes is lower. Additionally, Zanin (2021) explored Okun's coefficient in several Latin American countries from 1995 to 2017. He found that Okun's coefficient for Chile was -0.368 and noted that the estimated Okun coefficients for Argentina, Brazil, Chile and Colombia were similar. Analogously, Franco-Martin (2017), using data from 1980 to 2014, estimated an Okun coefficient for Chile of -0.157.

## 3. Methodology

Since this article aims to test asymmetric adjustments towards the long-term equilibrium of Okun's law in Chile – expansions and contractions in output have a different absolute effect on unemployment – an appropriate approach is the one that Harris and Silverstone described in their 2001 article. Instead of estimating a curve or piece-wise linear function, they built the asymmetry into the ECM, assuming that there are different correction paths depending upon whether real output is above or below its trend value. In effect, this approach allowed them to handle the co-integration between the variables, capturing the changes in unemployment and output in Chile in the long and short run, and to effectively test the asymmetric adjustment across the business cycle.

### 3.1. Basic approach to estimation

Okun argued in his 1962 article that the reason for the less than proportionate change in (un)employment is that changes in output are also associated with changes in participation, labour hours and capital utilisation. Using a production function in natural logs, Prachowny (1993) showed that Okun's argument can be derived from a production function whereby either employment or unemployment enters the function. In particular, equation 1 shows that labour services have three components: the labour force ($l_t$), the unemployment rate ($u_t$) and hours worked ($h_t$). The substance of Okun's law is to say that co-movements in output ($y_t$) and unemployment dominate any adjustment in capital and its utilisation ($k_t + c_t$), the labour force, hours worked and technological progress ($\tau_t$). Okun's relationship, as specified by Prachowny (1993), comprises the long and short run, while Attfield and Silverstone (1998) showed that Okun's coefficient can be interpreted as the slope coefficient in the co-integrating regression between output and unemployment.

$$\begin{aligned} Y_t &= \alpha(k_t + c_t) + \beta(\gamma n_t + \delta h_t) + \tau_t + \varepsilon_t \\ &= \alpha(k_t + c_t) + \beta[\gamma(l_t - U_t) + \delta h_t] + \tau_t + \varepsilon_t \end{aligned} \tag{1}$$

$where,$

$Y \quad : real\ output;$

$k$ : $capital\ input$;

$c$ : $capital\ utilization\ rate$;

$n$ : $number\ of\ workers\ (labour\ force\ less\ number\ unemployed)$;

$h$ : $average\ hours\ worked$;

$l$ : $supply\ of\ workers\ (labour\ force)$;

$U$ : $unemployment\ rate\ (l - n)$;

$\tau$ : $disembodied\ technological\ factor$;

$\varepsilon$ : $error\ term$;

$\gamma$ : $contributions\ of\ workers$;

$\delta$ : $weekly\ hours\ to\ the\ total\ labour\ input$;

$\alpha, \beta$ : $output\ elasticities$;

Thus, from equation 1, Prachowny (1993) showed that an alternative formulation of Okun's law could be expressed as:

$$u_t = \beta_0 + \beta_1 y_t + \beta_2 t + \varepsilon_t \qquad (2)$$

*where,*

$u_t$ : $natural\ log\ of\ unemployment\ rate$;

$y_t$ : $natural\ log\ of\ real\ output$;

$t$ : $time\ trend$;

$\varepsilon_t$ : $error\ term$;

Figure A2 in the Appendix shows the log of the quarterly unemployment rate against the log of real output, again between 1996:1 and 2019:4, when the analysis is disaggregated by sex. From this, it is possible to observe that the relationship between both log variables is nonlinear.

Since $u_t$ and $y_t$ are potentially non-stationary variables, their relationship must be estimated using the co-integration approach. This presupposes that there is a long- and a short-run relationship between the variables, which implies that there is, at most, a single long-run relationship between $u_t$ and $y_t$.

According to Engle and Granger (1987), assuming $u_t$ and $y_t$ are both $I(1)$, co-integration exists if $\varepsilon_t \sim I(0)$. Thus, the second step of the Engle–Granger test for co-integration, based on the ordinary least squares (OLS) estimate of $\rho$ in equation 3, provides the association of the long-run model established in equation 2 with a short-run ECM.

$$\Delta\hat{\varepsilon}_t = \rho\hat{\varepsilon}_{t-1} + \sum_{i=0}^{n} \Delta\hat{\varepsilon}_{t-i} + v_t \ , \ v_t \sim IID(0, \sigma^2) \tag{3}$$

Ultimately, if it is possible to reject the null hypothesis of no co-integration, $H_0: \rho = 0$, with a high level of statistical significance, then equations 2 and 3 could be defined as the following ECM:

$$A(L)\Delta u_t = B(L)\Delta y_{t-1} - (1-\alpha)\hat{\varepsilon}_{t-1} + \omega_t \ , \ \omega_t \sim IID(0, \sigma^2) \tag{4}$$

$where,$

$$\hat{\varepsilon}_{t-1} = ec_{t-1} = u_{t-1} - \hat{\beta}_0 - \hat{\beta}_1 y_{t-1} - \hat{\beta}_2 t \tag{5}$$

$and\ A(L)\ and\ B(L)\ are\ polynomial\ lag\ operators.$

Furthermore, when the two variables $u_t$ and $y_t$ are cointegrated, the ECM incorporates not only short-run but also long-run effects. This is because the long-run equilibrium $u_{t-1} - \hat{\beta}_0 - \hat{\beta}_1 y_{t-1} - \hat{\beta}_2 t$ is included in the model together with the short-run dynamics captured by the differenced term. Another important advantage is that all the terms in the ECM model are stationary, and standard OLS is therefore valid. This is because if $u_t$ and $y_t$ are $I(1)$, then $\Delta u_t$ and $\Delta y_t$ are $I(0)$, and by definition, if $u_t$ and $y_t$ are co-integrated, then their linear combination is $u_{t-1} - \hat{\beta}_0 - \hat{\beta}_1 y_{t-1} - \hat{\beta}_2 t \sim I(0)$. Thus, equation 4 implies that any short-run changes in unemployment and output resulting from disequilibrium $(1-\alpha)$ are strictly proportional to the absolute value of the error-correction term.

If, however, adjustment to disequilibrium is asymmetric, then Enders and Granger (1998) and Enders and Siklos (2001) have shown that an alternative specification for equation 3 – called the threshold autoregressive (TAR) model – can be written as:

$$\Delta\hat{\varepsilon}_t = I_t\rho_1\hat{\varepsilon}_{t-1} + (1-I_t)\rho_2\hat{\varepsilon}_{t-1} + \sum_{i=1}^{n}\Delta\hat{\varepsilon}_{t-i} + v_t^* \ , \ \ v_t^* \sim IID(0,\sigma^2) \tag{6}$$

$$where\ I_t\ is\ the\ Heaviside\ indicator\ function\ based\ on\ the\ threshold\ value\ \tau:$$

$$I_t \begin{cases} 1\,, & if\ \hat{\varepsilon}_{t-1} \geq \tau \\ 0\,, & if\ \hat{\varepsilon}_{t-1} < \tau \end{cases} \tag{7}$$

The asymmetric version of the ECM replaces the single error-correction term in equation 5 ($\hat{\varepsilon}_{t-1}$) with two error-correction terms multiplied by $I_t$ and $(1-I_t)$, respectively, producing the asymmetric version of equation 4, which would be as follows:

$$\Delta u_t = \beta_0 + \rho_1 I_t\hat{\varepsilon}_{t-1} + \rho_2(1-I_t)\hat{\varepsilon}_{t-1} + \beta_1\Delta y_{t-1} + \beta_2\Delta u_{t-1} + \omega_t \tag{8}$$

Finally, there is some evidence that this specification for testing asymmetry is powerful in detecting it because it allows alternative means for specifying thresholds that improve statistical performance (Cook et al, 1999; Cook & Holly, 2002). Nonetheless, the risk of perversity thanks to the introduction of bias through the threshold selection criterion still exists, and in this regard a selection procedure that has been tested should be chosen. Moreover, according to Mayes and Virén (2002), Harris and Silverstone (2001) encountered the problem of perversity but only at a limited scale and their estimates are well determined. Thus, incorporating the asymmetry into the ECM coefficients leads to a suitable approach for testing using a standard *F*-test, in addition to the advantage it provides for intuitive interpretation of the estimates.

## 3.2. Grid search for unknown threshold $\boldsymbol{\tau}$

As the threshold value $\tau$ in equation 7 is unknown, the procedure suggested in Enders and Siklos (2001) is used to perform a grid-search. Specifically, the estimated residuals from equation 2 are sorted in ascending order and called:

$$\hat{\varepsilon}_1^{\tau} < \hat{\varepsilon}_2^{\tau} < \cdots < \hat{\varepsilon}_T^{\tau} \ , \qquad \textit{where } T \textit{ is the number of usable observations}$$

Next, the largest and smallest 15% of the $\{\hat{\varepsilon}_i^{\tau}\}$ values are discarded to make sure to choose a threshold value that does not exclude a large portion of observations, which would not allow for the differentiating of values above and below the long-run equilibrium and consequently for testing the null hypothesis of no co-integration. Thus, the search is for the possible thresholds lying in the middle 70% of the arranged values of $\{\hat{\varepsilon}_t\}$. Equations 6 and 7 are estimated for each possible threshold. The model with the lowest residual sum of squares is chosen to obtain the preferred value of $\tau$. Chan (1993) showed that searching over the potential threshold values to minimise the sum of squared errors from the fitted model yields a remarkably consistent estimate of the threshold.

## 3.3. Testing for unit roots in $\boldsymbol{u_t}$ and $\boldsymbol{y_t}$

One of the most topical debates among economists is whether macroeconomic time series can be characterised as a random walk (unit root) or trend-stationary. For instance, Kydland and Prescott (1982) formalised the idea that the trend could be stochastic: a deviation from the view of long-run dynamics as slow-moving forces. This challenged the traditional view (eg Burns & Mitchell, 1946; Friedman, 1964; Lucas, 1973) of treating economic time series as temporary fluctuations around a deterministic trend function as opposed to permanent changes reflected in the trend. Hence, temporary shocks would produce permanent effects on GDP if they temporarily altered the long-term growth engine. This in turn has implications for the unit root properties of the stochastic trend.

As an illustration, Nelson and Plosser (1982) revealed that the GDP series of the US followed a random walk. They argued that most of the changes in the GDP were permanent, indicating that there was no tendency for output growth to revert to its underlying trend following a shock. Nonetheless, Perron (1989) demonstrated that Nelson and Plosser’s strong evidence supporting the unit root hypothesis resulted from their failure to account for structural changes in the data. Perron (1989) incorporated an exogenous structural break for the 1929 crash in the conventional unit root test (augmented Dickey–Fuller (ADF) test). On accounting for a structural break, the unit root hypothesis was rejected for 11 out of the 14 series analysed by Nelson and Plosser (1982). In addition, a common feature shared by all the linear models of $I(0)$ processes with structural change considered (eg Zivot & Andrews, 1992; Vogelsang & Perron, 1998; Lee & Strazicich, 2003; Narayan & Popp, 2010) is that the deterministic structural change is assumed to occur instantaneously, which is unlikely given that changes in economic aggregates are influenced by the changes in behaviour of many agents, and not all individual agents will react simultaneously to a given economic stimulus.

During the early 1990s, Banerjee et al (1992), Christiano (1992) and Zivot and Andrews (1992) opined that choosing the structural break(s) exogenously could lead to over-rejection of the unit root hypothesis. To address this problem, they proposed the one endogenous structural break test. Lumsdaine and Papell (1997) modified the endogenous break methodology to account for two endogenous breaks in the trend equation. They found more evidence against the unit root hypothesis than Zivot and Andrews (1992), but less than Perron (1989). A limitation of the ADF-type endogenous break unit root tests, such as the Zivot and Andrews (1992) and Lumsdaine and Papell (1997) tests, is that the critical values are derived while assuming no break(s) under the null. Thus, spurious rejections may occur when utilising the Zivot and Andrews (1992) and Lumsdaine and Papell (1997) tests. Lee and Strazicich (2013) proposed a one-break Lagrange Multiplier (LM) unit root test as an alternative to the Zivot and Andrews (1992) test, while Lee and Strazicich (2003) developed a two-break LM unit root test as a substitute for the Lumsdaine and Papell (1997) test. In contrast to the ADF test, the LM unit root test incorporates breaks under the null and alternative hypotheses. Nevertheless, when the time series presents more than two structural breaks, the problem persists and could lead to erroneous conclusions, especially if the variables are considered non-stationary.

Two hypotheses have been discussed frequently when economists consider researching the features of unemployment rates: hysteresis and asymmetry. The hysteresis hypothesis implies that shocks permanently influence unemployment. It indicates a non-stationary process. On the other hand, the alternative hypothesis, the natural unemployment rate, refers to a situation where the unemployment rate tends to revert to a long-run equilibrium level after a shock. Such existence of hysteresis was suggested by Blanchard and Summers (1986) and Mitchell (1993). Camarero et al (2006) point out that the distinction between the two hypotheses is not so clear-cut. In particular, there is a stage regarded as 'persistence', which implies a slow speed of adjustment towards the equilibrium level in the long run. In this sense, the unemployment rate is a mean-reverting process, and persistence can be regarded as a particular case of the natural unemployment rate. Another unique situation is that full persistence is taken as hysteresis (Skalin & Teräsvirta, 2002). The hysteresis hypothesis indicates that the unemployment rate has a unit root ($I(1)$ process), while the natural rate hypothesis would be in line with an $I(0)$ process, the stationary one. Persistence, then, according to Camarero et al. (2006), is $I(0)$ around *m* shifting means. Such characteristics would be appropriately estimated in a nonlinear model. Asymmetry, conversely, is not necessarily related to hysteresis or multiple equilibria. As Rothman (1998) pointed out, when business cycling is modelled, the unemployment rate increases quickly in recessions but declines relatively slowly during expansions, which can be regarded as a nonlinear phenomenon.

The ambiguity surrounding the order of integration of the variables in levels is increased by the fact that there is considerable disagreement in the literature on whether the finding of non-stationarity of unemployment and output can depend on the functional-form, for example in terms of a deterministic trend, a stochastic trend or structural breaks. The modelling of such alternative specifications also depends on whether the nature of shocks is a temporary phenomenon reflecting short-term variability or a permanent one affecting the long-run path of the variables, thereby causing nonlinearities in the evolution of the series. An aspect cannot be verified by visually inspecting the time-series plots. Consequently, after collecting information on potential structural breaks in the time series through the tests proposed by Page (1954) and Bai and Perron (2003) – Table A2 in the Appendix – the stationarity analysis will be divided into three types of unit root tests. The first such type can be referred to as classical linear models, such as the unit root tests described by Dicky and Fuller (1979), Elliott et al (ERS) (1996) and Ng and Perron (2001). The second type of test is composed of unit root tests that allow structural breaks, particularly those proposed by Carrion-i-Silvestre et al (2009), Narayan and Popp (2010), Enders and Lee (2012a, 2012b), Rodrigues and Taylor (2012) and Meng et al (2017). Lastly, the third type of unit root tests is considered within the group of smooth transition regression models, among which are those defined by Leybourne et al (1998), Sollis (2009) and Kruse (2011). The results of these tests are presented in Tables A3, A4 and A5 in the Appendix.

The purpose of incorporating an extensive analysis of unit root tests only responds to the opportunity to raise a criticism highlighting the problem that underlies econometric methods that depend on the stationarity of the variables. For instance, in order to determine a stable long-run relationship between two variables, these must be stationary; otherwise there will only be a long-run equilibrium if there exists a stationary linear combination of non-stationary random variables (co-integrating vector). Hence, examining the stationarity of variables is often a crucial element in time-series analysis. Fortunately, if the variables are not co-integrated, the worst that can happen when using an ECM is that the coefficient corresponding to the error-correction term is statistically insignificant, in which case a different approach will need to be considered, such as one that uses de-trended series. In summary, the asymmetric ECM does not depend *a priori* on stationarity or co-integration; however, including the analysis of unit roots provides a contribution because there is a vast literature that gives excessive emphasis to co-integration and unit root tests when there are other methods with which to address them.

## 4. Empirical results

This section discusses the results of the deployed (i) unit root tests allowing structural breaks to determine whether the time-series variables are non-stationary, of the (ii) tests for co-integration between unemployment and output, and of the (iii) asymmetric ECM to test whether unemployment adjusts following an asymmetric pattern concerning the business cycle.

### 4.1. Unit root tests

Based on evidence gathered from the time-series plots (Figures A3 and A4 in the Appendix), in addition to the results obtained by the Bai and Perron (2003) test for multiple structural changes (Table A2 in the Appendix), it was decided to deploy unit root tests that consider nonlinear functional forms and structural breaks. Unit root tests depend heavily on the underlying assumptions and properties of the models; thus linear unit root tests may result in misleading inferences in the presence of nonlinear dynamics. Consequently, for the stationarity analysis it was decided to group 12 unit root tests into three types to describe different possible scenarios and collect enough evidence to then continue with the co-integration tests. Likewise, it is worth mentioning that the unit root tests were deployed for the three unemployment series – total, male and female – in order to examine possible differences that were not ultimately reflected.

The first type (type-I) gathers non-stationarity tests – null hypothesis: the time is $I(1)$ – that follow a linear model. Within this category, it was decided to perform the tests proposed by Dickey and Fuller (1979), Elliott et al (1993) and Ng and Perron (2001). The second set of unit root tests (type-II) considered in this analysis is related to those that account for the presence of structural breaks, such as the tests implemented by Meng et al (2017), Carrion-i-Silvestre et al (2009, Narayan and Popp (2010), Rodrigues and Taylor (2009) and Enders and Lee (2012a, 2012b). The third (type-III) and last group involves unit root tests that allow for nonlinearity in the behaviour of time-series data. Among the nonlinear unit root tests, it was decided to carry out those developed by Leybourne et al (1998) based on a logistic smooth transition autoregressive model (LSTAR), by Kruse (2011) based on an exponential smooth transition autoregressive model (ESTAR), and by Sollis (2009) based on an asymmetric smooth transition autoregressive model (AESTAR).

Based on the results of the linear unit root tests, ie ADF, Ng-Perron and DF–GLS, apparently all the series under evaluation would be non-stationary; however, such tests do not consider structural breaks. The same result is obtained for the tests based on a Fourier functional form – which allows multiple structural breaks – for the DF–GLS test with two structural breaks and for the nonlinear unit root test introduced by Leybourne et al (1998). Nonetheless, according to the residual augmented least squares (RALS)–LM test with trend breaks and non-normal errors, Kruse's AESTAR-type test and Sollis's AESTAR-type test, the output (real GDP in log form) series might be considered stationary, since the null hypothesis of unit root is rejected with 5% of statistical significance in all three cases. Regarding the unemployment rate variables, only the RALS–LM test and the ADF with two structural breaks at an unknown time report the series as stationary. Table 1 provides a summary of the information in appendix Tables A3, A4 and A5. The results of the unit root tests for the first-difference variables have been omitted from this table, since the estimates indicate that they would be stationary in all cases.

## Table 1: Are the variables non-stationary?

| Unit root test | log($u_t$) | | | log($y_t$) |
|---|---|---|---|---|
| | **Total** | **Male** | **Female** | |
| ADF | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| Ng–Perron | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| DF–GLS | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| RALS–LM with non-normal errors (two structural breaks) | *I*(0) | *I*(0) | *I*(0) | *I*(0) |
| ADF (two structural breaks) | *I*(0) | *I*(0) | *I*(0) | *I*(1) |
| DF–GLS (two structural breaks) | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| Fourier DF (multiple structural breaks) | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| Fourier GLS (multiple structural breaks) | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| Fourier LM (multiple structural breaks) | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| LNV (LSTAR-type) | *I*(1) | *I*(1) | *I*(1) | *I*(1) |
| Kruse (ESTAR-type) | *I*(1) | *I*(1) | *I*(1) | *I*(0) |
| Sollis (AESTAR-type) | *I*(1) | *I*(1) | *I*(1) | *I*(0) |

*Notes: The null hypothesis was rejected with at least 5% statistical significance among all tests, from the drift plus trend model to the no drift, no trend model. ADF indicates the results obtained by the augmented Dickey–Fuller unit root test based on the procedure proposed by Dickey and Fuller (1979). Ng–Perron indicates the results obtained by the unit root test* *implemented by Ng and Perron (2001). DF–GLS indicates the results obtained by the unit root test developed by Elliott et al (1996). RALS–LM indicates the results obtained by the unit root test with trend breaks and non-normal errors introduced by Meng et al (2017). ADF unit root test with two structural breaks indicates the results obtained by the unit root test proposed by Narayan and Popp (2010). DF–GLS unit root test with two structural breaks indicates the results obtained by the unit root test suggested by Carrion-i-Silvestre et al (2009). Fourier DF indicates the results obtained by the unit root test with flexible Fourier form structural breaks proposed by Enders and Lee (2012b). Fourier GLS indicates the results obtained by the unit root test with flexible Fourier form structural breaks proposed by Rodrigues and Taylor (2009). Fourier LM indicates the results obtained by the unit root test with flexible Fourier form structural breaks proposed by Enders and Lee (2012a). LNV (LSTAR-type) indicates the results obtained by the nonlinear unit root test proposed by Leybourne et al (1998). Kruse (ESTAR-type) indicates the results obtained by the nonlinear unit root test proposed by Kruse (2011). Sollis (AESTAR-type) indicates the results obtained by the nonlinear unit root test proposed by Sollis (2009).*

Accordingly, this analysis intends to put into perspective the complexity around unit root tests, often forgotten, since the estimates only provide evidence under several assumptions. Consequently, drawing conclusions beyond what can be verified is not sensible. In this regard, what has been described in this subsection is related to the uncertainty present in the results of unit root tests when the data exhibit multiple structural breaks or the generating mechanism of a time series is not linear, given that practically each existing unit root test can deliver a different 'reality'. Based on the evidence provided by the tests implemented here, it is a challenge to verify whether the time series under evaluation are stationary. Thus, a reasonable path forward would be to focus on models that enable estimation without necessarily being tied to cointegration tests, and consequently to what unit root tests indicate, as was done in this study.

### 4.2. Asymmetric adjustment across the business cycle

Since the approach chosen for this research – asymmetric ECM – does not depend on co-integration, we have decided to omit a report of co-integration tests from the results section. When estimating an ECM, if the coefficient of the error-correction term is statistically significant, then the evidence indicates a long-run equilibrium between the variables, i.e., they are co-integrated. Otherwise, the most unfavourable outcome is obtaining a non-significant relationship and being forced to discard the ECM. Notwithstanding, Table 2 presents the results of the regression of equation 3, which demonstrates that the residuals of equation 2 are stationary, $I(0)$, and therefore it is appropriate to use an ECM.

**Table 2: Are the residuals of equation 2 stationary?**

| Variable | Total | Male | Female |
|---|---|---|---|
| **$\hat{\varepsilon}_t$ (*t*-stat)** | -0.10 (-2.67)*** | -0.10 (-2.68)*** | -0.11 (-2.39)** |

*Notes: Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*The number of lags was selected by the Bayesian Information Criterion (BIC).*

The asymmetric ECM assumes that any deviation from the long-run equilibrium between the two variables is corrected asymmetrically; this means that the speed at which the variables converge to the steady state differs when they move in opposite directions. Additionally, one of the strengths of the asymmetric ECM is that it allows the identification of the long-run relationship between variables, even when just one of the variables is non-stationary. Accordingly, the asymmetric ECM is a general case, understanding that it is always possible to revert to the symmetric version if the data do not support the hypothesis.

Table 3 summarises the asymmetric response to disequilibrium in the unemployment–output relationship in terms of changes in unemployment. There is no substantial variation across the series considered and unemployment adjusts as expected during a downturn in the business cycle, but in upturns it seems not to respond. In addition, the *t*-statistic of the estimated coefficient for the $\Delta y_{t-1}$ terms show that real GDP Granger-causes unemployment in the three cases. In other words, the estimated short-run Okun coefficients are statistically significant, and unemployment adjusts asymmetrically to disequilibrium according to the estimates on the error-correction terms, $\hat{\varepsilon}_{t-1}$. From Table 4, it is important to note that all equations are well specified, as shown by the various diagnostic tests, including Chow tests for parameter stability.

**Table 3: Adjustments to disequilibrium**

| Data | Upturn in business cycle ($\Delta u_t$) | Downturn in business cycle ($\Delta u_t$) | Short-run Okun's coefficient |
|---|---|---|---|
| Total unemployment rate, log($u_t$) | – | Expected response | -2.36*** |
| Male unemployment rate, log($u_t$) | – | Expected response | -3.18*** |
| Female unemployment rate, log($u_t$) | – | Expected response | -1.79** |

*Notes: – no significant response at 5% significance level.*
*Expected responses were declared with up to 5% statistical significance.*
*Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*

Moreover, positive values of $\hat{\varepsilon}_{t-1}$ are usually associated with short-run negative adjustments in the unemployment rate. This brings the long-run unemployment–output relationship back into equilibrium. Other things being equal, the speed of adjustment ($\rho_1$) for total unemployment indicates that around 23% of the disequilibrium is removed each quarter, so it would take about 13 months for the economy to return to its long-run trend, but some 1.6 years for male unemployment and female unemployment to achieve equilibrium.

In contrast, negative values of $\hat{\varepsilon}_{t-1}$ (indicating 'recession' conditions) do not have a significant impact on short-run changes in total unemployment, male unemployment or female unemployment; otherwise the adjustment would be in the 'wrong' direction because of the sign of the coefficients related to the $(1 - I_t)\hat{\varepsilon}_{t-1}$ term. That is, when $\hat{\varepsilon}_{t-1}$ is negative and the economy is in the upturn of the business cycle, it is expected that $u_t$ will adjust upwards and $y_t$ should fall. Since this is not the case, quantity adjustments in the labour market do not act to re-establish equilibrium. Upturns are presumably characterised by short-run adjustments in prices (which are not part of the model) more than by short-run adjustments in the real side of the economy. Regarding unemployment adjustments, the asymmetric ECM is superior to the symmetrical version for three main reasons: (1) the asymmetric model provides information on the behaviour of unemployment in the different phases of the business cycle; (2) the speed of adjustment estimated using the asymmetric ECM (Table 4) in all three cases is quite different from the estimates from the symmetric version; and (3) the estimates of the short-run Okun coefficients are also somewhat different, especially when comparing the effect of economic growth on male and female unemployment.

Finally, considering that the asymmetric approach is a general specification and allows us to test the hypothesis of the asymmetric adjustment of Okun's law, it is essential to review some of the findings that this model provides and the advantages of the analysis disaggregated by sex. First, using an asymmetric approach, it was possible to establish co-integration – statistically significant error-correction term – and to show that short-run adjustment to disequilibrium is confined mostly to downturns in the business cycle. Second, it was possible to find that, in the case of Chile, the impact of the changes in the output affected male unemployment much more than female unemployment, which implies a gender gap in the effectiveness of public policies that seek to reduce unemployment through economic growth. Third, using the asymmetric ECM it was possible to confirm an asymmetric unemployment–output relationship with disaggregated by sex. By conducting a joint hypothesis *F*-test for the null hypothesis $\rho_1 = \rho_2 = 0$, the null is rejected at a significance level of 5% or better when using male and female unemployment data (Table 4). Fourth, when using aggregate data – for the period 1996:1–2019:4 – the estimates from the asymmetric ECM indicate that Okun's relationship is asymmetric in Chile. Throughout the entire study, there were indications of asymmetric behaviour in the relationship between total unemployment and real GDP. This was confirmed through the *F*-test from the estimates obtained by equation 8, since the null hypothesis ($\rho_1 = \rho_2$) is rejected with a 5% level of significance (Table 4). Subsequently, in Chile, total unemployment adjusts in the expected manner during a downturn in the business cycle and the labour market continues to adjust as a response to disequilibrium. Nonetheless, unemployment responses to output changes are uncommon during upturns, and often wrongly signed.

## Table 4. Estimates of asymmetric ECM for $u_t$

| Variable | Total | Male | Female |
|---|---|---|---|
| ***Estimates of asymmetric ECM (equation 8)*** | | | |
| Intercept (*t*-stat) | 0.03 (3.38)*** | 0.04 (2.77)*** | 0.02 (1.99)** |
| $I_t\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.23 (-3.43)*** | -0.16 (-2.16)** | -0.15 (-2.02)** |
| $(1-I_t)\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.05 (-0.97) | -0.10 (-1.78)* | -0.07 (-0.95) |
| $\Delta y_{t-1}$ (*t*-stat) | -2.36 (-3.53)*** | -3.18 (-3.36)*** | -1.79 (-2.97)** |
| $\Delta u_{t-1}$ (*t*-stat) | 0.11 (1.06) | 0.03 (0.22) | 0.00 (0.04) |
| Adjusted $R^2$ | 0.26 | 0.23 | 0.12 |
| Engle's LM ARCH test (lags=4) | 3.78 | 1.11 | 0.74 |
| Ljung–Box test (lags=2) | 0.16 | 0.30 | 1.01 |
| Ljung–Box test (lags=4) | 1.75 | 0.78 | 1.25 |
| Durbin–Watson test | 2.06 | 2.08 | 2.09 |
| Jarque–Bera test | 1.18 | 4.21 | 1.94 |
| Chow test | 1.35 | 1.23 | 1.13 |
| RESET test | 0.83 | 0.58 | 0.11 |
| *F*-stat {$H_0$: $\rho_1=\rho_2=0$} | 6.82*** | 4.36*** | 3.68** |
| *F*-stat {$H_0$: $\rho_1=\rho_2$} | 4.49** | 0.31 | 0.48 |
| ***Estimates of symmetric ECM (equation 4)*** | | | |
| Intercept (*t*-stat) | 0.03 (2.75)*** | 0.03 (2.69)*** | 0.02 (2.07)** |

| | | | |
|---|---|---|---|
| $\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.10 (-2.73)*** | -0.12 (-2.65)*** | -0.11 (-2.74)*** |
| $\Delta y_{t-1}$ (*t*-stat) | -2.54 (-3.76)*** | -3.28 (-3.62)*** | -1.88 (-3.07)*** |
| $\Delta u_{t-1}$ (*t*-stat) | 0.08 (0.77) | 0.02 (0.15) | 0.00 (0.03) |
| ***Estimates of VECM (assuming that a co-integration vector exists)*** | | | |
| $\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.08 (-2.97)*** | -0.09 (-3.21)*** | -0.11 (-2.65)*** |
| $\Delta u_{t-1}$ (*t*-stat) | -0.04 (-0.38) | -0.13 (-1.13) | -0.12 (-1.21) |
| Long-run Okun's coefficient (*t*-stat) | -3.11 (-4.54)*** | -4.08 (-4.72)*** | -2.11 (-3.09)*** |

*Notes: Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*All the regressions were estimated using heteroscedasticity-consistent standard errors (HC2).*

## 5. Conclusion

Okun’s law is an elementary unit of many macro-econometric models and is often considered an empirical regularity. This study has investigated the possibility of asymmetries in that relationship using quarterly data from Chile, explicitly considering the asymmetric ECM proposed by Harris and Silverstone (2001). Using this asymmetric approach, it is possible to establish co-integration and examine short-run adjustment to disequilibrium during the upturns and downturns in the business cycle.

From the empirical analysis, the inverted relationship between the changes in the unemployment rate and real GDP growth is confirmed for Chile. We also note that Okun coefficients are not high in magnitude and are consistent with that of most OECD countries (Zanin, 2014). Based on the VECM, assuming one co-integrated vector, the estimates show that the three cases studied exhibit a long-run unemployment–output relationship, and that the Okun coefficients fluctuate between -2.11 and -4.08. Consequently, the fact that the existence of a long-term relationship is accepted in light of Okun's law has significance for policy makers in Chile, since variations in unemployment respond negatively to GDP growth. Failing to consider the asymmetric adjustments between these two macroeconomic variables does not facilitate the task of targeting specific types of public policies that seek to protect or strengthen the employment opportunities of particular interest groups in pursuit of national strategic development goals.

From this, the asymmetric ECM estimates for the 1996:1–2019:4 period conclude that the long-run relationship between unemployment and output for both men and women is subject to asymmetric effects. These results suggest that unemployment adjusts as expected during a downturn in the business cycle, whereas the labour market continues to ‘tighten’ in upturns, when there is disequilibrium between unemployment and output. An appealing explanation for this is that expectation and pessimism, possibly as a result of risk aversion, during the downturn invariably result in a stronger response of unemployment to negative output gaps. Further, it can be argued that labour supply flexibility commonly results in job losses during a downswing to minimise the effects on returns, but then during the upswing many of these jobs are not recovered, even though the economy is restored to the level it had reached before the downward turn.

These findings have important policy implications. It is worth noting that the detection of an asymmetric negative relationship between unemployment and output demonstrates the ineffectiveness of the various economic growth-inducing policies as unemployment-reducing strategies. In the case of Chile, and probably of other developing countries, economic growth does not necessarily lead to quality employment. Similarly, the asymmetries in Okun’s law across the business cycle have implications for both the nature and the timing of policies to improve labour market outcomes. Thus, focusing the analysis only on data disaggregated by sex, the presence of asymmetries suggests that counter-cyclical policies are fundamentally important. In other words, early action to mitigate the drop in aggregate demand will have a more pronounced effect on unemployment than will policies designed during the recovery to accelerate job growth.

To conclude, given the lack of other studies on asymmetry in Okun's law with Chilean data aggregated and disaggregated by sex, it is hoped that this paper represents a contribution such that policy makers might conduct effective labour market reforms by considering the identified long- and short-run effects of output on unemployment. Moreover, from a research perspective, it is expected that in the future the study of asymmetric adjustment of unemployment across the business cycle will continue to be deepened through other methodological approaches in order to contrast results, and that the analysis will be extended to other Latin American economies. Additionally, as long as data are available, it is desirable to incorporate some notable drivers of asymmetric Okun relationships such as labour participation rate, labour productivity, employment growth rate, informal employment and demographics. This type of research will allow policy makers and researchers to understand better the unemployment–output relationship, and how to improve the efficacy of government policies.

## References


Altissimo, F. and Violante, G. (2001). 'The non-linear dynamics of output and unemployment in the US'. *Journal of Applied Econometrics 16*, 461–486. http://www.jstor.org/stable/2678570.

Attfield, C. and Silverstone, B. (1998). 'Okun's law, cointegration and gap variables'. *Journal of Macroeconomics 20*, 625–637. https://doi.org/10.1016/S0164-0704(98)00076-7.

Bai, J. and Perron, P. (2003). 'Computation and analysis of multiple structural change models'. *Journal of Applied Econometrics 18*, 1–22. https://doi.org/10.1002/jae.659.

Ball, L., Furceri, D., Leigh, D. and Loungani, P. (2019). 'Does one law fit all? Cross-country evidence on Okun's law'. *Open Economies Review 30*, 841–874. https://doi.org/10.1007/s11079-019-09549-3.

Banerjee, A., Lumsdaine, R. and Stock, J. (1992). 'Recursive and sequential tests of the unit root and trend break hypotheses: theory and international evidence'. *Journal of Business & Economic Statistics 10*, 271–287. https://doi.org/10.2307/1391542.

Bartolucci, F., Choudhry, M., Marelli, E. and Signorelli, M. (2018). 'GDP dynamics and unemployment changes in developed and developing countries'. *Applied Economics 50*, 3338–3356. https://doi.org/10.1080/00036846.2017.1420894.

Blanchard, O. and Summers, L. (1986). 'Hysteresis and the European unemployment problem'. In *NBER Macroeconomics Annual 1986* (pp. 15–90).

New York: National Bureau of Economic Research (NBER). https://doi.org/10.3386/w1950.

Burns, A. and Mitchell, W. (1946). *Measuring Business Cycles*. New York: National Bureau of Economic Research.

Camarero, M., Carrion-i-Silvestre, J. and Tamarit, C. (2006). 'Testing for hysteresis in unemployment in OECD countries: new evidence using stationarity panel tests with breaks'. *Oxford Bulletin of Economics and Statistics 68*, 167–182. https://doi.org/10.1111/j.1468-0084.2006.00157.x.

Carrion-i-Silvestre, J., Kim, D. and Perron, P. (2009). 'GLS-based unit root tests with multiple structural breaks under both the null and the alternative hypotheses'. *Econometric Theory 25*, 1754–1792. https://doi.org/10.1017/S0266466609990326.

Chan, K. (1993). 'Consistency and limiting distribution of the least squares estimator of a threshold autoregressive model'. *Annals of Statistics 21*, 520–533. https://www.jstor.org/stable/3035605.

Christiano, L. (1992). 'Searching for a break in GNP'. *Journal of Business & Economic Statistics 10*, 237–250. https://doi.org/10.2307/1391540.

Christiano, L. and Fitzgerald, T. (1999). *The Band Pass Filter*. NBER Working Paper 7257. New York: NBER. https://doi.org/10.3386/w7257.

Cook, S. and Holly, S. (2002). 'Threshold specification for asymmetric error correction models'. *Applied Economics Letters 9*, 711–713. https://doi.org/10.1080/13504850110108111.

Cook, S., Holly, S. and Turner, P. (1999). 'Testing for non-linearity: the case of Granger–Lee asymmetry'. *Economics Letters 62*, 155–159. https://doi.org/10.1016/S0165-1765(98)00208-0.

Crespo-Cuaresma, J. (2003). 'Okun's law revisited'. *Oxford Bulletin of Economics and Statistics 65*, 439–451. https://doi.org/10.1111/1468-0084.t01-1-00056.

Dickey, D. and Fuller, W. (1979). 'Distribution of the estimators for autoregressive time series with a unit root'. *Journal of the American Statistical Association 74,* 427–431. https://www.jstor.org/stable/2286348.

Elliott, G., Rothenberg, T. and Stock, J. (1996). 'Efficient tests for an autoregressive unit root'. *Econometrica 64*, 813–836. https://www.jstor.org/stable/2171846.

Enders, W. and Granger, C. (1998). 'Unit-root tests and asymmetric adjustment with an example using the term structure of interest rates'. *Journal of Business & Economic Statistics 16*, 304–311. https://www.jstor.org/stable/1392506.

Enders, W. and Lee, J. (2012a). 'A unit root test using a Fourier series to approximate smooth breaks'. *Oxford Bulletin of Economics and Statistics 74*, 574–599. https://doi.org/10.1111/j.1468-0084.2011.00662.x.

Enders, W. and Lee, J. (2012b). 'The flexible Fourier form and Dickey–Fuller type unit root tests'. *Economic Letters 117*, 196–199. https://doi.org/10.1016/j.econlet.2012.04.081.

Enders, W. and Siklos, P. (2001). 'Cointegration and threshold adjustment'. *Journal of Business & Economic Statistics 19*, 166–176. http://www.jstor.org/stable/1392161.

Engle, R. and Granger, C. (1987). 'Co-integration and error correction: representation, estimation, and testing'. *Econometrica 55*, 251–276. https://www.jstor.org/stable/1913236.

Franco-Martin, A. (2017). *Evidencia de la Ley de Okun para Colombia, Chile y Argentina: 1980–2014*. Unpublished Bachelor thesis. Faculty of Economic and Administrative Sciences, Catholic University of Colombia [available at https://hdl.handle.net/10983/14428]. Accessed: 23 November 2023.

Friedman, M. (1964). 'Monetary studies of the National Bureau'. In *NBER: The National Bureau enters its 45th Year – 44th Annual Report* (pp. 7–25). New York: NBER [available at http://www.nber.org/chapters/c4453]. Accessed: 23 November 2023.

Harris, R. and Silverstone, B. (2001). 'Testing for asymmetry in Okun's law: a cross-country comparison'. *Economics Bulletin 5*, 1–13 [available at http://www.accessecon.com/pubs/EBFT08/2001/Volume5/EB-01E00001A.pdf].

Hodrick, R. and Prescott, E. (1997). 'Postwar US business cycles: an empirical investigation'. *Journal of Money, Credit and Banking 29*, 1–16. https://www.jstor.org/stable/2953682.

Holmes, M. and Silverstone, B. (2006). 'Okun's law, asymmetries and jobless recoveries in the United States: a Markov-switching'. *Economics Letters 92*, 293–299. https://doi.org/10.1016/j.econlet.2006.03.006.

Huang, H. and Yeh, C. (2013). 'Okun's law in panels of countries and states'. *Applied Economics 45*, 191–199. https://doi.org/10.1080/00036846.2011.597725.

Johansen, S. (1995). *Likelihood-based Inference in Cointegrated Vector Autoregressive Models*. Oxford: Oxford University Press [available at https://oxford.universitypressscholarship.com/view/10.1093/0198774508.001.0001/acprof-9780198774501].

Kruse, R. (2011). 'A new unit root test against ESTAR based on a class of modified statistics'. *Statistical Papers 52*, 71–85. https://doi.org/10.1007/s00362-009-0204-1.

Kydland, F. and Prescott, E. (1982). 'Time to build and aggregate fluctuations'. *Econometrica 50*, 1345–1370. https://doi.org/10.2307/1913386.

Lee, J. (2000). 'The robustness of Okun's law: evidence from OECD countries'. *Journal of Macroeconomics 22*, 331–356. https://doi.org/10.1016/S0164-0704(00)00135-X.

Lee, J. and Strazicich, M. (2003). 'Minimum Lagrange multiplier unit root test with two structural breaks'. *Review of Economics and Statistics 85*, 1082–1089. https://doi.org/10.1162/003465303772815961

Lee, J. and Strazicich, M. (2013). 'Minimum LM unit root test with one structural break'. *Economics Bulletin 33*, 2483–2892. [available at http://www.accessecon.com/pubs/eb/2013/volume33/eb-13-v33-i4-p234.pdf].

Leybourne, S., Newbold, P. and Vougas, D. (1998). 'Unit roots and smooth transitions'. *Journal of Time Series Analysis 19*, 83–97. https://doi.org/10.1111/1467-9892.00078.

Lucas, R.E. (1973). 'Some international evidence on output–inflation tradeoffs'. *American Economic Review 63*, 326–334 [available at https://www.aeaweb.org/aer/top20/63.3.326-334.pdf].

Lumsdaine, R. and Papell, D. (1997). 'Multiple trend breaks and the unit-root hypothesis'. *Review of Economics and Statistics 79*, 212–218. https://doi.org/10.1162/003465397556791.

MacKinnon, J. (2010). *Critical Values for Co-integration Tests*. Queen's Economics Department Working Paper 1227 [available at http://hdl.handle.net/10419/67744].

Mankiw, N.G. (2015). *Macroeconomics*. New York: Worth Publishers.

Mayes, D. and Virén, M. (2002). 'Asymmetry and the problem of aggregation in the Euro area'. *Empirica 29*, 47–73. https://doi.org/10.1023/A:1014681414484.

Meng, M., Lee, J. and Payne, J. (2017). RALS–LM unit root test with trend breaks and non-normal errors: application to the Prebisch–Singer hypothesis'. *Studies in Nonlinear Dynamics & Econometrics 21*, 31–45. https://doi.org/10.1515/snde-2016-0050.

Mitchell, W. (1993). 'Testing for unit roots and persistence in OECD unemployment rates'. *Applied Economics 25*, 1489–1501. https://doi.org/10.1080/00036849300000153.

Narayan, P. and Popp, S. (2010). 'A new unit root test with two structural breaks in level and slope at unknown time'. *Journal of Applied Statistics 37*, 1425–1438. https://doi.org/10.1080/02664760903039883.

Nelson, C. and Plosser, C. (1982). 'Trends and random walks in macroeconomic time series: some evidence and implications'. *Journal of Monetary Economics 10*, 139–162. https://doi.org/10.1016/0304-3932(82)90012-5.

Ng, S. and Perron, P. (2001). 'LAG length selection and the construction of unit root tests with good size and power'. *Econometrica 69*, 1519–1554. https://doi.org/10.1111/1468-0262.00256.

Okun, A. (1962). 'Potential GNP: its measurement and significance'. In *Proceedings of the Business and Economics Statistics Section of the American Statistical Association* (pp. 98–104). Washington DC: American Statistical Association.

Page, E. (1954). 'Continuous inspection schemes'. *Biometrika 41*, 100–115. https://www.jstor.org/stable/2333009.

Perron, P. (1989). ‘The great crash, the oil shock and the unit root hypothesis’. *Econometrica 57*, 1361–1401. https://www.jstor.org/stable/1913712.

Prachowny, M. (1993). ‘Okun’s law: theoretical foundations and revised estimates’. *Review of Economics and Statistics 75*, 331–336. https://www.jstor.org/stable/2109440.

Rodrigues, M. and Taylor, R. (2012). ‘The flexible Fourier form and local generalised least squares de-trended unit root tests’. *Oxford Bulletin of Economics and Statistics 74*, 736–759. https://doi.org/10.1111/j.1468-0084.2011.00665.x.

Rothman, P. (1998). ‘Forecasting Asymmetric Unemployment Rates’. *Review of Economics and Statistics 80*, 164–168. http://www.jstor.org/stable/2646739.

Shin, Y., Yu, B. and Greenwood-Nimmo, M. (2014). ‘Modelling asymmetric cointegration and dynamic multipliers in a nonlinear ARDL framework’. In Horrace, W. and Sickles, R. (Eds), *The Festschrift in Honor of Peter Schmidt: Econometric Methods and Applications* (pp. 281–314). New York: Springer. https://doi.org/10.1007/978-1-4899-8008-3_9.

Silvapulle, P., Moosa, I. and Silvapulle, M. (2004). ‘Asymmetry in Okun's law’. *Canadian Journal of Economics/Revue Canadienne d'Economique 37*, 353–374. http://www.jstor.org/stable/3696151.

Skalin, J. and Teräsvirta, T. (2002). ‘Modeling asymmetries and moving equilibria in unemployment rates’. *Macroeconomic Dynamics 6*, 202–241. https://doi.org/10.1017/S1365100502031024.

Sollis, R. (2009). ‘A simple unit root test against asymmetric STAR nonlinearity with an application to real exchange rates in Nordic countries’. *Economic Modelling 26*, 118–125. https://doi.org/10.1016/j.econmod.2008.06.002.

Tang, B. and Bethencourt, C. (2017). ‘Asymmetric unemployment–output tradeoff in the Eurozone’. *Journal of Policy Modeling 39*, 461–481. https://doi.org/10.1016/j.jpolmod.2017.01.003.

Virén, M. (2001). ‘The Okun curve is non-linear’. *Economics Letters 70*, 253–257. https://doi.org/10.1016/S0165-1765(00)00370-0.

Vogelsang, T. and Perron, P. (1998). ‘Additional tests for a unit root allowing for a break in the trend function at an unknown time’. *International Economic Review 39*, 1073–1100. https://doi.org/10.2307/2527353.

Zanin, L. (2014). 'On Okun's law in OECD countries: an analysis by age cohorts'. *Economics Letters 125*, 243–248. https://doi.org/10.1016/j.econlet.2014.08.030.

Zanin, L. (2021). 'On the estimation of Okun's coefficient in some countries in Latin America: a comparison between OLS and GME estimators'. *Empirical Economics 60*, 1575–1592. https://doi.org/10.1007/s00181-019-01798-y.

Zivot, E. and Andrews, D. (1992). 'Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis'. *Journal of Business & Economic Statistics 10*, 251–270. https://doi.org/10.2307/1391541.

## Appendix

### Table A1: Linear model, long-run model and tests for co-integration

| Variable | Total | Male | Female |
|---|---|---|---|
| ***Estimates of linear model*** | | | |
| Intercept (*t*-stat) | 1.27 (4.49)*** | 1.37 (4.30)*** | 1.09 (4.38)*** |
| $\Delta y/y$ {Okun's coefficient} (*t*-stat) | -0.32 (-5.43)*** | -0.34 (-5.32)*** | -0.28 (-5.11)*** |
| Adjusted $R^2$ | 0.37 | 0.36 | 0.30 |
| | | | |
| ***Estimates of long-run model (equation 2)*** | | | |
| Intercept (*t*-stat) | 37.04 (5.80)*** | 52.34 (6.87)*** | 17.23 (3.16)*** |
| $y_t$ (*t*-stat) | -2.07 (-5.46)*** | -2.99 (-6.60)*** | -0.89 (-2.74)*** |
| *t* (*t*-stat) | 0.02 (4.81)*** | 0.03 (5.96)*** | 0.01 (1.94)* |
| Adjusted $R^2$ | 0.24 | 0.31 | 0.20 |
| | | | |
| ***Asymmetric Dickey–Fuller test (equation 6)*** | | | |
| $I_t\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.18 (-3.49)*** | -0.16 (-3.18)*** | -0.14 (-2.50)** |
| $(1-I_t)\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.06 (-1.37) | -0.08 (-1.66)* | -0.07 (-1.23) |
| $\Delta\hat{\varepsilon}_{t-1}$ (*t*-stat) | 0.19 (1.68)* | 0.14 (1.12) | - |
| $\tau$ (threshold) | 0.145 | 0.169 | -0.135 |
| Adjusted $R^2$ | 0.08 | 0.06 | 0.04 |

| | | | |
|---|---|---|---|
| Engle's LM ARCH test (lags=4) | 3.88 | 4.04 | 0.73 |
| Ljung–Box test (lags=2) | 0.57 | 0.31 | 0.79 |
| Ljung–Box test (lags=4) | 1.04 | 0.89 | 0.96 |
| Durbin–Watson test | 1.95 | 1.97 | 1.91 |
| Jarque–Bera test | 1.55 | 0.24 | 2.61 |
| RESET test | 1.45 | 0.45 | 0.92 |
| *F*-stat {$H_0$: $\rho_1$=$\rho_2$} | 3.17* | 1.52 | 0.63 |
| | | | |
| ***Asymmetric co-integration test*** | | | |
| Co-integration *t*-Max | -3.49*** | -3.18*** | -2.50*** |
| Co-integration *F*-stat {$H_0$: $\rho_1$=$\rho_2$= 0} | 7.01* | 6.29* | 3.88 |
| | | | |
| ***Symmetric co-integration test*** | | | |
| Engle–Granger $\hat{\varepsilon}_{t-1}$ (*t*-stat) | -0.10 (-2.67)*** | -0.10 (-2.68)*** | -0.11 (-2.39)** |
| Johansen $\lambda_{trace}$ (*r*=0) | 15.65 | 18.15 | 12.23 |
| Johansen $\lambda_{max}$ (*r*=0) | 10.92 | 13.74 | 7.14 |

*Notes: t-Max and F-stat of asymmetric Engle–Granger co-integration test are evaluated by critical values in Enders and Siklos (1999).*
*t-stat of symmetric Engle–Granger co-integration test is evaluated by critical values in Mackinnon (2010).*
*Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*All the regressions were estimated using heteroscedasticity-consistent standard errors (HC2).*

## Table A2: Testing for multiple structural breaks

| | Number of breaks | | | | |
|---|---|---|---|---|---|
| **Variable** | **Total** | | **Male** | | **Female** |
| ***Bai-Perron tests of L+1 vs L sequentially determined breaks*** | | | | | |
| Log of unemployment rate, log($u_t$) | 0 | | 0 | | 1 |
| Log of real GDP, log($y_t$) | 0 | | - | | - |
| $\Delta u_t$ | 0 | | 0 | | 0 |
| $\Delta y_t$ | 0 | | - | | - |
| | | | | | |
| ***Bai–Perron tests of L+1 vs L globally determined breaks*** | | | | | |
| Log of unemployment rate, log($u_t$) | 0 | | 0 | | 1 |
| Log of real GDP, log($y_t$) | 2 | | - | | - |
| $\Delta u_t$ | 0 | | 0 | | 0 |
| $\Delta y_t$ | 0 | | - | | - |
| | | | | | |
| | **Recursive test statistic** | | | | |
| | **Total** | | **Male** | | **Female** |
| ***CUSUM test for parameter stability*** | | | | | |
| Log of unemployment rate, log($u_t$) | 1.83*** | | 1.87*** | | 1.46*** |
| Log of real GDP, log($y_t$) | 1.90*** | | - | | - |
| $\Delta u_t$ | 0.93 | | 0.80 | | 0.85 |

| | | | | | |
|---|---|---|---|---|---|
| $\Delta y_t$ | 0.53 | | - | | - |

*Notes: The number of lags for Bai–Perron tests was selected by the Bayesian Information Criterion (BIC).*
*The number of structural breaks determined by the Bai–Perron tests was evaluated by the critical values in Bai and Perron (2003).*

## Table A3: Linear unit root tests

| Variable | Total | Male | Female |
|---|---|---|---|
| ***ADF unit root test*** | | | |
| Log of unemployment rate, log($u_t$) (drift+trend) | -2.72 (lags=1) | -2.71 (lags=1) | -2.31 (lags=0) |
| Log of unemployment rate, log($u_t$) (drift) | -2.35 (lags=1) | -2.37 (lags=1) | -2.02 (lags=0) |
| Log of unemployment rate, log($u_t$) (none) | 0.08 (lags=1) | 0.05 (lags=1) | -0.23 (lags=0) |
| Log of real GDP, log($y_t$) (drift+trend) | -0.58 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (drift) | -1.83 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (none) | 3.18 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) (drift+trend) | -7.61*** (lags=0) | -7.70*** (lags=0) | -9.53*** (lags=0) |
| $\Delta$log($u_t$) (drift) | -7.63*** (lags=0) | -7.71*** (lags=0) | -9.57*** (lags=0) |
| $\Delta$log($u_t$) (none) | -7.66*** (lags=0) | -7.75*** (lags=0) | -9.62*** (lags=0) |
| $\Delta$log($y_t$) (drift+trend) | -5.45*** (lags=0) | - | - |

| | | | |
|---|---|---|---|
| $\Delta\log(y_t)$ (drift) | -5.17*** (lags=0) | - | - |
| $\Delta\log(y_t)$ (none) | -3.88*** (lags=0) | - | - |
| | | | |
| ***Ng–Perron unit root test*** | | | |
| Log of unemployment rate, $\log(u_t)$ (drift+trend) | -2.13 (lags=1) | -2.09 (lags=1) | -2.09 (lags=0) |
| Log of unemployment rate, $\log(u_t)$ (drift) | -2.01** (lags=1) | -1.93* (lags=1) | -1.96* (lags=0) |
| Log of real GDP, $\log(y_t)$ (drift+trend) | -1.84 (lags=1) | - | - |
| Log of real GDP, $\log(y_t)$ (drift) | 1.35 (lags=1) | - | - |
| | | | |
| $\Delta\log(u_t)$ (drift+trend) | -4.48*** (lags=0) | -4.58*** (lags=0) | -4.73*** (lags=0) |
| $\Delta\log(u_t)$ (drift) | -4.07*** (lags=0) | -4.37*** (lags=0) | -4.30*** (lags=0) |
| $\Delta\log(y_t)$ (drift+trend) | -3.87*** (lags=0) | - | - |
| $\Delta\log(y_t)$ (drift) | -3.78*** (lags=0) | - | - |
| | | | |
| ***DF–GLS unit root test*** | | | |
| Log of unemployment rate, $\log(u_t)$ (drift+trend) | -2.24 (lags=1) | -2.18 (lags=1) | -2.20 (lags=0) |
| Log of unemployment rate, $\log(u_t)$ (drift) | -2.06** (lags=1) | -1.96** (lags=1) | -2.03** (lags=0) |
| Log of real GDP, $\log(y_t)$ (drift+trend) | -1.01 (lags=1) | - | - |
| Log of real GDP, $\log(y_t)$ (drift) | 0.73 (lags=1) | - | - |
| | | | |

| | | | |
|---|---|---|---|
| Δlog($u_t$) (drift+trend) | -6.50*** (lags=0) | -6.94*** (lags=0) | -7.80*** (lags=0) |
| Δlog($u_t$) (drift) | -5.34*** (lags=0) | -6.20*** (lags=0) | -5.93*** (lags=0) |
| Δlog($y_t$) (drift+trend) | -5.12*** (lags=0) | - | - |
| Δlog($y_t$) (drift) | -5.18*** (lags=0) | - | - |

*Notes: Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*t-stat of ADF unit root test is evaluated by critical values in Mackinnon (1996).*
*t-stat of Ng–Perron unit root test is evaluated by critical values in Ng and Perron (2001).*
*t-stat of DF–GLS unit root test is evaluated by critical values in Elliott et al (1996).*
*The number of lags was selected by the Bayesian Information Criterion (BIC).*

## Table A4: Alternative unit root tests

| Variable | Total | Male | Female |
|---|---|---|---|
| ***RALS–LM unit root test with non-normal errors (two structural breaks)*** | | | |
| Log of unemployment rate, log($u_t$) (drift+trend) | -5.45*** (lags=1) | -5.77*** (lags=1) | -5.85*** (lags=0) |
| Log of real GDP, log($y_t$) (drift+trend) | -5.18*** (lags=1) | - | - |
| | | | |
| Δlog($u_t$) (drift+trend) | -8.26*** (lags=0) | -9.02*** (lags=0) | -9.86*** (lags=0) |
| Δlog($y_t$) (drift+trend) | -6.37*** (lags=0) | - | - |
| | | | |
| ***ADF unit root test (two structural breaks)*** | | | |

| | | | |
|---|---|---|---|
| Log of unemployment rate, log($u_t$) (break in level and trend) | -5.96*** (lags=1) | -6.09*** (lags=1) | -5.18** (lags=0) |
| Log of unemployment rate, log($u_t$) (break in level) | -5.54*** (lags=1) | -5.59*** (lags=1) | -4.81** (lags=0) |
| Log of real GDP, log($y_t$) (break in level and trend) | -4.57 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (break in level) | -3.23 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) (break in level and trend) | -9.50*** (lags=0) | -9.93*** (lags=0) | -11.08*** (lags=0) |
| $\Delta$log($u_t$) (break in level) | -9.45*** (lags=0) | -9.60*** (lags=0) | -10.68*** (lags=0) |
| $\Delta$log($y_t$) (break in level and trend) | -6.64*** (lags=0) | - | - |
| $\Delta$log($y_t$) (break in level) | -6.73*** (lags=0) | - | - |
| | | | |
| ***DF–GLS unit root test (two structural breaks)*** | | | |
| Log of unemployment rate, log($u_t$) (level and trend shift) | -2.52 (lags=1) | -2.41 (lags=1) | -3.02 (lags=0) |
| Log of unemployment rate, log($u_t$) (trend shift) | -2.57 (lags=1) | -2.46 (lags=1) | -3.20 (lags=0) |
| Log of unemployment rate, log($u_t$) (level shift) | -2.50 (lags=1) | -2.48 (lags=1) | -2.84* (lags=0) |
| Log of real GDP, log($y_t$) (level and trend shift) | -3.18 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (trend shift) | -3.39 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (level shift) | -1.06 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) (level and trend shift) | -6.33*** (lags=0) | -6.67*** (lags=0) | -6.95*** (lags=0) |

| | | | |
|---|---|---|---|
| Δlog($u_t$) (trend shift) | -8.15*** (lags=0) | -7.07*** (lags=0) | -8.08*** (lags=0) |
| Δlog($u_t$) (level shift) | -6.35*** (lags=0) | -5.18*** (lags=0) | -5.18*** (lags=0) |
| Δlog($y_t$) (level and trend shift) | -5.69*** (lags=0) | - | - |
| Δlog($y_t$) (trend shift) | -6.23*** (lags=0) | - | - |
| Δlog($y_t$) (level shift) | -4.03*** (lags=0) | - | - |
| | | | |
| ***Fourier DF unit root test (multiple structural breaks)*** | | | |
| Log of unemployment rate, log($u_t$) (break in level and trend) | -2.85 (lags=1) | -3.38 (lags=0) | -3.80 (lags=0) |
| Log of unemployment rate, log($u_t$) (break in level) | -3.26 (lags=0) | -3.18 (lags=0) | -3.59* (lags=0) |
| Log of real GDP, ($y_t$) (break in level & trend) | -3.46 (lags=1) | - | - |
| Log of real GDP, ($y_t$) (break in level) | -2.35 (lags=1) | - | - |
| | | | |
| Δlog($u_t$) (break in level and trend) | -8.09*** (lags=0) | -8.17*** (lags=0) | -9.94*** (lags=0) |
| Δlog($u_t$) (break in level) | -8.07*** (lags=0) | -8.16*** (lags=0) | -9.96*** (lags=0) |
| Δlog($y_t$) (break in level and trend) | -5.67*** (lags=0) | - | - |
| Δlog($y_t$) (break in level) | -5.40*** (lags=0) | - | - |
| | | | |
| ***Fourier GLS unit root test (multiple structural breaks)*** | | | |

| | | | |
|---|---|---|---|
| Log of unemployment rate, log($u_t$) (break in level and trend) | -3.55 (lags=0) | 3.47 (lags=0) | -3.47 (lags=0) |
| Log of unemployment rate, log($u_t$) (break in level) | -3.28* (lags=0) | -3.03* (lags=0) | -3.31** (lags=0) |
| Log of real GDP, log($y_t$) (break in level and trend) | -3.25 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (break in level) | -0.16 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) (break in level and trend) | -6.70*** (lags=0) | -7.66*** (lags=0) | -8.98*** (lags=0) |
| $\Delta$log($u_t$) (break in level) | -7.27*** (lags=0) | -7.58*** (lags=0) | -7.82*** (lags=0) |
| $\Delta$log($y_t$) (break in level and trend) | -5.70*** (lags=0) | - | - |
| $\Delta$log($y_t$) (break in level) | -5.42*** (lags=0) | - | - |
| | | | |
| ***Fourier LM unit root test (multiple structural breaks)*** | | | |
| Log of unemployment rate, log($u_t$) | -3.43 (lags=0) | -3.37 (lags=0) | -3.45 (lags=0) |
| Log of real GDP, log($y_t$) | -3.62 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) | -6.70*** (lags=0) | -6.81*** (lags=0) | -8.66*** (lags=0) |
| $\Delta$log($y_t$) | -4.99*** (lags=0) | - | - |

*Notes: Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*t-stat of RALS–LM unit root test with non-normal errors is evaluated by critical values in Meng et al (2017).*
*t-stat of ADF unit root test with two structural breaks is evaluated by critical values in Narayan and Popp (2010).*
*t-stat of DF–GLS unit root test with two structural breaks is evaluated by critical values in*

*Carrion-i-Silvestre et al (2009).*
*t-stat of Fourier DF unit root test is evaluated by critical values in Enders and Lee (2012b).*
*t-stat of Fourier GLS unit root test is evaluated by critical values in Rodrigues and Taylor (2009).*
*t-stat of Fourier LM unit root test is evaluated by critical values in Enders and Lee (2012a).*
*The number of lags was selected by the BIC.*

## Table A5: Nonlinear unit root tests

| Variable | Total | Male | Female |
|---|---|---|---|
| ***LNV unit root test (LSTAR-type)*** | | | |
| Log of unemployment rate, log($u_t$) (intercept) | -2.99 (lags=1) | -2.89 (lags=1) | -2.85 (lags=0) |
| Log of unemployment rate, log($u_t$) (trend) | -3.87 (lags=1) | -3.69 (lags=1) | -4.03 (lags=0) |
| Log of unemployment rate, log($u_t$) (trend function) | -3.95 (lags=1) | -3.91 (lags=1) | -3.23 (lags=0) |
| Log of real GDP, log($y_t$) (intercept) | -3.76 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (trend) | -3.75 (lags=1) | - | - |
| Log of real GDP, log($y_t$) (trend function) | -3.72 (lags=1) | - | - |
| | | | |
| $\Delta$log($u_t$) (intercept) | -7.72*** (lags=0) | -7.80*** (lags=0) | -9.68*** (lags=0) |
| $\Delta$log($u_t$) (trend) | -7.75*** (lags=0) | -7.86*** (lags=0) | -9.71*** (lags=0) |
| $\Delta$log($u_t$) (trend function) | -7.90*** (lags=0) | -8.00*** (lags=0) | -9.86*** (lags=0) |

| | | | |
|---|---|---|---|
| $\Delta\log(y_t)$ (intercept) | -5.52*** (lags=0) | - | - |
| $\Delta\log(y_t)$ (trend) | -5.57*** (lags=0) | - | - |
| $\Delta\log(y_t)$ (trend function) | -6.06*** (lags=0) | - | - |
| | | | |
| ***Kruse unit root test (ESTAR-type)*** | | | |
| Log of unemployment rate, $\log(u_t)$ | 5.63 (lags=1) | 5.05 (lags=1) | 3.97 (lags=0) |
| Log of real GDP, $\log(y_t)$ | 14.15*** (lags=1) | - | - |
| | | | |
| $\Delta\log(u_t)$ | 23.94*** (lags=0) | 14.07*** (lags=1) | 13.57*** (lags=1) |
| $\Delta\log(y_t)$ | 18.76*** (lags=0) | - | - |
| | | | |
| ***Sollis unit root test (AESTAR-type)*** | | | |
| Log of unemployment rate, $\log(u_t)$ | 2.84 (lags=1) | 2.39 (lags=1) | 1.96 (lags=0) |
| Log of real GDP, $\log(y_t)$ | 7.11*** (lags=1) | - | - |
| | | | |
| **$\Delta\log(u_t)$** | 14.80*** (lags=0) | 16.83*** (lags=0) | 8.44*** (lags=1) |
| **$\Delta\log(y_t)$** | 10.13*** (lags=0) | - | - |

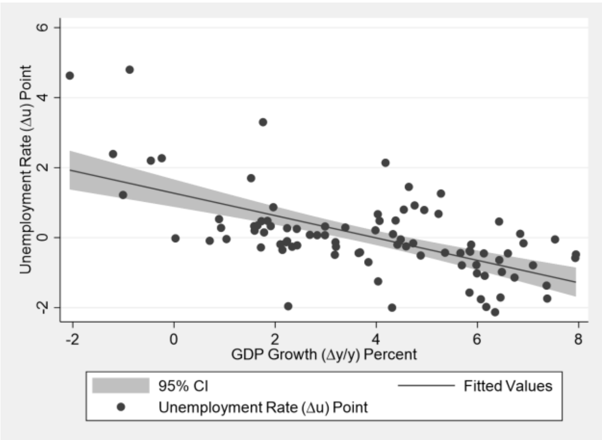
*Notes: Rejects the null hypothesis at ***1%, **5% and *10% levels, respectively.*
*t-stat of LNV nonlinear unit root test is evaluated by critical values in Leybourne et al (1998).*
*F-stat of ESTAR model unit root test is evaluated by critical values in Kruse (2011).*

*F-stat of AESTAR model unit root test is evaluated by critical values in Sollis (2009).*
*The number of lags was selected by the BIC.*

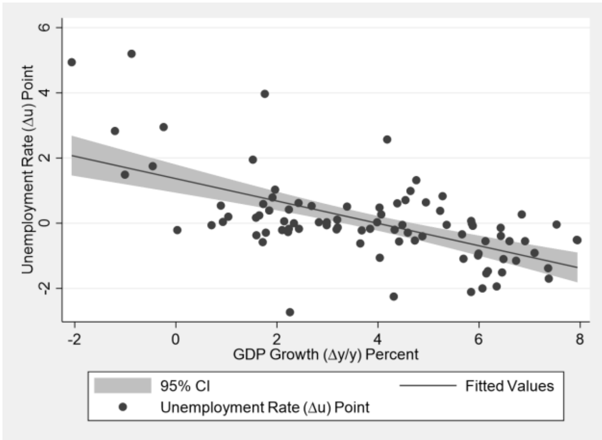
**Figure A1: Unemployment and real output in Chile (1996:1–2019:4)**

**Annual changes, seasonally adjusted**

Unemployment rate point (total) and GDP growth (%)




Unemployment rate point (male) and GDP growth (%)




Unemployment rate point (female) and GDP growth (%)

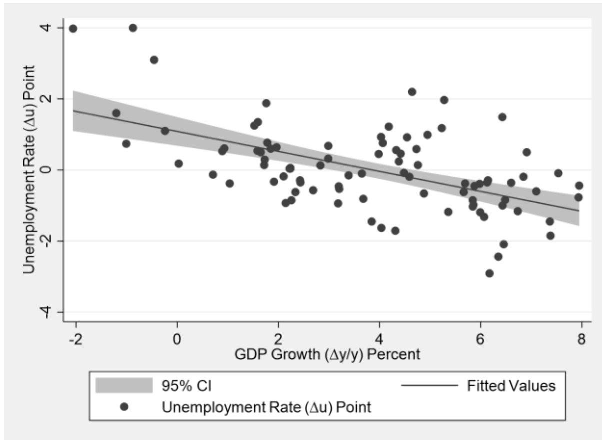


**Figure A2: Unemployment and real output in Chile (1996:1–2019:4)**

**Natural log scales, quarterly, seasonally adjusted**

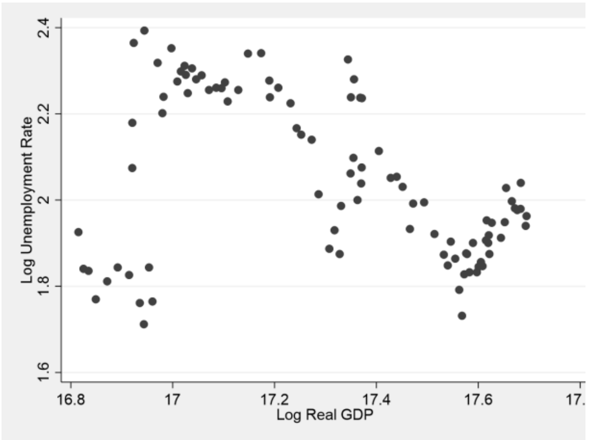
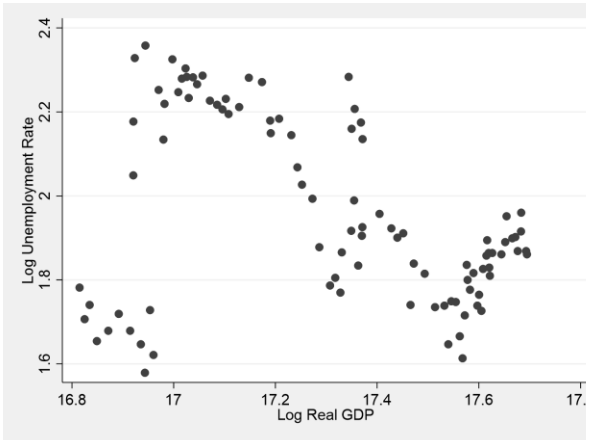
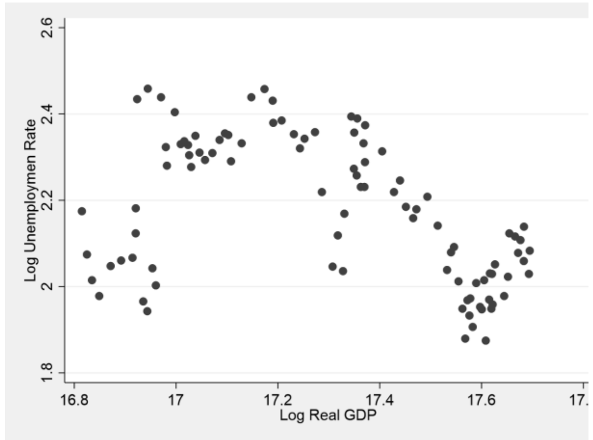
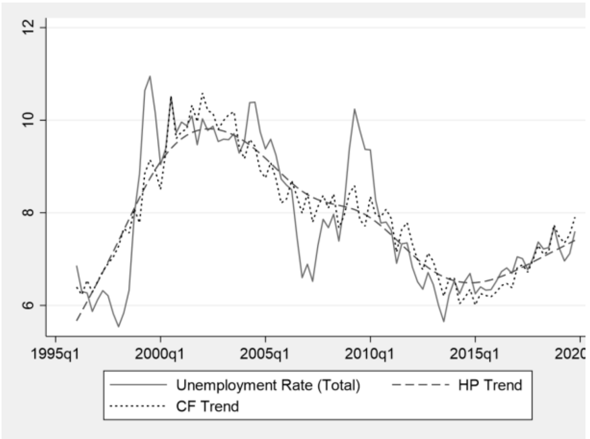
| Log unemployment rate (total) and log real GDP | Log unemployment rate (male) and log real GDP | Log unemployment rate (female) and log real GDP |
|---|---|---|
|  |  |  |

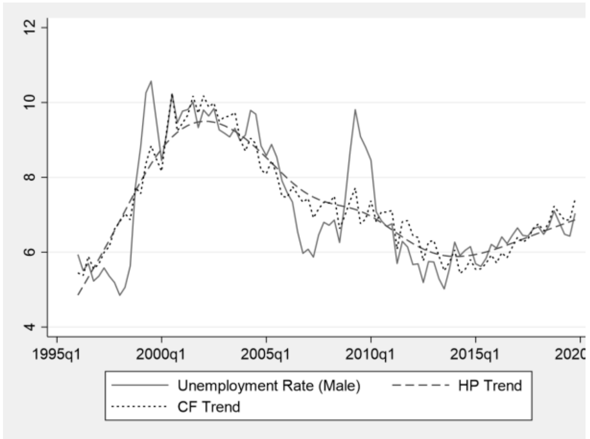
**Figure A3: Unemployment rate in Chile**

**Seasonally adjusted, 1996:1–2019:4**

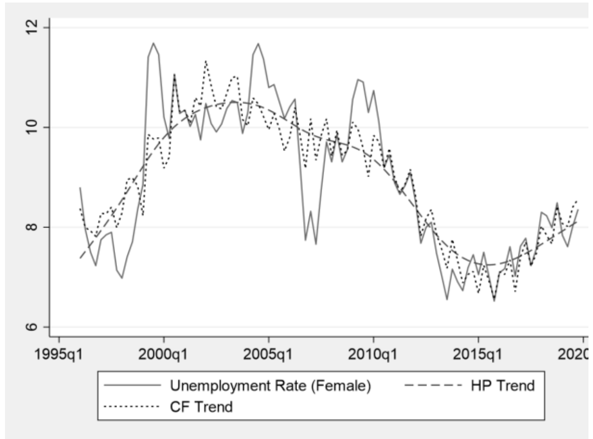
Unemployment rate in Chile (total)




Unemployment rate in Chile (male)



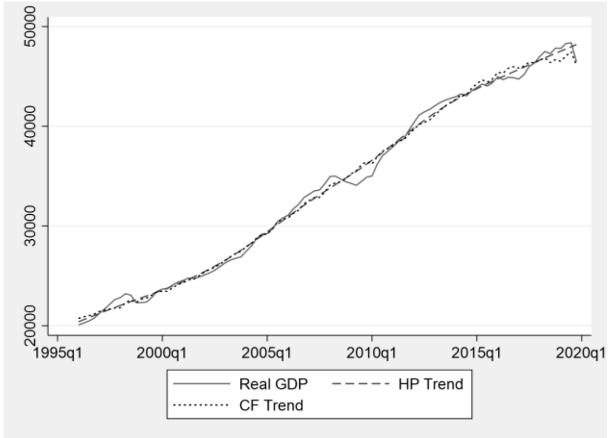

Unemployment rate in Chile (female)




*Notes: Figure A3 shows actual unemployment rates, their associated Hodrick-Prescott (1997) and Christiano and Fitzgerald (1999)*

**Figure A4: Real GDP in Chile**

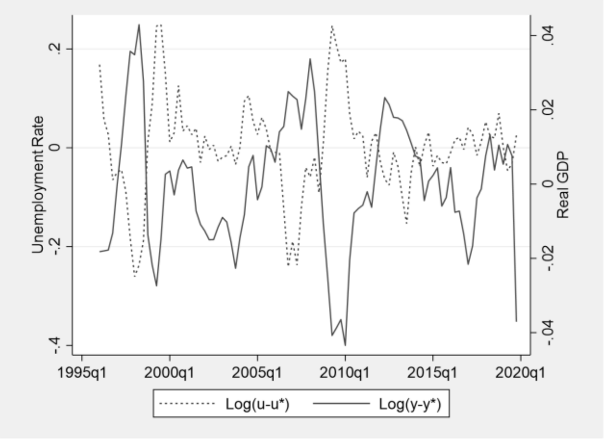
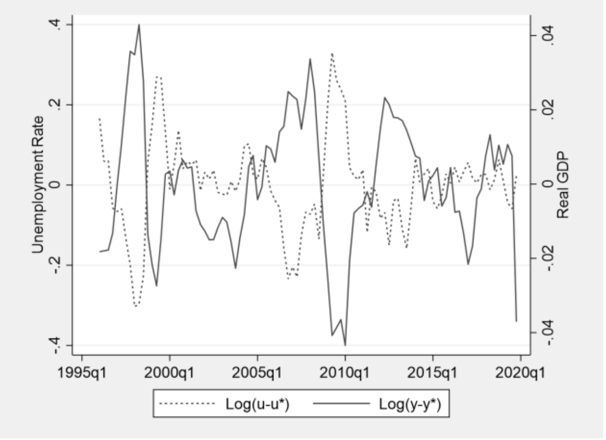
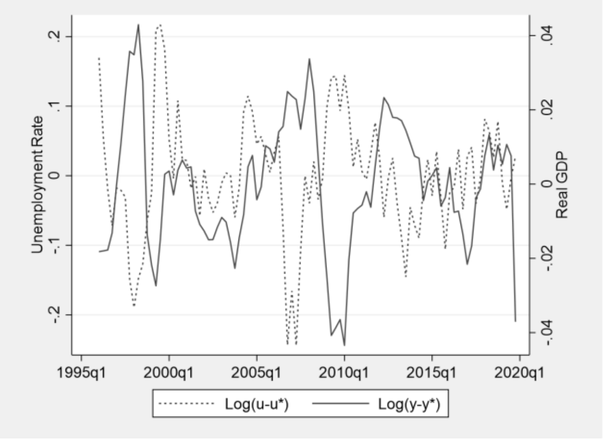
**Seasonally adjusted, 1996:1–2019:4, $billion (Chilean pesos)**




*Notes: Figure A4 shows actual real GDP, its associated Hodrick-Prescott (1997) and Christiano and Fitzgerald (1999).*

**Figure A5: Cyclical unemployment and real GDP in Chile**

**1996:1–2019:4, quarterly**

| Cyclical unemployment rate (total) and real GDP | Cyclical unemployment rate (male) and real GDP | Cyclical unemployment rate (female) and real GDP |
|---|---|---|
|   |   |   |