Economics Bulletin

Volume 41, Issue 3

Testing hysteresis in unemployment using artificial network (ANN) unit root test

Fumitaka Furuoka
Asia-Europe Institute, Universiti Malaya

Abstract

This paper employs artificial neural network (ANN) unit root test to examine unemployment hysteresis in five economies in Europe and North America. The findings indicated that unemployment hysteresis does exist in these countries. These results have some notable policy implications.

Contact Email: fumitaka@um.edu.my. Postal address: Asia-Europe Institute, University of Malaya, 50606 Kuala Lumpur, Malaysia. The OxEdit was used for the analysis; the OxGauss codes are available at: https://sites.google.com/site/fumitakafuruokaswebpage/dat.a-and-oxgauss-codes-iii/paper-47

Citation: Fumitaka Furuoka, (2021) "Testing hysteresis in unemployment using artificial network (ANN) unit root test ", *Economics Bulletin*, , Vol. 41 No. 3 pp. 1947-1958
Contact: Fumitaka Furuoka - fumitaka@um.edu.my.
Submitted: April 22, 2021. **Published:** September 17, 2021.

1. Introduction

In 1987, Olivier Blanchard and Lawrence Summers put forward an argument that unemployment rates do not follow a stationary process. This would mean that a high unemployment rate will persist even after an economic downturn ends. This hypothesis is known as unemployment hysteresis (Blanchard and Summers 1987). The unemployment hysteresis could be operationally defined as a unit root process of unemployment rates (Romero-Avila and Usabiaga 2007).

Researchers used various unit root tests to assess the existence unemployment hysteresis. However, the findings remain mixed (Bakas and Makhlouf 2020; Yaya *et al.* 2021). Some studies found that unemployment hysteresis in labour market *does* exist (Neudorfer *et al.* 1990, Brunello 1990, Mitchell 1993, Leon-Ledesma 2002, Lee *et al.* 2010, Meng *et al.* 2017, Akdogan 2017, Albulescu and Tiwari 2018, Bechný 2019, Akay *et al.* 2020, Yaya *et al.* 2021). Others reported the opposite findings (Song and Wu 1998, Smyth 2003, Camarero and Tamarit 2004, Camarero *et al.* 2004, Camarero *et al.* 2005, Lee *et al.* 2009, Bolat *et al.* 2014, Furuoka 2017, Yaya *et al.* 2019, Khraief *et al.* 2020).

Against this background, the current paper employs the artificial neural network (ANN) unit root test (Yaya *et al.* 2021). This is the first empirical research to employ the ANN unit root test to examine unemployment hysteresis. In other words, this study aims to contribute to the existing literature on unemployment hysteresis by applying a newly developed unit root test that incorporates a neural network framework into a unit root analysis. A methodological advantage of this approach is that the test includes a hidden layer in the estimation model, which could capture a latent structure of the time-series data.

2. Artificial neural network (ANN) model

The ANN unit root test incorporates a neural network model into a unit root analysis. In this study, the ANN (*s, q, h*) model will be considered, where *s* is number of hidden layers, *q* is number of inputs and *h* is number of hidden units. The ANN (*1*, *q*, *h*) model with a feedforward single hidden layer could be expressed as (Rech 2002, Yaya *et al.* 2021):

$$x_t = \sum_{j=1}^{h} \beta_j \psi(\gamma_j w_t) \tag{1}$$

where x_t is the output, $w_t = (w_{1t,}w_{2t},.....w_{qt})'$ is the $q \times 1$ vector of inputs, $\gamma_j = (\gamma_{1j,}\gamma_{2j},.....\gamma_{qj,})'$ is the $q \times 1$ vector of weights for the relationship between *j^th^* hidden unit and inputs, $\psi(\gamma_j w_t)$ is the hidden units known as the activation function, β_j is the connector strength parameter that measures the strength of connection between the j^{th} hidden unit and outputs. The activation function could be expressed as the following logistic function (Rech 2002):

$$\psi(\gamma_j w_t) = 1/(1 + \exp(-\gamma_j w_t)) \tag{2}$$

The *h*th order expansion of the Taylor series function on the logistic function could be expressed as (Rech 2002):

$$\psi(\gamma_i w_t) = \psi(\gamma_i w_t^0) + \frac{\partial\psi(\gamma_i w_t)}{\partial w_t}|_{w_t=w_0}(w_t - w_0) + \frac{\partial^2\psi(\gamma_i w_t)}{\partial w_t \partial w_t}|_{w_t=w_0}(w_t - w_0)^2 + \frac{\partial^3\psi(\gamma_i w_t)}{\partial w_t \partial w_t \partial w_t}|_{w_t=w_0}(w_t - w_0)^3 + ... + R_h \tag{3}$$

where R_h is the remainder of the hth order expansion. Using the Maclaurin series (i.e. $w_0 = 0$) with the hth order expansion, the ANN (*1, q, h*) model could be approximated as:

$$\psi(\gamma_i w_t) = \sum_{i=1}^{q} k_i w_{ti} + \sum_{i=1}^{q} \sum_{l=i}^{q} k_{il} w_{ti} w_{tl} + \sum_{i=1}^{q} \sum_{l=i}^{q} \sum_{j=l}^{q} k_{ilj} w_{ti} w_{tl} w_{tj} + \ldots + R_h \quad (4)$$

where k_i are coefficients for the linear components, k_{il} are coefficients for the quadratic components, k_{ilj} are coefficients for the cubic components, w_{ti} are the linear components, $w_{ti} w_{tj}$ are the quadratic components and $w_{ti} w_{tj} w_{tl}$ are the cubic components. To give an example, an autoregressive ANN (*1, 1, 3*) model with $w_t = y_{t-1}$ is depicted in Figure 1.

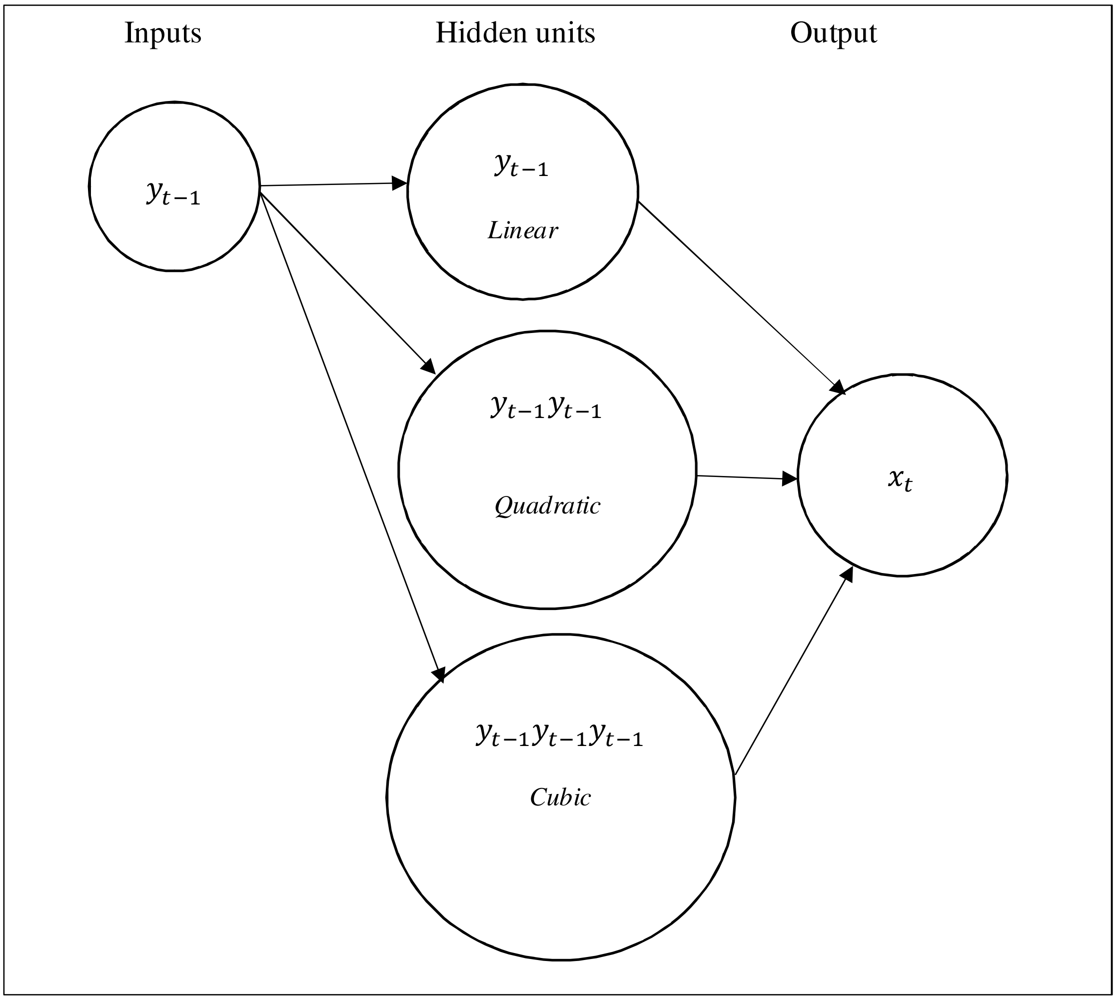

Figure 1: Visualization of the ANN (*1, 1, 3*) model

The ANN unit root test is a modified version of a standard ADF model. The ADF model could be expressed as:

$$(1-L)y_t = \alpha + \beta t + \rho y_{t-1} + \sum_{k=1}^{p} \delta_k (1-L) y_{t-k} + \varepsilon_t \tag{5}$$

where α is the intercept, β is the parameter for the deterministic trend, L is the lag operator, t is the time trend, ρ is the parameter for the autoregressive term, δ is the parameter for augmentation, $(1-L)\,y_{t-k}$ is the augmentation component. By combining Equation (4) and Equation (5), the ANN (*1, q, h*) unit root test could be specified as:

$$(1-L)y_t = \alpha + \beta t + \rho y_{t-1} + \sum_{i=1}^{q}\sum_{j=i}^{q} k_{ij} w_{ti} w_{tj} + \sum_{i=1}^{q}\sum_{j=i}^{q}\sum_{l=j}^{q} k_{ijl} w_{ti} w_{tj} w_{tl} + \ldots + \sum_{k=1}^{p} \delta_k (1-L) y_{t-k} + \varepsilon_t \tag{6}$$

3. Simulation analysis

This study used the Monte Carlo method suggested by Schwert (1989) to simulate the empirical distribution, the empirical size and the power of the ANN unit root test as well as the ADF test for some comparisons. In this simulation analysis, two designs of data generating process (DGP) could be considered. In the first design, the residuals would follow the first-order moving average (MA) process (Davidson and MacKinnon 2004, Box *et al.* 2015):

$$y_t = \rho y_{t-1} + u_t - \theta u_{t-1} \tag{7}$$

where ρ is the AR parameter, θ is the MA parameter, u_t is a standard normal variable or $u_t \sim N(0,1)$. The nominal levels are set equal to 0.01, 0.05 and 0.10 and θ is set to 0 and 0.5. For the size analysis, ρ is set to 1 and ρ is set to 0.9 for the power analysis. In this simulation design, 10,000 replications of the four sample sizes $T = 50, 100, 500$ and 1000 were generated.

In the second design, the residuals would follow the first-order autocorrelation process (Davidson and MacKinnon 2004, Box *et al.* 2015):

$$y_t = \rho y_{t-1} + \alpha(y_{t-1} - y_{t-2}) + u_t \tag{8}$$

where α is the parameter for residual autocorrelation which is set to 0.1. For the size analysis, ρ is set to 1; for the power analysis, ρ is set to 0.9. In this simulation design 10,000 replications of the four sample sizes $T = 50, 100, 500$ and 1000 were generated.

In their simulation of analysis, Yaya *et al.* (2021) examined an autoregressive ANN (*1,2,3*) model with $w_t = (y_{t-1}, y_{t-2})$ by setting the number of inputs to 2. In the current simulation analysis, a more fundamental model, an autoregressive ANN (*1,1,3*) model with $w_t = y_{t-1}$, was examined by setting the number of inputs to 1. In this current simulation analysis, Equation (6) can be reformulated as:

$$(1-L)y_t = \alpha + \beta t + \rho y_{t-1} + k_{11}y_{t-1}y_{t-1} + k_{111}y_{t-1}y_{t-1}y_{t-1} + \sum_{k=1}^{p}\delta_k(1-L)y_{t-k} + \varepsilon_t \quad (9)$$

In the simulation analysis, the following two model specifications were considered: the ANN unit root test without augmentation component or *Model 1* and the ANN unit root test with augmentation component ($p = 1$) or *Model 2*. Table 1 shows empirical distribution of the ADF unit root test and ANN root test with two different model specifications. Figure 2 depicts their distribution in comparison with a student's t distribution. As the figure shows, the ANN distribution is less skewed to the left. Furthermore, the ADF distribution tends to be a distribution with a positive excess kurtosis. In other words, the ADF distribution is more leptokurtic than the ANN distribution.

Table 1: Empirical distribution of the ADF test and ANN unit root test

			0.01	**0.05**	**0.10**	**0.50**	**0.90**	**0.95**	**0.99**
T=50	Model 1	ADF	-4.165	-3.533	-3.182	-2.152	-1.214	-0.896	-0.310
		ANN	-3.404	-2.650	-2.260	-0.885	0.434	0.845	1.656
	Model 2	ADF	-4.177	-3.508	-3.177	-2.165	-1.190	-0.841	-0.184
		ANN	-3.361	-2.676	-2.254	-0.852	0.464	0.844	1.636
T=100	Model 1	ADF	-4.080	-3.468	-3.162	-2.164	-1.222	-0.924	-0.286
		ANN	-3.490	-2.729	-2.329	-0.998	0.330	0.741	1.528
	Model 2	ADF	-4.073	-3.464	-3.150	-2.152	-1.207	-0.905	-0.290
		ANN	-3.413	-2.684	-2.314	-0.972	0.395	0.758	1.567
T=500	Model 1	ADF	-3.998	-3.414	-3.122	-2.179	-1.242	-0.896	-0.310
		ANN	-3.487	-2.798	-2.429	-1.005	0.304	0.699	1.463
	Model 2	ADF	-3.935	-3.429	-3.142	-2.185	-1.238	-0.939	-0.307
		ANN	-3.450	-2.794	-2.364	-1.055	0.298	0.724	1.448
T=1000	Model 1	ADF	-3.979	-3.404	-3.123	-2.183	-1.239	-0.904	-0.293
		ANN	-3.530	-2.784	-2.467	-1.064	0.325	0.710	1.487
	Model 2	ADF	-4.003	-3.446	-3.144	-2.161	-1.233	-0.914	-0.343
		ANN	-3.436	-2.746	-2.376	-1.054	0.340	0.730	1.524

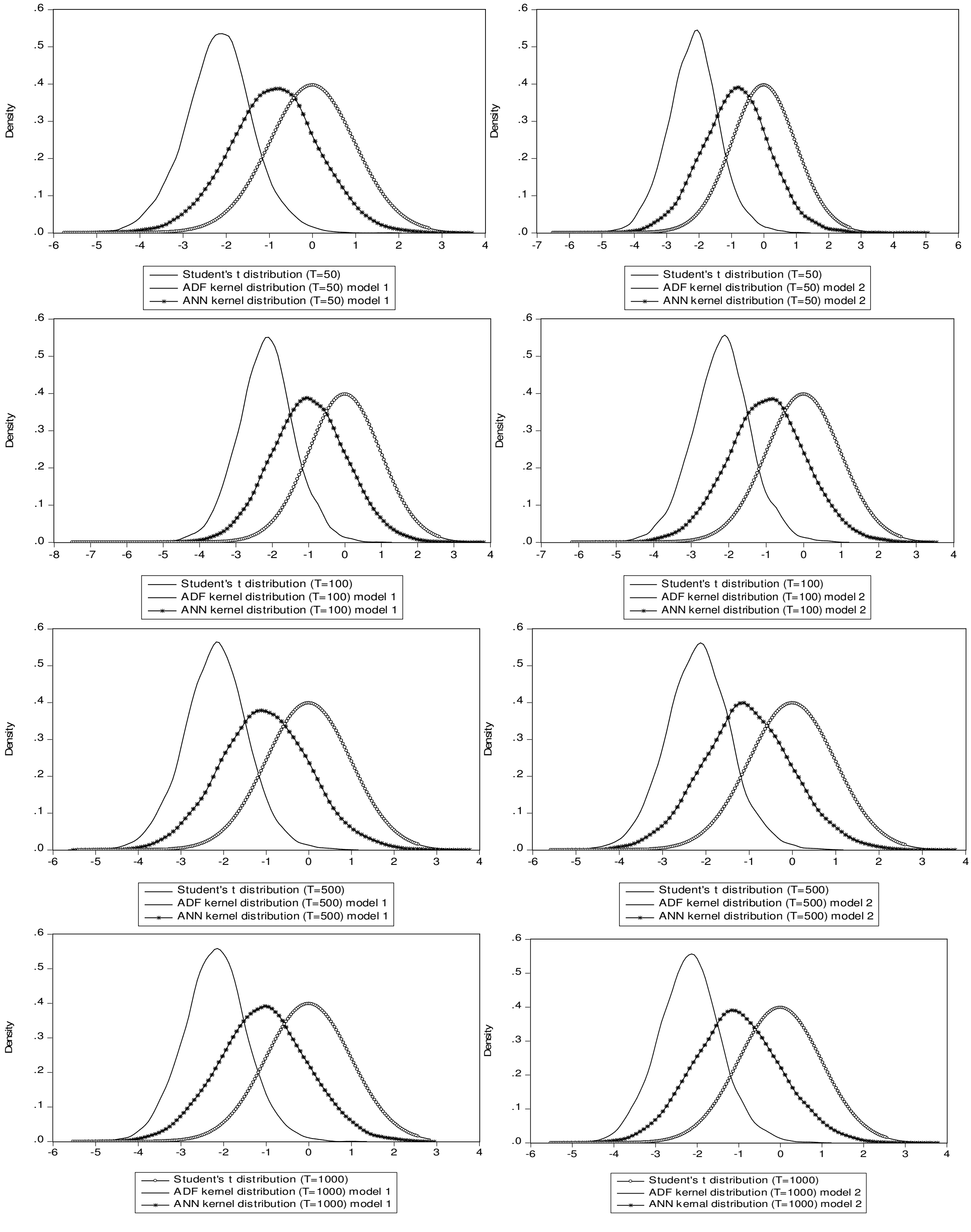

Figure 2: Student's *t* distribution, ADF distribution and ANN distribution

Table 2 reports empirical size of the ADF test and ANN unit root test. As the findings indicate, the ADF test tended to suffer the size distortion when the MA parameter was set to 0.5. Similar patterns could be observed in the ANN unit root test. However, the size distortion in the ANN test were relatively smaller than those in the ADF test. This would mean that, with the presence of the MA component in the DGP, the ANN test would suffer less from the size distortion in comparison with the ADF test.

Table 2: Empirical size of the ADF test and ANN unit root test

T=50		*MA=0*		*MA=0.5*	
	Nominal Size	**ADF**	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.011	0.009	0.463	0.079
	0.05	0.047	0.046	0.694	0.193
	0.10	0.099	0.100	0.802	0.294
Model 2	**0.01**	0.009	0.012	0.079	0.028
	0.05	0.051	0.118	0.223	0.138
	0.10	0.101	0.126	0.394	0.198
T=100		***MA=0***		***MA=0.5***	
	Nominal Size	**ADF**	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.010	0.012	0.594	0.160
	0.05	0.047	0.034	0.785	0.250
	0.10	0.096	0.101	0.871	0.395
Model 2	**0.01**	0.011	0.011	0.144	0.043
	0.05	0.050	0.050	0.306	0.026
	0.10	0.096	0.114	0.422	0.226
T=500		***MA=0***		***MA=0.5***	
	Nominal Size	**ADF**	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.009	0.021	0.719	0.348
	0.05	0.047	0.052	0.853	0.439
	0.10	0.096	0.105	0.907	0.522
Model 2	**0.01**	0.010	0.009	0.191	0.068
	0.05	0.050	0.053	0.377	0.184
	0.10	0.099	0.106	0.490	0.279
T=1000		***MA=0***		***MA=0.5***	
	Nominal Size	**ADF**	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.009	0.009	0.705	0.315
	0.05	0.056	0.056	0.859	0.460
	0.10	0.093	0.115	0.900	0.537
Model 2	**0.01**	0.089	0.011	0.181	0.091
	0.05	0.044	0.053	0.366	0.204
	0.10	0.090	0.107	0.485	0.298

Table 3 reports empirical power of the ADF and ANN unit root tests. The estimated powers for the ADF test were approximately equal to 1.000 when the sample size was set to 500 or 1,000. However, the estimated powers for the ANN unit root test were relatively smaller than those in the ADF test. When the sample size was set to 1,000, the estimated powers for the ANN unit root test were also approaching 1.000. This means that the ANN unit root test would suffer less from the power loss when the sample is large.

Table 3: Empirical power of the ADF test and ANN unit root test

T=50	*Nominal power*	*MA=0*		*MA=0.5*	
		ADF	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.018	0.007	0.651	0.164
	0.05	0.086	0.042	0.858	0.377
	0.10	0.163	0.101	0.927	0.532
Model 2	**0.01**	0.016	0.008	0.130	0.060
	0.05	0.076	0.125	0.349	0.358
	0.10	0.148	0.134	0.499	0.374
T=100	*Nominal power*	*MA=0*		*MA=0.5*	
		ADF	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.042	0.016	0.952	0.388
	0.05	0.184	0.034	0.993	0.541
	0.10	0.317	0.124	0.998	0.728
Model 2	**0.01**	0.049	0.012	0.454	0.138
	0.05	0.171	0.005	0.730	0.087
	0.10	0.293	0.127	0.844	0.526
T=500	*Nominal power*	*MA=0*		*MA=0.5*	
		ADF	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	0.977	0.338	1.000	0.951
	0.05	1.000	0.518	1.000	0.998
	0.10	1.000	0.632	1.000	0.999
Model 2	**0.01**	0.994	0.220	1.000	0.888
	0.05	1.000	0.515	1.000	0.976
	0.10	1.000	0.668	1.000	0.991
T=1000	*Nominal power*	*MA=0*		*MA=0.5*	
		ADF	**ANN**	**ADF**	**ANN**
Model 1	**0.01**	1.000	0.738	1.000	1.000
	0.05	1.000	0.900	1.000	1.000
	0.10	1.000	0.962	1.000	1.000
Model 2	**0.01**	1.000	0.770	1.000	0.999
	0.05	1.000	0.928	1.000	0.999
	0.10	1.000	0.968	1.000	1.000

Table 4 reports empirical size of the ADF test and ANN unit root test when there was autocorrelation in the residuals. The empirical size of the ADF and ANN tests with the residual autocorrelations was found to be similar to those without the residual autocorrelation. Especially, the size distortion of the ANN test was relatively smaller when the sample size was set to either 500 or 1000. This means that, with the presence of the residual autocorrelation, the ANN unit root test would suffer less from the size distortion when the number of observations are larger.

Table 4: Empirical size of the ADF test and ANN unit root test with residual autocorrelation

	Nominal Size	*ADF test*			
		T=50	***T=100***	***T=500***	***T=1000***
Model 1	**0.01**	0.004	0.003	0.004	0.004
	0.05	0.031	0.023	0.023	0.023
	0.10	0.060	0.054	0.052	0.046
Model 2	**0.01**	0.010	0.012	0.010	0.007
	0.05	0.048	0.054	0.048	0.042
	0.10	0.101	0.104	0.075	0.096
	Nominal Size	*ANN test*			
		T=50	***T=100***	***T=500***	***T=1000***
Model 1	**0.01**	0.006	0.007	0.009	0.004
	0.05	0.035	0.023	0.034	0.030
	0.10	0.082	0.078	0.075	0.068
Model 2	**0.01**	0.011	0.011	0.008	0.011
	0.05	0.126	0.005	0.052	0.054
	0.10	0.135	0.119	0.103	0.109

Table 5 reports empirical power of the ADF test and ANN unit root test when there was autocorrelation in the residuals. The patterns of the empirical power with the residual autocorrelation have a similarity with those without the residual autocorrelation. In other words, the power distortion of the ANN unit root test, with the presence of the residual autocorrelation, was also relatively smaller when the sample size was set to either 500 or 1000. This indicates that the ANN unit root test, with or without the presence of the residual autocorrelation, would suffer less from the power distortion when the number of observations are larger.

Table 5: Empirical power of the ADF test and ANN unit root test with residual autocorrelation

	Nominal Power	*ADF test*			
		T=50	***T=100***	***T=500***	***T=1000***
Model 1	**0.01**	0.006	0.013	0.971	1.000
	0.05	0.046	0.081	0.999	1.000
	0.10	0.097	0.177	1.000	1.000
Model 2	**0.01**	0.016	0.016	0.961	1.000
	0.05	0.074	0.059	0.999	1.000
	0.10	0.150	0.111	1.000	1.000
	Nominal Power	*ANN test*			
		T=50	***T=100***	***T=500***	***T=1000***
Model 1	**0.01**	0.003	0.003	0.207	0.593
	0.05	0.020	0.014	0.378	0.851
	0.10	0.060	0.076	0.551	0.930
Model 2	**0.01**	0.008	0.016	0.193	0.742
	0.05	0.106	0.005	0.472	0.909
	0.10	0.116	0.133	0.688	0.956

4. Empirical findings

This paper examined quarterly unemployment rates (1969Q1–2019Q1) in five major economies in Europe and North America, namely Germany, France, the United Kingdom, the United States and Canada. The total number of observations was 201. The source of data was the Thomson Reuters Datastream (Thomson Reuters 2021). The ADF and ANN unit root tests analyzed unemployment hysteresis in these five countries.

The findings reported in Table 6 show that the ADF test failed to reject the null hypothesis of hysteresis for all five countries. Similarly, the ANN unit root test failed to reject the null hypothesis for all countries. In other words, the ADF test and ANN unit root test yielded consistent findings on the unemployment hysteresis.

Table 6: Results of the ADF tests and ANN unit root test

Model 1	*ADF statistic*	*Bootstrapped 1% critical value*	*Bootstrapped 5% critical value*	*Bootstrapped 10% critical value*
Germany	-1.687	-5.146	-4.360	-4.016
France	-1.646	-3.682	-3.131	-2.812
United Kingdom	-1.435	-3.575	-2.651	-2.311
United States	-3.007	-5.208	-4.453	-4.071
Canada	-3.665	-4.865	-4.061	-3.697
	ANN statistic	*Bootstrapped 1% critical value*	*Bootstrapped 5% critical value*	*Bootstrapped 10% critical value*
Germany	-0.546	-4.381	-3.470	-2.994
France	0.275	-3.335	-2.607	-2.242
United Kingdom	-0.640	-3.091	-2.146	-1.750
United States	-1.030	-4.351	-3.590	-3.157
Canada	0.081	-4.077	-3.271	-2.808
Model 2	*ADF statistic*	*Bootstrapped 1% critical value*	*Bootstrapped 5% critical value*	*Bootstrapped 10% critical value*
Germany	-1.072	-4.012	-3.413	-3.131
France	-1.865	-3.951	-3.494	-3.128
United Kingdom	-1.958	-3.959	-3.401	-3.117
United States	-2.401	-3.961	-3.446	-3.173
Canada	-3.091	-4.075	-3.523	-3.180
	ANN statistic	*Bootstrapped 1% critical value*	*Bootstrapped 5% critical value*	*Bootstrapped 10% critical value*
Germany	-0.025	-3.565	-2.842	-2.504
France	0.021	-3.790	-2.914	-2.520
United Kingdom	-0.829	-4.265	-3.640	-2.555
United States	-0.853	-3.491	-2.613	-2.301
Canada	-1.313	-3.406	-2.752	-2.368

These findings could have some notable policy implications. Thus, it was found that the unemployment rates in the five countries would not return to their normal levels after an economic downturn ends. Therefore, policymakers in these countries need to be aware of the presence of unemployment hysteresis in the labour market so that the measures and policies they devise to reduce the unemployment rates would be more effective.

In short, this study has detected the presence of hysteresis in the unemployment rates. These findings are in line with recent research studies that reported the existence of unemployment hysteresis in the labour market (Meng *et al*. 2017, Akdogan 2017, Albulescu and Tiwari 2018, Yaya *et al*. 2021). At the same time, the findings from the ANN unit root test contradict the results reported in some earlier studies (Furuoka 2017, Yaya *et al*. 2019, Khraief *et al*. 2020). The difference may be due to the ability of a unit root test to incorporate unknown structural break or nonlinearity in unemployment time-series. In other words, the findings from empirical studies based on unit root tests with structural break or nonlinear unit root test tended to dispute the existence of unemployment hysteresis.

5. Conclusion

This paper employed the ANN unit root test to examine whether unemployment hysteresis exists in five major economies, namely, Germany, France, the United Kingdom, the United States and Canada. The findings from the ANN test indicated the existence of unemployment hysteresis in these countries.

References

Akay, E. Ç., Oskonbaeva, Z. and H. Bülbül (2020) "What Do Unit Root Tests Tell Us about Unemployment Hysteresis in Transition Economies?" *Applied Economic Analysis*. doi: 10.1108/AEA-05-2020-0048.

Akdogan, K. (2017) "Unemployment Hysteresis and Structural Change in Europe" *Empirical Economics* **53**(4), 1415–1440.

Albulescu, C.T. and A.K. Tiwari (2018) "Unemployment Persistence in EU Countries: New Evidence Using Bounded Unit Root Tests" *Applied Economics Letters* **25**(12), 807–810.

Aleksynska, M. and F. Eberlein (2016) "Coverage of Employment Protection Legislation" *IZA Journal of Labour Policy* **5**(1), 1–20.

Asenjo, A. and C. Pignatti (2019*) Unemployment Insurance Schemes around the World: Evidence and Policy Options*, International Labour Office.

Bakas, D. and Y. Makhlouf (2020) "Can the Insider–Outsider Theory Explain Unemployment Hysteresis in OECD Countries?" *Oxford Economic Papers* **72**, 149–163.

Bechný, J. (2019) "Unemployment Hysteresis in the Czech Republic" *Prague Economic Papers* **28**(5). 532–546.

Blanchard, O. and L. Summers (1987) "Hysteresis in Unemployment" *European Economic Review* **31**, 288–295.

Bolat, S., Tiwari, A.T. and A.U. Erdayi (2014) "Unemployment Hysteresis in the Eurozone Area: Evidences from Nonlinear Heterogeneous Panel Unit Root Test" *Applied Economics Letters* **21**(8), 536–540.

Box, G. E., Jenkins, G. M., Reinsel, G. C. and G. M. Ljung (2015) *Time Series Analysis: Forecasting and Control*, John Wiley & Sons.

Brunello, G. (1990) "Hysteresis and the Japanese Unemployment Problem: A Preliminary Investigation" *Oxford Economics Paper* **42**(3), 483–500.

Camarero, M. and C. Tamarit (2004) "Hysteresis vs. Natural Rate of Unemployment: New Evidence for OECD Countries" Economics Letters **84**(3), 413–417.

Camarero, M., Carrion-i-Silvestre, J. L. and C. Tamarit (2005) "Unemployment Dynamics and NAIRU Estimates for Accession Countries: A Univariate Approach" *Journal of Comparative Economics* **33**(3), 584-603.

Camarero, M., Carrion-i-Silvestre, J.L. and C. Tamarit (2006) "Testing for Hysteresis in Unemployment in OECD Countries: New Evidence Using Stationarity Panel Tests with Breaks" *Oxford Bulletin of Economics and Statistics* **68**(2), 167–182.

Davidson, R. and J.G. MacKinnon (2004) *Econometric Theory and Methods*, Oxford University Press: New York.

Dickey, D.A. and W.A. Fuller (1979) "Distribution of the Estimators for Autoregressive Time Series with a Unit Root" *Journal of the American Statistical Association* **74**, 427–431.

Furuoka, F. (2017) "A New Approach to Testing Unemployment Hysteresis" *Empirical Economics* **53**, 1253–1280.

International Labour Organization (2020) *Global Wage Report 2020–21: Wages and minimum wages in the time of COVID-19*, International Labour Office: Geneva.

Katris, C. (2015) "Dynamics of Greece's Unemployment Rate: Effect of the Economic Crisis and Forecasting Models" *International Journal of Computational Economics and Econometrics* **5**(2), 127–142.

Khraief, N., Shahbaz, M., Heshmati, A., and M. Azam (2020) "Are Unemployment Rates in OECD Countries Stationary? Evidence from Univariate and Panel Unit Root Tests" *North American Journal of Economics and Finance* **51**, 100838.

Lee, J.D., Lee, C.C. and C.P. Chang (2009) "Hysteresis in Unemployment Revisited: Evidence from Panel LM Unit Root Tests with Heterogeneous Structural Breaks" *Bulletin of Economic Research* **61**(4), 325–334.

Lee, H.Y., Wu, J.L. and C.H. Lin (2010) "Hysteresis in East Asian Unemployment" *Applied Economics* **42**(7), 887–898.

Leon-Ledesma, M.A. (2002) "Unemployment Hysteresis in the US States and the EU: A Panel Approach" *Bulletin of Economic Research* **54**(2), 95–103.

Meng, M., Strazicich, M. C. and J. Lee (2017) "Hysteresis in Unemployment? Evidence from Linear and Nonlinear Unit Root Tests and Tests with Non-normal Errors" *Empirical Economics* **53**(4), 1399–1414.

Mitchell, W.F. (1993) "Testing for Unit Roots and Persistence in OECD Unemployment Rates" *Applied Economics* **25**(12), 1489–1501.

Neudorfer, P., Pichelmann, K. and M. Wagner (1990) "Hysteresis, Nairu and Long Term Unemployment in Austria" *Empirical Economics* **15**(2), 217–229

Rech, G. (2002) *Modelling and Forecasting Economic Time Series with Single Hidden-layer Feedforward Autoregressive Artificial Neural Networks,* Stockholm School of Economics, PhD Thesis.

Romero-Avila, D. and C. Usabiaga (2007) "Unit Root Tests, Persistence, and the Unemployment Rate of the US States" *Southern Economic Journal* **73**(3), 698–716.

Schwert, G. (1989) "Tests for Unit Roots: A Monte Carlo Investigation" *Journal of Business & Economic Statistics* **7**(2), 147–59.

Smyth, R. (2003) "Unemployment Hysteresis in Australian States and Territories: Evidence from Panel Data Unit Root Tests" *Australian Economic Review* **36**(2), 181–192.

Song, F.M. and Y. Wu (1998) "Hysteresis in Unemployment: Evidence from OECD Countries" *Quarterly Review of Economics and Finance* **38**(2), 181–191.

Thomson Reuters (2021) *Thomson Reuters Datastream*. Accessed on 16 February 2021, from https://eikon.thomsonreuters.com/index.html.

Yaya, O.S., Ogbonna, A.E. and R. Mudida (2019) "Hysteresis of Unemployment Rates in Africa: New Findings from Fourier ADF Test" *Quality and Quantity* **53**(6), 2781–2795.

Yaya, O.Y, Ogbonna, A.E., Furuoka, F. and L. Gil-Alana (2021) "New Unit Root Test for Unemployment Hysteresis Based on the Autoregressive Neural Network" *Oxford Bulletin of Economics and Statistics*. doi: 10.1111/obes.12422.

Zellner, A. (1962) "An Efficient Method of Estimating Seemingly Unrelated Regression Equations and Tests for Aggregation Bias" *Journal of the American Statistical Association* **57**, 348–368.