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Testing the hysteresis effect in the US state-level unemployment series

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ABSTRACT

This paper re-examines the stochastic time series behaviour of the monthly unemployment rate in 50 states of the United States (US) for the period 1976–2017 using a number of state-of-the-art unit root tests. The new developments incorporate structural break, nonlinearity, asymmetry, and cross-sectional correlation within panel-data estimation including the use of a sequential panel selection method. While not previously considered, sequential panel selection enabled us to determine and separate the stationary and nonstationary series in the sample. The empirical findings are in support of the stationarity of unemployment rate in 47 states. The findings confirm a natural rate hypothesis for the labour markets in the most US states, indicating that labour market shocks have solely temporary effects on state-level unemployment. This empirical study provides significant state-specific policy implications.

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Linear nonlinear and structural break; panel unit root; cross-section dependency; common correlated estimator CCE; hysteresis

1. Introduction

Unemployment presents a worldwide macroeconomic problem that has challenged the field of labour economics with renewed vigour since the onset of the global financial crisis in 2008 (Chang, 2011). While scholars agree that each labour market has its own characteristics and the dynamics of unemployment are likely to differ among countries, they continue to discuss its nature or time path. Currently, economists distinguish between two main competing hypotheses while analysing the nexus of unemployment and business cycle. The first hypothesis is the natural rate hypothesis (NAIRU[1]), pioneered by Phelps (1967) and Friedman (1968). The natural rate hypothesis assumes that output fluctuations will generate cyclical movements in the rate of unemployment that will tend to revert to its equilibrium (i.e., its natural rate) in the long-run (Leon–Ledesma, 2002). If the natural rate hypothesis properly describes the characteristics of unemployment, deviations from the natural rate are just temporary and will disappear over time (Cheng., Durmaz., Kim, & Stern, 2012). However, the long-lasting high unemployment rate, as seen in developed countries during the 1970s and 1980s, undermines the validity of natural rate theory (Gustavsson & Osterholm, 2007). Following the first and second oil

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[1]NAIRU stands for the term "Non-accelerating inflation rate of unemployment".

crises, the theory of natural unemployment rate has been challenged by the theory of hysteresis, modelling extreme persistence in unemployment series (Papell., Murray, & Ghiblawi, 2000).

As a concept, "hysteresis" is lacking of any unanimous definition, but the general argument is that hysteresis is inconsistent with a constant natural rate of unemployment (Gustavsson & Osterholm, 2007). For instance, Blanchard. and Summers (1986) loosely describe it as a case where the degree of dependence on the past is very high, where the sum of autoregressive coefficients is close but not necessarily equal to one. The hysteresis hypothesis, formulated by Blanchard. and Summers (1986, 1987), indicates that the rate of unemployment is path-dependent and cyclical fluctuations have permanent effects on unemployment. Scholars have suggested different reasons for the unemployment hysteresis. For instance, the traditional Keynesian model considers the persistence of high unemployment rates to be an outcome of sluggish adjustment of nominal wages to aggregate demand shocks (Srinivasan & Mitra, 2016). The wage inflexibility was demonstrated in insider-outsider model proposed by Lindbeck and Snower (1988). Therein, the insiders, union members or labourers who are currently working, have a large dominance on wage bargaining and may demand higher wages when firms' vacancy and training costs increase (Dreger & Reimers, 2009). However, the outsiders, the long-term unemployed, lack bargaining power as they may accept lower wages as the cost of securing themselves employment. Given balanced bargaining positions, wage levels remain stable and will not tend towards falling, and high equilibrium wages suggest unemployment hysteresis maintained by the insiders' bargaining power. Thus, in general, unemployment hysteresis is seen as an outcome of labour market regulations and rigidities.

Other than those two main hypotheses mentioned above, the structuralist view (hypothesis) proposed by Phelps (1994) as a third hypothesis provides some alternative explanations on the time path of unemployment. It is asserted that variations in the structural factors, such as labour productivity, technological change, real exchange rates, real interest rates and energy prices, affect and change the natural rate of unemployment (Papell. et al., 2000; Romero-Avila & Usabiaga, 2007). The natural rate could be endogenous and affected by market forces as any other economic variable leading to increases in the movements of the natural rate due to changes either in real macroeconomic variables or in the institutional framework (Camarero., Carrion-i-Silvestre, & Tamarit, 2006). In this theory, similar to the natural rate theory, unemployment reverts to an equilibrium level after being hit by a shock; however, some infrequent structural breaks stemming from changes in economic fundamentals affect the equilibrium itself (Caporale & Gil-Alana, 2008). As such, some occasional shocks are likely to trigger permanent changes in the natural rate itself (Papell. et al., 2000). Therefore, the structuralist view could be accepted as special cases of the natural rate hypothesis as the series show mean reversion after all (Camarero. et al., 2006).

Whether unemployment hysteresis holds true is of importance not only for empirical researchers but also for policymakers and remains a strong debate among applied econometric scholars (Jiang & Chang, 2016). For this reason, unit root tests are widely used to decide on the right theory explaining the characteristics of unemployment. In this respect, the hysteresis hypothesis is formulated as a nonstationary or a unit root process, implying that any shock affecting unemployment will have permanent effects and shifts the unemployment equilibrium from one level to another level (Gil-Alana, 2001).

However, rejection of unit root provides evidence for the natural rate hypothesis if no breaks are included in the model specification of unit root testing process. Thus, dynamics of unemployment are characterized as a mean reverting process as the deviations from the natural rate are just temporary, i.e., the effect of any shock to unemployment is only transitory. However, the structuralist hypothesis assumes that unemployment rate is characterized as a stationary process with a small number of structural breaks (Romero-Avila & Usabiaga, 2007). That has to say, the majority of shocks to unemployment are accepted as highly persistent but have temporary impacts. In this regard, as in the natural rate theory, after being hit by a shock, unemployment reverts to an equilibrium level, but some occasional structural breaks resulting from changes in economic fundamentals changes the natural rate itself (Caporale & Gil-Alana, 2008).

Concerning the policy perspectives, it is worth noting that behaviour of unemployment series provides important clues for the effectiveness of economic policies. For instance, the hysteresis hypothesis suggests that high unemployment may persist and continue to be an economic threat even in the long-run if left by itself (Song & Wu, 1997, 1998). Therefore, a combination of Keynesian demand-driven and structural policies should be implemented to reduce unemployment rate in the protracted recessions and to bring unemployment back to its original equilibrium level (Cevik & Dibooglu, 2013). However, in the case of the natural rate hypothesis, the need for government intervention or aggregate demand policies is less binding because unemployment will eventually return to its equilibrium level. Finally, the structuralist hypothesis indicates that policy models, which ignore structural breaks in the level and/or trend of unemployment rates, cannot avoid the wasted costs of government interference, which can also cause fluctuations in other macroeconomic variables (Lee & Chang, 2008). Thus, if the structuralist hypothesis is confirmed, it is not necessary for the government to pay much attention to the unemployment issue as a part of its labour market policy.

In this study, we aim to define the true characteristics of unemployment series for the 50 states of the United States (US), spanning the period 1976–2017 using monthly data and employing a number of state-of-the-art unit root tests. US states deserve a special research interest because each state's labour market has its own dynamics and characteristics. State-level analysis would reveal local characteristics of unemployment that could be hidden on a national-level. Moreover, understanding the behaviour of unemployment over the business cycle is crucial for formulating adequate policy prescriptions (Cevik & Dibooglu, 2013). Along with the last financial crisis, the US unemployment rate in January 2010 reached 10.6%, a level not seen since 1963 (Chang & Lee, 2011). Regarding the structure of the US labour market, there is a high flexibility and deregulation level, resulting in better labour market outcomes. For instance, Caporale and Gil-Alana (2008) indicate that inferior unemployment performance of the UK compared to that of US is the result of the imperfections and rigidities preventing or slowing down labour market adjustment. Additionally, Dreger and Reimers (2009) argue that hysteresis is more likely to occur in more regulated labour markets such as in the European Union (EU) rather than in the US.

Based on the above-mentioned features of the US unemployment series, we introduce different dynamics to capture structural breaks and nonlinearity in unemployment series resulting from business cycles and other sources. First, we classify three types of

nonlinearities such as nonlinearity stemming from structural breaks, sign nonlinearity and size nonlinearity. Size and sign nonlinearity are state-dependent nonlinearity, which can be modelled by smooth transition (ST) type transition functions and threshold autoregressive (TAR) type models. Sign nonlinearity simply searches for nonlinearity in the sign of different regimes; hence, logistic functions (LSTAR) and the TAR model itself are best candidates for these nonlinear models. Size nonlinearity stems from exponential smooth transition behaviour (ESTAR) and the search for nonlinearity in the size of the deviation from the mean, hence, ESTAR and the three regime TAR models are best candidates for these behaviours.

Moreover, we classify structural breaks as time-varying nonlinearity, therefore, any nonlinearity which takes the state variable as time is classified as a time-varying nonlinearity. Thus, for sign nonlinearity, we used Leybourne., Newbold, and Vougas (1998) (henceforth LNV), Omay (2015) (henceforth FFFFF), Enders and Lee (2012a) (henceforth EL), and Corakci., Emirmahmutoglu, and Omay (2017) (henceforth CEO) tests. Besides, for sign nonlinearity, we also employed Enders and Granger (1998) (henceforth EG) and Sollis (2009) tests where for the size nonlinearity, we utilized the Kapetanios, Shin, and Snell (2003) (henceforth KSS) test. Furthermore, these nonlinearities may emerge simultaneously in the data generating process (DGP), hence to detect these hybrid structures, we applied Omay. and Yildirim (2014) (henceforth OY), Christopoulos and Leon-Ledesma (2010) (henceforth CL) and Omay., Emirmahmutoglu, and Hasanov (2018) (henceforth OEHa,b) tests modelling time-varying nonlinearity and state-dependent nonlinearity together. This study contributes to the literature by using these recently developed unit root tests modelling different characteristics of unemployment series in a simultaneous way. Moreover, it has a novelty regarding economic intuition because previous studies for the US concluded stationarity under the structuralist view, but we reveal that this case is not true for the US states. Instead of structural breaks, the state-dependent nonlinear structure allows for stationarity for most of the US states, i.e. business cycles provide the natural rate hypothesis. Even though previous papers confirmed the structuralist view, this paper concludes that macroeconomic labour policies should be implemented in the most US states in the framework of business cycle theory. Finally, a very recent study by Emirmahmutoglu, Gupta, Miller, and Omay (2020) confirmed that US state-level income should be modelled by state-dependent nonlinearity instead of multiple structural breaks. They also revealed that state-dependent nonlinear estimation of the 48 states supported the nonlinear panel unit-root test results and that indicated that the state-level income series exhibited at least five regime shifts, which did not support the estimation with structural breaks. Therefore, the recent study by Emirmahmutoglu et al. (2020) firmly confirms our results, as well.[2]

In addition to time series nonlinear unit root analysis, we employed the nonlinear panel unit root test, as well. By applying the panel unit root tests, we exploit cross-sectional and time-series information as well as checking for cross-section dependency

[2]They have analysed this by using the extensive linearity and structural break test, however, they have also concluded that the test they have used is inconclusive. They used the similar panel and time unit root tests and these tests have a hybrid alternative structure; hence, they have concluded that the test decided whether the series under investigation is nonlinear or have a structural break in their data generating process. Therefore, they have stated that the linearity and structural break tests are not necessary to confirm their studies. Moreover, Omay (2011) has also shown the nonlinearities in the US GDP and Inflation data by using similar tests.

by which we can control the spill over effects and common shocks. For the panel unit root tests, we used two recently proposed tests, i.e. Ucar and Omay (2009) (henceforth, UO), and Emirmahmutoglu and Omay (2014) (henceforth, EO). UO and EO are state-dependent nonlinear panel unit root tests consisting of exponential smooth transition autoregressive (ESTAR) and asymmetric ESTAR, respectively. We have selected the above-mentioned tests (UO and EO) among all other nonlinear panel-unit-root-tests due to the reason that the time series counterparts are well performed in the time series unit root comparisons. Thus, instead of using different panel unit root tests, we first checked for the nonlinearity in DGP by employing time series tests as a pre-identification of the panel unit root testing process. Thereby, we utilize the best performing panel unit root tests based on the results of the time series unit root tests.

The remainder of the paper is organized as follows. Section 2 provides a brief literature review. Section 3 explains econometric methodology, while Section 4 provides empirical results. Finally, we conclude the study in Section 5.

2. A brief literature review

Previously, a number of studies analysed the characteristics of the US unemployment data by utilizing different unit root tests. Song and Wu (1997), Leon–Ledesma (2002), Romero-Avila and Usabiaga (2007, 2009), Mohan., Kemegue, and Sjuib (2008), Dreger and Reimers (2009), Sephton (2009), Cheng. et al. (2012), and Bahmani-Oskooee, Chang, and Ranjbar (2018) employed state-specific studies. For instance, an earlier study by Song and Wu (1997) used unemployment data from 48 US states for the period 1962–1993 and confirmed mostly the hysteresis hypothesis in case of univariate unit root tests and the natural rate hypothesis in case of panel-based unit root tests. In the framework of the IPS panel unit root test, Leon–Ledesma (2002) searched for the hysteresis effect in the unemployment rates of the 51 US states by employing quarterly data from 1985: Q1 to 1994: Q4. The results in general provided evidence of the natural rate hypothesis for the US states. Based on monthly data over the period 1976–2004, Romero-Avila and Usabiaga (2007) investigated the hysteresis hypothesis for the US state-level unemployment rates. The individual Lagrange multiplier (LM) unit root tests supported the hysteresis hypothesis in 40 states, while the panel LM unit root test with up to two changes in level confirmed the structuralist hypothesis. In another study, Romero-Avila and Usabiaga (2009) tested the main unemployment paradigms for the US states and the EU–15 countries by using a state-of-the-art panel stationarity test. Their results provided evidence in favour of regime-wise stationarity in the US state unemployment rates. Using a number of first-generation panel unit root tests, Mohan. et al. (2008) found that natural rate hypothesis does hold for the three Massachusetts regions over the years 1990–2006. For the 14 EU countries and 51 US states, Dreger and Reimers (2009) examined the hysteresis effect in the unemployment rates using quarterly and seasonally adjusted data from 1983: Q1 to 2004: Q4 by using different panel unit root tests. For the US, their results provided evidence favouring stationarity in the idiosyncratic components and the nonstationarity in the common component. Sephton (2009), using fractional integration approach for monthly data from 1976 to 2007, confirmed the structuralist hypothesis for the most US states when two structural breaks are allowed in testing procedure. Cheng. et al. (2012) investigated the stochastic

nature of the US state-level unemployment rates using quarterly data from 1976: Q1 to 2010: Q2 and employing the PANIC-RMA (recursive mean adjustment) method. They obtained much stronger evidence for the hysteresis effect when Great Recession data were included. Finally, a recent study by Bahmani-Oskooee et al. (2017) revisited the hysteresis hypothesis by using a nonlinear quantile unit root test for the US states from 1976:M1 to 2016:M7 based on monthly data. Their results indicated that 19 out of 52 states display hysteresis behaviour and the remaining 33 states followed different types of behaviour.

Additionally, most earlier studies (see, inter alia, Blanchard. & Summers, 1986; Jaeger. & Parkinson, 1994; Roed, 1996; Papell. et al., 2000; Camarero & Tamarit, 2004; Gustavsson & Osterholm, 2007) analysed the issue at the US national level. Of them, the pioneering study by Blanchard. and Summers (1986) employed annual unemployment data from Britain, France, Germany and the US over the period 1953–1984 and supported the natural rate hypothesis for the US. Jaeger. and Parkinson (1994) indicated that hysteresis hypothesis was not valid for the US using the augmented Dickey–Fuller (ADF) unit root test. Roed (1996) investigated the presence of unemployment hysteresis in 16 OECD countries using quarterly data from 1970 to 1994 and strongly rejected the presence of unemployment hysteresis only for the US. Papell. et al. (2000) applied unit root tests with structural breaks to the postwar unemployment data from 16 OECD countries and supported the structuralist hypothesis for the US. Camarero and Tamarit (2004) tested the hysteresis hypothesis by applying a sequential procedure based on the MADF and SURADF panel unit root tests for 19 OECD countries from 1956 to 2001. For the US, they confirmed the natural rate hypothesis. Finally, Gustavsson and Osterholm (2007) concluded that US unemployment data have under the effect of hysteresis by employing a range of unit root tests to the monthly employment and unemployment data from Australia, Austria, Canada, Finland, Sweden, UK and the USA for the period 1951: M1-2004:M11.

3. Econometric methodology

In this study, the linear ADF unit root test and eight relevant nonlinear unit root tests are used to empirically estimate whether the US state-level unemployment series are stationary. During the analysis, the source of nonlinearity of the employed unit root tests have been considered as a time-dependent nonlinearity, a state-dependent nonlinearity, and a mixture of them which may be called as a hybrid type of nonlinearity.

LNV, FFFFF, CEO, EG, KSS, AESTAR, OY, CL, and OEHa, b tests are used in this study. The OEH test, suggested by Omay., Hasanov, and Shin (2018), is the most comprehensive one among the aforementioned unit root tests because it combines the unit root tests by Leybourne. et al. (1998) and Sollis (2009). Given that most of the aforementioned tests are nested in one another; therefore, we explain all other tests by using OEH test due to the reason that it is the most comprehensive one. Depending on the explanation of the OEH test, other tests' explanations will be given, except the FFFFF test, which will be introduced separately since its testing methodology is different than the ones included in the OEH test.

3.1. Omay, Emirmahmutoglu and Hasanov, OEH (2018) test

The OEH test is a hybrid test, which combines the time-dependent nonlinearity and state-dependent nonlinearity of the LNV and Sollis (2009) type tests. The OEH test utilizes the following equation for modelling the gradual structural breaks:

$$y_t = \phi(t) + u_t \tag{1}$$

$\phi(t)$ is the deterministic nonlinear trend function and u_t is the deviation from the trend. A logistics transition function and a Fourier function are used to model the deterministic nonlinear trend function of Equation (1). The following three logistic smooth transition equations are used:

$$y_t = \alpha_1 + \alpha_2 S_t(\gamma, \tau) + \varepsilon_t \tag{2a}$$

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma, \tau) + \varepsilon_t \tag{2b}$$

$$y_t = \alpha_1 + \beta_1 t + \alpha_2 S_t(\gamma, \tau) + \beta_2 t S_t(\gamma, \tau) + \varepsilon_t \tag{2c}$$

where t = 1,2, ….,T; ε_t is a zero-mean process; and $S_t(\gamma, \tau)$ is the logistic smooth transition function with a sample size of T:

$$S_t(\gamma, \tau) = [1 + exp\{-\gamma(t - \tau T)\}]^{-1} \tag{3}$$

$S_t(\gamma, \tau)$ is a continuous function and allows the transition between two different regimes having the extreme values as 0 and 1. The parameters γ and τ denote the speed of transition and location between two regimes, respectively. Since the value of $S_t(\gamma, \tau)$depends on the value of the parameter, the transition between two regimes is very slow for small values of γ whereas the transition between the regimes becomes almost instantaneous at time $t = \tau T$ for very large values of γ. When $\gamma = 0$, then $S_t(\gamma, \tau) = 0.5$ for all values of t. Therefore, in Equation (2a), y_t is stationary around a mean that changes from α_1 to $\alpha_1 + \alpha_2$. Equation (2b) allows for a fixed slope term where the intercept term changes from α_1 to $\alpha_1 + \alpha_2$. In Equation (2c), in addition to the similar changes in the intercept, the slope changes from β_1 to $\beta_1 + \beta_2$ at the same time (Leybourne. et al., 1998).

The logistic smooth transition function given in Equation (3) is able to capture only one gradual structural break. Therefore, the OEH test utilizes the following Fourier function to capture multiple structural breaks:

$$\phi(t) = \alpha_0 + \delta t + \sum_{k=1}^{n} a_k \sin\left(\frac{2\pi k t}{T}\right) + \sum_{k=1}^{n} b_k \cos\left(\frac{2\pi k t}{T}\right) u_t; N\frac{T}{2} \tag{4}$$

N represents the number of cumulative frequencies contained in the approximation while k is the selected frequency in the approximation process. a_i and b_i are the measurements for the amplitude and displacement of the sinusoidal components of the deterministic function. As stated in Omay., Corakci, and Emirmahmutoglu (2017), under some circumstances, the Fourier series with an appropriate lag order in Equation (4) might approximate any function with unknown numbers of breaks in unknown forms. However, under the assumption of $a_i = b_i = 0$ for all i, the Fourier function becomes a

linear model without a structural break. If Equation (4) allows for a structural break, the minimum frequency component must be at least one. As a result, the rejecting null of $a_i = b_i = 0$, implies a structural break in the series.

The OEH test also utilizes an asymmetric exponential smooth transition autoregressive (AESTAR) model to capture the nonlinear asymmetric adjustment process as in Sollis (2009). The AESTAR model considers both a logistic function and an exponential function as follows:

$$\Delta u_t = G_t(\theta_1, u_{t-1})\{F_t(\theta_2, u_{t-1})\rho_1 + (1 - F_t(\theta_2, u_{t-1}))\rho_2\}u_{t-1} + \epsilon_t \tag{5}$$

$$G_t(\theta_1, u_{t-1}) = 1 - \exp\left(-\theta_1\left(u_{t-1}^2\right)\right)\theta_1 > 0 \tag{6}$$

$$F_t(\theta_2, u_{t-1}) = [1 + \exp(-\theta_2(u_{t-1}))]^{-1}\theta_2 > 0 \tag{7}$$

where $\epsilon_t \sim iid(0, \sigma^2)$.

As u_t is a zero-mean variable, $F_t(\theta_2, u_{t-1})$, the logistic transition function for two regimes is determined by the positive and negative deviations from the equilibrium of u_t (i.e. the sign of disequilibrium) $G_t(\theta_1, u_{t-1})$, a U-shaped symmetric exponential transition function, ranged from 0 and 1 determines the small and large deviations from the equilibrium in absolute terms.

The AESTAR function implies a globally stationary process that requires $\theta_1 > 0$, $\rho_1 < 0$ and $\rho_2 < 0$ as stated in Sollis (2009). If $\rho_1 \neq \rho_2$ is the case, the adjustment process captures not only sign but also size adjustment to the equilibrium. On the other hand, if $\rho_1 = \rho_2$ is the case, the adjustment to the equilibrium becomes a symmetric exponential smooth transition autoregressive (ESTAR) process.

The null hypothesis of a linear unit root can be tested against the alternative hypothesis of a globally stationary AESTAR process. The hypotheses are as follows:

$$H_0 = \theta_1 = 0 \tag{8}$$

$$H_1 = \theta_1 > 0 \tag{9}$$

Nevertheless, due to the existence of unidentified nuisance parameters under the null, testing the null hypothesis directly is not suitable. Hence, Im., Pesaran, and Shin (2003) and Sollis (2009) suggest rearranging the transition functions by using a first-order Taylor approximation model as follows:

$$\Delta u_t = \varphi_1 u_{t-1}^3 + \varphi_2 u_{t-1}^4 + \omega_t \tag{10}$$

Equation-5 assumes a serially uncorrelated error term. After the rearrangement above, the null hypothesis in equation-8 takes the form of $\mathrm{H}_0 : \theta_1 = \theta_2 = 0 \mathrm{H}_0 : \varphi_1 = \varphi_2 = 0$. In order to allow for serial correlation, the regression equation is augmented as follows:

$$\Delta u_t = G_t(\theta_1, u_{t-1})\{F_t(\theta_2, u_{t-1})\rho_1 + (1 - F_t(\theta_2, u_{t-1}))\rho_2\}u_{t-1} + \sum_{j=1}^{p} \delta_j \Delta u_{t-j}\epsilon_t \tag{11}$$

where $\epsilon_t \sim iid(0, \sigma^2)$. Therefore, the following auxiliary regression is used to test the null hypothesis $H_0 : \varphi_1 = \varphi_2 = 0$:

$$\Delta u_t = \varphi_1 u_{t-1}^3 + \varphi_2 u_{t-1}^4 + \sum_{j=1}^{p} \delta_j \Delta u_{t-j} + \vartheta_t \tag{12}$$

The testing procedure of the OEH test consists of two steps. First, one estimates the preferred component using Equations (2)-(4) and obtain residuals, $\hat{u}_t$. In the second step, one uses the residuals and estimate the regression in equation-12 by OLS and testing the null hypothesis by using F test.

In the case of logistic trend functions, nonlinear least squares (NLS) can be used for estimating the deterministic trend. By using OLS, the coefficients of a Fourier series can be estimated for the frequency, k. k is determined by the estimation of trend function in the range of $1 \leq k \leq k_{max}$ and choosing the one having the smallest sum of squared residuals.

OEH suggests two test statistics as F_{LBAE} and F_{FSAE}. F_{LBAE} is the test statistics for modelling the gradual break by using the logistic transition functions given in Equations (2a)- (2c). F_{FSAE} is used in the case of modelling breaks using the Fourier series given in Equation (4).

3.2. The fractional frequency flexible fourier form, FFFFF (2015) test

As one of the time-dependent nonlinear unit root models, the FFFFF unit root test is suggested by Omay (2015). It was developed by following Becker, Enders, and Lee (2004) and Enders and Lee (2012a, 2012b). The main feature of FFFFF is that its testing methodology provides for determining multiple structural breaks even in the presence of an unknown form of the function by using the Fourier transformation. In the FFFFF test, a fractional frequency is employed instead of integer ones.

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 \sin\left(\frac{2\pi k^{fr} t}{T}\right) + c_3 cos\left(\frac{2\pi k^{fr} t}{T}\right) + e_t \tag{13}$$

The critical values obtained for the fractional frequency are labelled as $\tau_{DF\_C}^{fr}$. The critical values for integer ones are used as in Enders and Lee (2012b) and labelled as $\tau_{DF\_\tau}^{fr}$.

3.3. The other unit root tests

After providing a comprehensive explanation for the OEH test, the methodologies for the other nonlinear unit root tests can be introduced by means of OEH test. One of the unit root tests that allows for one gradual structural break is the LNV test[3] which uses the models in Equations (2a)-(2c) and the transition function provided in Equation-3 for smooth structural break or nonlinear trend. After estimating the models defined in Equations (2a)-(2c) by using nonlinear least squares (NLS), the residuals are obtained. The remaining residuals are then used in an ADF test for a smooth structural break unit root test. In the LNV test, the null hypothesis of linear unit root is tested against the logistic smooth transition around a nonlinear trend. The test statistics of LNV are s_α, $s_{\alpha(\beta)}$, $s_{\alpha\beta}$ for Model A, Model B and Model C, respectively.

[3]See Leybourne. et al. (1998) for details.

The other unit root test for structural break is the CEO[4] test. Corakci. et al. (2017) consider Equations (2a)-(2c) by using the exponential transition function, based on a sample size T as follows:

$$F_t(\gamma,\tau) = 1 - exp\left[-\gamma(t-\tau)^2\right], \gamma > 0 \tag{14}$$

In the CEO test, after de-trending the nonlinear trend from the series, the remaining residuals are used in an ADF test for smooth temporary structural break unit root test. By means of CEO test, structural breaks can be modelled gradually instead of instantaneously. The null hypothesis of linear unit root is tested against the stationarity around a smoothly changing trend and intercept. The test statistics are labelled as $\tilde{s}_{\alpha}, \tilde{s}_{\alpha(\beta)}$ *and* $\tilde{s}_{\alpha\beta}$ for the models used, respectively.

EG test[5] is a TAR type state-dependent nonlinear unit root test and utilizes Equation-7 with a slight change of using the indicator function with a threshold value instead of a logistic transition function. The null hypothesis of linear unit root is tested against the stationary asymmetric adjustment to the mean or deterministic trend.

The first state-dependent nonlinear unit root test employing ESTAR as a transition function is the KSS test.[6] It considers Equations (2a)-(2c) and uses the exponential transition function defined in Equation (6). KSS test enables modelling the size of the symmetric adjustment towards equilibrium. By using the KSS test, the null hypothesis of linear unit root is tested against the symmetric state-dependent nonlinearity with intercept and deterministic terms. One is able to say, by this way, the null hypothesis of the linear nonstationary process is tested against the globally stationary nonlinear process.

The second state-dependent nonlinear unit root test is the Sollis (2009)[7] which utilizes Equations (5)-(7). It is an extension of the KSS test and implies testing the asymmetric state-dependent nonlinearity with intercept and trend deterministic terms in its alternative hypothesis. The Sollis test can capture the sign and size of the adjustment towards equilibrium at the same time by employing the AESTAR function which uses LSTR and ESTAR function together.

OY[8] test is one of the hybrid test which combines the LNV and KSS tests. OY uses equations (2a)-(2c) and employs the transition function given in Equation (3) for smooth structural break or nonlinear trend. After de-trending the nonlinear trend from the series, the remaining residuals are used in the framework of KSS test where the null hypothesis of linear unit root is tested against the nonlinear and stationary around smoothly changing trend and intercept (Omay. & Yildirim, 2014).

4. Results from empirical analysis

The monthly unemployment data for the 50 US states are obtained from the US Bureau of Labour Statistics[9] for the period 1976–2017. Since we employed time series and panel

[4]See Corakci. et al. (2017) for details.
[5]See Enders and Granger (1998) for details.
[6]See Kapetanios et al. (2003) for details.
[7]See, Sollis (2009) for details.
[8]See Omay. and Yildirim (2014) for details.
[9]See https://www.bls.gov/web/laus/laumstrk.htm.

unit root tests, we first tabulated the results of time series unit root tests in a summary with Table 1.[10]

We found that 47 out of 50 states (except with Arkansas, Iowa and North Carolina) have a stationary unemployment series with different data generating features, namely size, sign and time-varying nonlinearity. With the exceptions of Arkansas, Connecticut, Indiana, Iowa, Mississippi and North Carolina, 44 states are stationary in the union of both KSS (2003) and Sollis (2009) tests. On the other hand, the TAR unit root test, namely Enders and Granger (1998) test, provides evidence of stationarity only for one stationary state (Vermont) which indicates that governing nonlinearity is smooth (gradual) not an instantaneous change. Besides, LNV test provides stationarity for three states (Alaska, Montana, Utah), while CEO test does not provide any evidence of stationarity. These two tests are structural break unit root tests and have a very little power capturing the stationarity. Besides, EL test is also classified as a structural break test and provides better results. From Enders and Lee (2012a, 2012b), we know that this test is also powerful with respect to the ESTAR nonlinearity, which means that it can be substituted for the Im. et al. (2003) and Sollis (2009) tests. Therefore, we conclude that better results obtained with the EL test stemming from the state-dependent nonlinearity. A very similar argument could be suggested for the FFFFF test, as well. The FFFFF test provides 22 stationary states while the EL test shows 16 stationary states. Omay (2015), who found that fractional frequency leads to a better specification of nonlinear trends, supports the better performance of the FFFFF test with respect to EL test and hence, a better power performance. Omay. et al. (2018) states that using of a Fourier form, a state-dependent nonlinearity annihilates the nonlinear effects of each other, and thus, OEHa (2018), and CL (2010) tests have worse performance than the KSS and Sollis (2009) tests. However, the OEHa (2018) and the OY (2014) tests are not faced with this kind of problem, and their performances are better than that of Fourier counterparts, namely the OEHa (2018) and CL (2010) tests. Moreover, performances of these tests are not better than those of state-dependent nonlinear tests, i.e. Im. et al. (2003) and Sollis (2009). As we explained, the structural break is not suitable for this data structure. The structural breaks obtained from the US state-level unemployment series are smooth where the LNV and CEO tests capture sharp breaks; hence, these smooth breaks can also be modelled as state-dependent nonlinearities as we mentioned before. In this context, modelling the US state unemployment data with sharp break or any other structure without considering the state-dependent or business cycle behaviour leads to misleading results. Finally, the good performance of the ADF test can be explained by the power analysis explained by Im. et al. (2003). As pointed out in Im. et al. (2003), as θ grows large, the model becomes approximately linear. On the other hand, Im. et al. (2003) point out that it is hard to determine an exact description of "small" and "large" θ since it is not a scale-free parameter. From these arguments, it can be stated that power analyses of the nonlinear tests perform better relative to the linear tests in the region of the null, where the series is relatively more persistent (Kapetanios et al., 2003). This argument also indicates that the ADF unit root test retains its power unless the series has a state-dependent nonlinear feature. The test results obtained in this study are also supported by this argument.[11]

[10]The separate time series unit root test results are available upon request.

[11]In some cases, state-dependent nonlinearity can also be captured by time-varying nonlinearity if the threshold level coincides with each other. However, this result is not considered primarily as the tests robustly support for state-dependent nonlinearity. There is no need to further explain why LNV and CEO tests obtained three and zero stationary state unemployment rates.

Table 1. Summary of unit root analysis.

	Lin	State dependent			S. break				Hybrid test			
States	ADF	EG	KSS	Sollis	LNV	EL	CEO	FFFFF	OY	OEHa	CL	OEHb
Alabama			+	+				+	+	+		
Alaska	+		+	+	+	+		+	+	+	+	+
Arizona	+		+	+		+		+			+	+
Arkansas												
California	+			+								
Colorado	+		+	+				+				
Connecticut	+											
Delaware	+		+									
Florida	+		+	+								
Georgia	+			+								
Hawaii				+		+					+	+
Idaho			+	+					+			
Illinois	+		+	+				+		+	+	
Indiana								+				
Iowa												
Kansas	+		+	+				+	+	+		
Kentucky				+				+			+	
Louisiana				+				+	+	+		+
Maine			+	+		+					+	+
Maryland	+		+	+								
Massachusetts	+		+	+		+				+	+	+
Michigan			+	+				+	+	+		
Minnesota	+		+						+	+		
Mississippi								+				
Missouri	+			+				+			+	
Montana	+		+	+	+				+	+		
Nebraska			+	+					+	+		
Nevada	+			+				+				
New Hampshire	+		+	+		+			+	+	+	+
New Jersey	+		+	+								
New Mexico	+		+	+		+		+			+	+
New York	+		+	+		+					+	+
North Carolina												
North Dakota			+	+				+	+	+		
Ohio	+		+	+		+		+		+	+	
Oklahoma	+		+	+		+		+	+	+	+	+
Oregon	+		+	+		+		+		+	+	+
Pennsylvania	+		+	+					+	+		
Rhodelsland	+		+	+								
South.Caroli	+		+	+		+		+			+	+
South Dakota	+		+	+						+		
Tennessee			+	+		+		+		+	+	+
Texas	+		+	+					+	+	+	
Utah	+		+	+	+					+		
Vermont	+	+	+	+		+			+	+	+	+
Virginia	+		+									
Washington	+		+							+		
West Virginia			+	+		+		+	+	+	+	+
Wisconsin	+		+	+								
Wyoming			+	+		+		+	+	+	+	+
Total =50	33	1	38	40	3	16	0	22	17	24	20	16
Group Total	33		45				30				33	

Note 1: + Stands for stationarity at different significance levels.
Note 2: All the results obtained by using the %10 significance level by aggregating the intercept and intercept& trend cases.

The tests we used for testing the unit root features of unemployment series were also used to identify DGP of the unemployment series. The alternative hypotheses are non-linear stationarity, asymmetric nonlinearity, stationary around smooth trend, and

nonlinear stationary around smooth trend. Therefore, we also concluded that out of 47 stationary states, 45 states have state-dependent nonlinearity in their unemployment series. Out of 47 stationary states, two states (Mississippi and Indiana) have unemployment rates stationary around a smooth trend. As sum, the stationarity results obtained for most US states provide evidence of the natural rate hypothesis, implying that unemployment rates in the most US states are flexible enough to easily revert to their long-run equilibriums determined by the labour market (Chang, 2011). As such, there is less need for mandatory policy action since the shocks affecting the unemployment series will merely become transitory. Confirmation of the natural rate hypothesis for 45 states indicates that labour markets in those states are less regulated and more flexible, and deviations from the natural rate are just temporary and eventually will die out. Besides, from a policy perspective, the fact that unemployment rates in many states are stationary or mean-reverting supports discretionary policies implemented by the US Federal and states governments as well as those by the Federal Reserve Bank (Bahmani-Oskooee et al., 2018). In addition, the presence of stationary unemployment series implies that some macroeconomic variables linked to unemployment rate via flow-on effects will not inherit that non-stationarity and transmit it to major economic variables, e.g., inflation rate (Lee & Chang, 2008). Moreover, policymakers of the US states with stationary unemployment series might forecast future movements in unemployment based on past behaviour during the process of policy design. For those states confirming the structuralist view (Indiana and Mississippi), the results signal that economic models which ignore breaks in the trend of unemployment cannot avoid the costs of interference, which can also increase fluctuations in other macroeconomic variables (Lee & Chang, 2008). According to the structuralist view of unemployment, shocks to unemployment are highly persistent but not permanent. For Indiana and Mississippi, the natural rate of unemployment might be endogenous and affected by market forces like other economic variables, resulting in increases in the movements of natural rate due to changes either in real macroeconomic variables or in the institutional structure (Camarero. et al., 2006). For Arkansas, Iowa and North Carolina, the presence of hysteresis effects might be explained by some state-idiosyncratic factors, such as the percentage of the population living in an owner-occupied residence, which increases the state equilibrium rate of unemployment, and the larger proportion of college-educated labour, which reduces it (Romero-Avila & Usabiaga, 2007). For those three states, confirmation of the hysteresis hypothesis implies that Keynesian demand-driven policies have great importance in the fight against unemployment in the long-run. A successful combination of demand-driven and structural policies should be implemented to reduce unemployment because there is a path dependence in the unemployment series (Cevik & Dibooglu, 2013).

Our results are generally consistent with those of previous studies, e.g., Blanchard. and Summers (1986), Camarero and Tamarit (2004), Caner and Hansen (2001), Chang and Lee (2011), Jaeger. and Parkinson (1994), Gil-Alana (2001), Lee and Chang (2008), Leon–Ledesma (2002), Lee (2010), Lin., Kuon, and Yuan (2008), Mohan. et al. (2008), Roed (1996), Song and Wu (1998) and Yilanci (2008), who found supportive evidence of the natural rate hypothesis for the US labour market. However, they are in sharp contrast with those of Arestis and Mariscal (1999), Arestis. & Mariscal. (2000), Caporale and Gil-Alana (2007), Cevik and Dibooglu (2013), Cheng. et al. (2012), Gustavsson and Osterholm (2007), Mitchell (1993), Romero-Avila and Usabiaga (2007) and Srinivasan

and Mitra (2016), who found evidence against the natural rate hypothesis for the US unemployment series. Regarding the results for other economies, our result in favour of natural rate hypothesis for the most US states is in line with those of Song and Wu (1998) for 15 OECD economies and Johansen (2002) for 29 rural areas of Norway. However, it is in sharp contrast to those of Lee., Wu, and Lin (2010) for nine East Asian countries; Chang., Lee, Nieh, and Wei (2005) for 8 European countries; Cuestas and Gil-Alana (2011) for Central and Eastern Europe; and Caporale and Gil-Alana (2008) for the United Kingdom, who confirmed the hysteresis hypothesis. Besides, Lee and Chang (2008) for 14 OECD countries; Camarero, Carrion-i-Silvestre, and Tamarit (2008) for transition economies, and Caporale and Gil-Alana (2008) for the US and Japan found strong evidence in support of the structuralist view.

As a next step,we proceed with the panel unit root tests in order to understand the behaviour when the spill over effects, spatial and other causes of cross-section dependency are taken into consideration. Hence, controlling these factors contributes to the understanding of the DGP of the state unemployment rates. Time series unit root tests make identification of the unemployment series as we mentioned above, hence following the results obtained by the time series analysis, we solely employed the state-dependent nonlinear panel unit root tests, namely Ucar and Omay (2009) and Emirmahmutoglu and Omay (2014) as seen in Table 2.

Taylor and Sarno (1998) note that panel unit-root tests may reject the joint non-stationarity even if only one of the processes exhibits stationarity under the alternative hypothesis. If the test rejects the unit-root null, it provides importance to distinguish between non-stationary and stationary series within the panel. To resolve this problem, Choartareas and Kapetanios (CK hereafter, 2009), propose a sequential panel selection method (SPSM) that allows the identification of the stationary series. The SPSM procedure of CK (2009) proceeds as follows: First, we apply the unit-root test to the full sample. If we cannot reject the unit-root null, then we stop and accept non-stationarity of panel. If we reject the null, then we continue to other steps. Second, we drop the series with the maximum significant $F_{i,AE}$ statistic, which indicates the state with the strongest evidence for stationarity, repeat the analysis for the remaining panel data set. Finally, we end up when the individual $F_{i,AE}$ proves insignificant.

As is shown in Table 3, Kentucky, Mississippi, Delaware, Hawaii, North Carolina and Georgia are found to be nonstationary. These six states' unemployment rates are not stationary in time series analysis of Sollis (2009) test, as well. It is well known that neglecting the presence of cross-sectional dependence can lead to biased estimates and produce misleading inference. Along these lines, many authors applied panel unit root tests that take cross-sectional dependence into account (for the US, see Camarero & Tamarit, 2004; Cheng. et al., 2012; Dreger & Reimers, 2009; Leon–Ledesma, 2002; Romero-Avila & Usabiaga, 2007).

Previous studies for the US mostly supported the existence of a structural break in the unemployment series; but, their testing strategies were not able to account for different dynamics. Therefore, we consider every type of data structure in order to guarantee the data dynamics and to identify the best testing strategy by using different forms of nonlinearity, structural breaks and different forms of data structure, i.e., time-series data and panel data. Thereby, we control for cross-section dependency, as well. Our findings may shed more lights on the previous findings in the literature. In this sense,

Table 2. Nonlinear panel unit root analysis.

	Ucar and Omay (2009)		EO(2014)	
	Intercept	Int and Tr	Intercept	Int and Tr
U_{it}	−2.887**	−3,234*	4.627*	5,412*

Note: *, ** and *** are representing the 1%, 5% and 10% significance level, respectively.

Table 3. Emirmahmutoglu And Omay (2014) unit root test with intercept and trend.

	Intercept and Trend	
	Sollis (2009)	Emirmahmutoglu and Omay (2014)
Montana	8.912	5.412*
Idaho	8.907	5.341*
Texas	8.874	5.267*
Pennsylvania	8.819	5.190*
Vermont	8.723	5.111*
Alaska	7.663	5.031*
Kansas	7.632	4.971*
West Virginia	7.419	4.909*
Utah	7.315	4.850*
Michigan	7.219	4.789*
New Hampshire	7.137	4.729*
California	6.849	4.667*
Nebraska	6.592	4.609*
Rhode Island	6.545	4.556*
Oregon	6.307	4.501*
Alabama	6.323	4.449*
New York	6.141	4.394*
Maryland	6.129	4.341*
South Dakota	6.077	4.285*
Oklahoma	5.803	4.227*
Wisconsin	5.62	4.175*
Florida	5.592	4.125*
North Dakota	5.552	4.073*
New Jersey	5.465	4.018*
Massachusetts	5.355	3.962*
New Mexico	5.318	3.906*
Minnesota	5.144	3.848*
Tennessee	4.94	3.791*
Ohio	4.923	3.739*
Washington	4.921	3.683*
South Carolina	4.824	3.621*
Nevada	4.685	3.557*
Connecticut	4.331	3.495*
Wyoming	4.32	3.445**
Arkansas	4.162	3.391**
Iowa	4.137	3.339**
Illinois	4.089	3.282**
Virginia	3.997	3.220**
Missouri	3.99	3.156**
Louisiana	3.977	3.080**
Maine	3.852	2.990**
Indiana	3.839	2.894**
Colorado	3.795	2.776**
Arizona	3.681	2.631***
Kentucky	3.307	2.456
Mississippi	3.183	2.286
Delaware	2.588	2.061
Hawaii	2.285	1.886
North Carolina	2.199	1.686
Georgia	1.173	

Note: *, **, and *** are representing the 1%, 5% and 10% significance levels, respectively.

most of the studies wrongly concluded that there is a structural break in the US unemployment series. However, as we pointed out, time-varying nonlinearity may imitate the state-dependent nonlinearity. Thus, for the US state-level unemployment series, the best data generating process that can be represented is the state-dependent nonlinearity with asymmetries. Finally, the best testing strategy is the Emirmahmutoglu and Omay (2014) nonlinear asymmetric panel unit root test that controls for cross-section dependency.

5. Concluding remarks

We extensively investigated the stochastic behaviour of US state-level unemployment data. The data exhibits a robust state-dependent nonlinear behaviour, which contradicts the findings of the previous literature where insufficient techniques were applied. Most of the studies presumed structural breaks in the unemployment data and did not investigate the other possible features that may emerge. Thus, they incorrectly concluded that the US state-level unemployment series has structural breaks. In this study, we investigated every possible data structure by comparing and contrasting them with each other. This extensive comparison was also based on the theoretical findings of the available unit root tests. For example, a Fourier-based unit root test also has power against state-dependent nonlinear behaviour. Therefore, obtaining stationarity results with such kind of tests does not show structural break in the data in isolation. On the other hand, smooth transition types of unit root tests are also capturing sharp breaks and have very low performance with the US state unemployment data. This is an indication of the rare occurrence of sharp breaks in the US state-level unemployment data. Moreover, we revealed that smooth break and state-dependent nonlinearity obtained by smooth transition functions may have power against each other. Fortunately, our sample reveals a very good performance of state-dependent nonlinearity.

A number of questions arise when determining the structure of the data. For example, if there is not a sharp structural break in the data that are explicitly investigated in the previous literature what will be the consequences of the state-dependent nonlinearity with respect to policy issues. From the unit root test results, we can understand that including the asymmetric behaviour of business cycle in the testing procedure, we can obtain the stationarity of the US state-level unemployment rate. The results favouring the stationarity of the unemployment rate in most US states confirm the natural rate hypothesis; 47 out of 50 states, exceptions with Arkansas, Iowa and North Carolina, have a stationary unemployment series, implying that shocks to their labour markets have only temporary effects and deviations from the natural rate of unemployment are possible only in the short term. Besides, it might be possible to forecast future movements in unemployment series based on its past behaviour since state-level unemployment series follows mean-reverting processes. Moreover, as we have mentioned previously macroeconomic variables linked to unemployment rate via flow-on effects will not inherit that non-stationarity and not transmit it to crucial economic variables, such as inflation rate. From a policy perspective, a stationarity result indicates that aggregate demand policies may not be over-implemented in those 47 states because a fiscal or monetary stabilization policy would not possibly have permanent impacts on the unemployment series. Among 47 states with stationary unemployment series, two states,

namely Indiana and Mississippi, have stationary unemployment series with smooth structural breaks. Therefore, the structuralist hypothesis is valid for Indiana and Mississippi. That is to say, some variations in the structural factors of Indiana and Mississippi change the natural rate of unemployment and thereby, unemployment reaches a new and stationary equilibrium. Therefore, while modelling the unemployment series of Indiana and Mississippi, we should consider structural breaks; otherwise, we cannot avoid the wasted costs of government interference, resulting in fluctuations in some macroeconomic variables.

For the remaining three states with nonstationary unemployment rates (Arkansas, Iowa and North Carolina) the unemployment hysteresis hypothesis is confirmed. As such, their unemployment series appears to be path-dependent and labour market shocks will have permanent effects and shift the unemployment equilibrium from one level to another level. Therefore, for these three states, a combination of Keynesian demand-driven and structural policies should be implemented to reduce unemployment in the period of protracted recessions. Overall, the findings are mostly in support of the natural rate hypothesis in the US state-level unemployment series. The high flexibility degree of the US labour market is a crucial reason for this result because hysteresis is more likely to occur in more regulated labour markets, such as in the EU. Moreover, in the previous study, the researchers' tendency is to find stationarity by using unit root tests with structural break, and this proclivity of researchers leads to a structuralist view. However, we can claim that this tendency produces an incorrect analysis of US state-level unemployment as we confirmed that state-dependent asymmetric nonlinearity is the key determinant of the behaviour of the US unemployment series at the state level. Accordingly, the policy authority should look at the business cycle behaviour of the US state-level unemployment series. Moreover, this study confirms the validity of this approach by implementing the recently developed panel and time series unit root test. Thus, we can recommend that policy authorities in each state should consider the state-specific dynamics of unemployment series.

Disclosure statement

No potential conflict of interest was reported by the authors.

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