Supplementary information

MULTIDIMENSIONAL HOUSE PRICE PREDICTION WITH SOTA RNNs

Yasin KÜTÜK

International Journal of Strategic Property Management
https://doi.org/10.3846/ijspm.2024.22661

1. Unit root tests

Table S1. ADF unit root test results

Variables	Model: Intercept							Model: Trend & Intercept						
	Level			First difference			Result	Level			First difference			Result
	ADF test statistics	*P*-value	Lag(s)	ADF test statistics	*P*-value	Lag(s)		ADF test statistics	*P*-value	Lag(s)	ADF test statistics	*P*-value	Lag(s)	
lnbist100	–2.34	0.16	0	–14.97	0.00	0	I (1)**	–3.00	0.14	0	–15.03	0.00	0	I (1)**
lnbpkm2	–3.32	0.02	2	–15.31	0.00	1	I (0)*	–2.94	0.15	2	–15.44	0.00	1	I (1)**
lncpi	1.68	1.00	1	–10.67	0.00	0	I (1)**	–0.18	0.99	1	–10.85	0.00	0	I (1)**
lnrealgdp	–0.80	0.82	13	–2.53	0.11	14	I (2)**	–2.11	0.53	13	–2.56	0.30	14	I (2)**
growthrate	–3.67	0.01	13	–3.99	0.00	14	I (0)**	–3.57	0.03	13	–3.97	0.01	14	I (0)*
lnhomeownershiprate	–2.60	0.09	12	–0.15	0.94	10	I (2)**	–2.84	0.18	12	0.49	1.00	10	I (2)**
lnhouseholddebttogdp	–3.45	0.01	12	–2.10	0.25	11	I (0)*	–4.03	0.01	13	–2.18	0.50	11	I (0)**
lnipi	–1.00	0.75	2	–17.15	0.00	1	I (1)**	–2.34	0.41	2	–17.12	0.00	1	I (1)**
lnpricetorent	–3.48	0.01	1	–4.01	0.00	0	I (0)**	–4.44	0.00	1	–5.13	0.00	0	I (0)**
lnrealconstructioncosts	–1.66	0.45	1	–9.43	0.00	0	I (1)**	–1.67	0.76	1	–9.44	0.00	0	I (1)**
lnrealgoldtry	–0.47	0.89	2	–10.45	0.00	1	I (1)**	–2.74	0.22	1	–10.44	0.00	1	I (1)**
lnrealgrossminimum-wage	–2.14	0.23	0	–15.04	0.00	0	I (1)**	–3.23	0.08	0	–15.05	0.00	0	I (1)**
lnrealhpi	–1.77	0.39	3	–3.52	0.01	2	I (1)**	–1.78	0.71	3	–3.51	0.04	2	I (1)*
lnrealrent	–2.65	0.08	3	–3.59	0.01	2	I (1)**	–2.53	0.31	3	–3.84	0.02	2	I (1)*
lnrealusdtry	–2.43	0.14	2	–10.69	0.00	1	I (1)**	–2.45	0.35	2	–11.09	0.00	1	I (1)**
lnunemployment	–2.36	0.16	4	–4.91	0.00	3	I (1)**	–2.90	0.17	4	–4.92	0.00	3	I (1)**
creditgrowthrate	–11.25	0.00	0	–10.22	0.00	5	I (0)**	–11.22	0.00	0	–10.21	0.00	5	I (0)**
lnrealcreditvolume	–0.70	0.84	3	–5.71	0.00	2	I (1)**	–1.28	0.89	3	–5.71	0.00	2	I (1)**
lnpricetoincome	–4.30	0.00	3	–7.14	0.00	6	I (0)**	–5.88	0.00	3	–6.87	0.00	6	I (0)**
lnxmgyo	–3.17	0.02	0	–13.37	0.00	0	I (0)*	–2.91	0.16	0	–13.44	0.00	0	I (1)**
lnyouthunemployment	–1.29	0.63	13	–3.61	0.01	14	I (1)**	–1.22	0.90	13	–3.60	0.03	14	I (1)**
mir	–5.31	0.00	2	–9.42	0.00	1	I (0)**	–4.80	0.00	2	–9.74	0.00	1	I (0)**
Model	Intercept							Trend & Intercept						
Level of significance		10%		5%		1%			10%		5%		1%	
Critical values	Level	–2.57		–2.88		–3.46		Level	–3.14		–3.43		–4.00	
	First difference	–2.57		–2.88		–3.46		First difference	–3.14		–3.43		–4.00	

Note: The null hypothesis is the existence of unit root that concludes the series are random walk for ADF test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. ADF critical values are due to MacKinnon (1996). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S2. Phillips-Perron unit root test results

Variables	Model: Intercept							Model: Trend & Intercept						
	Level			First difference			Result	Level			First difference			Result
	PP test statistics	*P*-value	Bandwidth	PP test statistics	*P*-value	Bandwidth		PP test statistics	*P*-value	Bandwidth	PP test statistics	*P*-value	Bandwidth	
lnbist100	–2.36	0.16	1	–14.95	0.00	2	I (1)**	–3.00	0.13	2	–15.03	0.00	1	I (1)**
lnbpkm2	–4.13	0.00	5	–28.40	0.00	11	I (0)**	–4.95	0.00	6	–32.26	0.00	14	I (0)**
lncpi	1.67	1.00	2	–10.70	0.00	1	I (1)**	0.18	1.00	2	–10.72	0.00	4	I (1)**
lnrealgdp	–1.44	0.56	3	–3.61	0.01	47	I (1)**	–2.40	0.38	3	–3.63	0.03	46	I (1)*
growthrate	–3.04	0.03	21	–3.68	0.01	57	I (0)*	–3.01	0.13	21	–3.64	0.03	57	I (1)**
lnhomeownershiprate	–1.31	0.63	9	–5.83	0.00	7	I (1)**	–2.43	0.36	9	–5.69	0.00	8	I (1)**
lnhouseholddebttogdp	–7.44	0.00	9	–2.55	0.10	5	I (0)**	–3.12	0.10	8	–4.02	0.01	5	I (1)**
lnipi	–0.91	0.78	9	–39.22	0.00	5	I (1)**	–8.98	0.00	9	–39.19	0.00	5	I (0)**
lnpricetorent	–2.82	0.06	10	–4.01	0.00	0	I (1)**	–3.49	0.04	9	–5.07	0.00	3	I (0)*
lnrealconstructioncosts	–1.51	0.53	5	–9.50	0.00	5	I (1)**	–1.50	0.83	4	–9.51	0.00	5	I (1)**
lnrealgoldtry	–0.34	0.92	2	–11.47	0.00	6	I (1)**	–2.65	0.26	1	–11.44	0.00	6	I (1)**
lnrealgrossminimum-wage	–2.12	0.24	5	–15.04	0.00	5	I (1)**	–3.27	0.07	6	–15.06	0.00	5	I (1)**
lnrealhpi	–1.31	0.63	10	–7.88	0.00	8	I (1)**	–1.33	0.88	10	–7.87	0.00	8	I (1)**
lnrealrent	–1.96	0.30	10	–7.56	0.00	8	I (1)**	–1.69	0.75	10	–7.96	0.00	8	I (1)**
lnrealusdtry	–2.45	0.13	0	–9.67	0.00	6	I (1)**	–2.43	0.36	4	–9.77	0.00	8	I (1)**
lnunemployment	–2.05	0.27	8	–9.75	0.00	7	I (1)**	–2.32	0.42	8	–9.73	0.00	7	I (1)**
creditgrowthrate	–11.82	0.00	7	–60.49	0.00	31	I (0)**	–11.79	0.00	7	–63.48	0.00	32	I (0)**
lnrealcreditvolume	–0.35	0.91	8	–11.53	0.00	6	I (1)**	–1.58	0.80	8	–11.50	0.00	6	I (1)**
lnpricetoincome	–4.03	0.00	8	–4.95	0.00	19	I (0)**	–4.98	0.00	5	–5.20	0.00	19	I (0)**
lnxmgyo	–3.18	0.02	5	–13.49	0.00	5	I (0)*	–3.06	0.12	5	–13.49	0.00	4	I (1)**
lnyouthunemployment	–1.12	0.71	0	–3.20	0.02	43	I (1)*	–1.78	0.71	1	–3.12	0.10	43	I (2)**
mir	–3.76	0.00	3	–8.86	0.00	8	I (0)**	–3.31	0.07	3	–8.92	0.00	10	I (1)**
Model	Intercept							Trend & Intercept						
Level of significance		10%		5%		1%			10%		5%		1%	
Critical values	Level	–2.57		–2.88		–3.46		Level	–3.14		–3.43		–4.00	
	First difference	–2.57		–2.88		–3.46		First difference	–3.14		–3.43		–4.00	

Note: The null hypothesis is the existence of unit root that concludes the series are stationary for PP test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. PP critical values are due to Phillips and Perron (1988). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S3. KPSS unit root test results

Variables	Model: Intercept					Model: Trend & Intercept				
	Level		First difference		Result	Level		First difference		Result
	LM test statistics	Bandwidth	LM test statistics	Bandwidth		LM test statistics	Bandwidth	LM test statistics	Bandwidth	
lnbist100	1.57	11	0.19	1	I (1)**	0.22	10	0.05	1	I (1)**
lnbpkm2	0.88	10	0.21	23	I (1)**	0.23	10	0.06	26	I (1)**
lncpi	1.79	11	0.40	4	I (1)**	0.23	11	0.19	2	I (2)**
lnrealgdp	1.76	11	0.14	2	I (1)**	0.09	11	0.07	3	I (0)**
growthrate	0.13	6	0.06	28	I (0)**	0.07	6	0.06	28	I (0)**
lnhomeownershiprate	0.74	11	0.22	9	I (1)**	0.22	11	0.08	9	I (1)**
lnhouseholddebttogdp	1.29	11	1.35	10	I (2)**	0.42	11	0.15	9	I (2)**
lnipi	1.74	11	0.04	9	I (1)**	0.12	10	0.04	9	I (0)**
lnpricetorent	0.38	11	1.03	10	I (0)**	0.38	11	0.30	10	I (2)**
lnrealconstructioncosts	0.23	11	0.14	4	I (0)**	0.24	11	0.07	4	I (1)**
lnrealgoldtry	1.61	11	0.09	2	I (1)**	0.20	11	0.08	2	I (1)**
lnrealgrossminimumwage	1.51	11	0.10	5	I (1)**	0.09	10	0.06	5	I (0)**
lnrealhpi	0.32	11	0.18	10	I (0)**	0.31	11	0.17	10	I (2)**
lnrealrent	0.14	11	0.30	10	I (0)**	0.12	11	0.14	10	I (0)**

End of Table S3

Variables	Model: Intercept					Model: Trend & Intercept				
	Level		First difference		Result	Level		First difference		Result
	LM test statistics	Bandwidth	LM test statistics	Bandwidth		LM test statistics	Bandwidth	LM test statistics	Bandwidth	
lnrealusdtry	0.43	11	0.54	1	I (0)**	0.43	11	0.04	5	I (1)**
lnunemployment	0.48	11	0.07	8	I (1)**	0.13	11	0.06	8	I (0)**
creditgrowthrate	0.28	8	0.16	48	I (0)**	0.28	8	0.14	49	I (1)**
lnrealcreditvolume	1.77	11	0.28	8	I (1)**	0.20	11	0.28	8	I (2)**
lnpricetoincome	0.30	10	0.62	8	I (0)**	0.21	10	0.17	8	I (2)**
lnxmgyo	0.84	11	0.19	5	I (1)**	0.12	11	0.07	5	I (0)**
lnyouthunemployment	0.15	11	0.11	1	I (0)**	0.15	11	0.05	2	I (1)**
mir	0.89	10	0.35	3	I (1)**	0.33	10	0.09	1	I (1)**
Model	Intercept					Trend & Intercept				
Level of significance	10%		5%		1%	10%		5%		1%
Critical values	0.35		0.44		0.74	0.12		0.15		0.22

Note: The null hypothesis is the series have no unit root that concludes the series are non-stationary for KPSS test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. KPSS critical values from Kwiatkowski et al. (1992). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S4. DF-GLS unit root test results

Variables	Model: Intercept					Model: Trend & Intercept				
	Level		First difference		Result	Level		First difference		Result
	DF-GLS test statistics	Lag(s)	DF-GLS test statistics	Lag(s)		DF-GLS test statistics	Lag(s)	DF-GLS test statistics	Lag(s)	
lnbist100	0.81	0	–8.01	1	I (1)**	–1.49	0	–14.73	0	I (1)**
lnbpkm2	–1.00	2	–0.17	9	I (2)**	–1.88	2	–1.86	9	I (2)**
lncpi	4.06	3	–2.63	2	I (0)**	–0.84	1	–4.04	2	I (1)**
lnrealgdp	2.10	13	–2.18	14	I (0)*	–1.60	13	–2.43	14	I (2)**
growthrate	–3.67	13	–3.64	14	I (0)**	–3.69	13	–3.64	14	I (0)**
lnhomeownershiprate	–2.63	11	–0.97	10	I (0)**	–3.17	11	–0.48	10	I (0)*
lnhouseholddebttogdp	–0.31	14	–2.33	11	I (1)**	–1.78	14	–2.39	11	I (2)**
lnipi	1.35	2	–0.29	11	I (2)**	–2.35	2	–2.23	11	I (2)**
lnpricetorent	–0.40	1	–2.09	1	I (1)*	–0.79	1	–2.53	1	I (2)**
lnrealconstructioncosts	–1.69	1	–9.21	0	I (1)**	–1.75	1	–9.47	0	I (1)**
lnrealgoldtry	0.40	1	–1.51	5	I (2)**	–2.15	1	–8.63	0	I (1)**
lnrealgrossminimumwage	0.51	0	–2.44	5	I (1)*	–1.98	0	–13.62	0	I (1)**
lnrealhpi	–1.46	3	–2.91	2	I (1)**	–1.67	3	–3.37	2	I (1)*
lnrealrent	–1.25	3	–2.15	2	I (1)*	–1.65	3	–2.78	2	I (2)**
lnrealusdtry	–0.55	2	–4.44	2	I (1)**	–0.57	2	–6.89	2	I (1)**
lnunemployment	–1.15	4	–3.89	3	I (1)**	–2.86	4	–4.76	3	I (1)**
creditgrowthrate	–2.60	2	–0.79	10	I (0)**	–4.03	2	–15.64	1	I (0)**
lnrealcreditvolume	1.43	3	–3.28	2	I (1)**	–1.16	3	–4.52	2	I (1)**
lnpricetoincome	–0.63	3	–1.02	6	I (2)**	–0.75	3	–3.04	6	I (1)*
lnxmgyo	0.01	0	–2.58	4	I (1)**	–1.23	0	–12.22	0	I (1)**
lnyouthunemployment	–1.36	13	–2.51	14	I (1)*	–1.41	13	–2.98	14	I (1)*
mir	–0.07	2	–9.27	1	I (1)**	–1.19	2	–9.39	1	I (1)**
Model	Intercept					Trend & Intercept				
Level of significance		10%	5%	1%			10%	5%	1%	
Critical values	Level	–1.62	–1.94	–2.58		Level	–2.64	–2.93	–3.46	
	First difference	–1.62	–1.94	–2.58		First difference	–2.64	–2.93	–3.46	

Note: The null hypothesis is the existence of unit root that concludes the series are random walk for DF-GLS test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. The DFGLS for the drift term (μ) follows the critical values of MacKinnon (1996) while the asymptotic distributions for the drift and deterministic trend are obtained from Elliot et al. (1996, Table I, pp. 825). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S5. ERS point optimal unit root test results

Variables	Model: Intercept					Model: Trend & Intercept				
	Level		First difference		Result	Level		First difference		Result
	ERS test statistics	*k*	ERS test statistics	*k*		ERS test statistics	*k*	ERS test statistics	*k*	
lnbist100	111.47	0	0.29	0	I (1)**	22.70	0	0.97	0	I (1)**
lnbpkm2	14.78	2	0.85	1	I (1)**	13.59	2	1.34	1	I (1)**
lncpi	2879.65	1	0.94	0	I (1)**	24.96	1	1.90	0	I (1)**
lnrealgdp	703.17	13	4.20	14	I (2)**	14.66	13	13.41	14	I (2)**
growthrate	0.26	13	2.09	14	I (0)**	0.93	13	7.31	14	I (0)**
lnhomeownershiprate	0.06	12	101.45	10	I (0)**	0.27	12	139.10	10	I (0)**
lnhouseholddebttogdp	1955.30	12	14.63	11	I (2)**	3718.41	13	29.73	11	I (2)**
lnipi	133.38	2	2.05	1	I (1)*	12.26	2	2.55	1	I (1)**
lnpricetorent	96.36	1	2.56	0	I (1)*	355.58	1	6.46	0	I (2)**
lnrealconstructioncosts	4.07	1	0.30	0	I (1)**	13.26	1	1.05	0	I (1)**
lnrealgoldtry	49.84	2	0.74	1	I (1)**	10.54	1	1.13	1	I (1)**
lnrealgrossminimumwage	62.35	0	0.35	0	I (1)**	13.88	0	1.03	0	I (1)**
lnrealhpi	5.20	3	1.69	2	I (1)**	15.06	3	4.94	2	I (1)*
lnrealrent	9.13	3	3.01	2	I (1)*	19.24	3	6.70	2	I (2)**
lnrealusdtry	41.75	2	0.29	1	I (1)**	69.80	2	0.60	1	I (1)**
lnunemployment	7.28	4	1.00	3	I (1)**	5.23	4	2.99	3	I (0)*
creditgrowthrate	0.80	0	8.73	5	I (0)**	1.37	0	28.70	5	I (0)**
lnrealcreditvolume	290.55	3	1.26	2	I (1)**	29.79	3	2.75	2	I (1)**
lnpricetoincome	43.07	3	12.02	6	I (2)**	122.13	3	9.92	6	I (2)**
lnxmgyo	56.30	0	0.42	0	I (1)**	32.47	0	1.13	0	I (1)**
lnyouthunemployment	6.52	13	0.04	14	I (1)**	24.32	13	0.01	14	I (1)**
mir	80.69	2	0.22	1	I (1)**	51.26	2	0.79	1	I (1)**
Model	Intercept					Trend & Intercept				
Level of significance		10%	5%	1%			10%	5%	1%	
Critical values	Level	4.33	3.17	1.94		Level	6.87	5.65	4.05	
	First difference	4.33	3.17	1.94		First difference	6.87	5.65	4.05	

Note: The null hypothesis is the existence of unit root against the (trend-) stationary alternative for the ERS point optimal test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. k denotes the lag length for the HACC corrected long-run variance using OLS spectral autoregression and it is chosen using Schwarz' information criteria for each case (with a maximum of 14 lags). The ERS critical values from Elliott et al. (1996). Stationarity values of the variables were determined according to 5% significance level.

Table S6. Ng-Perron modified unit root test results

Variables	Model: Intercept											Model: Trend & Intercept										
	Level					First difference					Result	Level					First difference					Result
	MZa	MZt	MSB	MPT	*k*	MZa	MZt	MSB	MPT	*k*		MZa	MZt	MSB	MPT	*k*	MZa	MZt	MSB	MPT	*k*	
lnbist100	0.74	0.86	1.16	87.24	0	–64.88	–5.69	0.09	0.38	1	I (1)**	–4.59	–1.45	0.32	19.41	0	–100.84	–7.09	0.07	0.95	0	I (1)**
lnbpkm2	–1.81	–0.90	0.50	12.85	2	–0.01	–0.01	1.60	132.47	9	I (2)**	–7.25	–1.77	0.24	12.82	2	–0.17	–0.17	1.03	203.08	9	I (2)**
lncpi	1.99	6.41	3.23	805.86	3	–12.68	–2.51	0.20	1.95	2	I (1)*	–2.90	–0.87	0.30	23.32	1	–26.47	–3.61	0.14	3.60	2	I (1)**
lnrealgdp	1.28	2.58	2.01	277.69	13	–3.35	–1.29	0.38	7.31	14	I (2)**	–5.42	–1.57	0.29	16.58	13	–4.79	–1.55	0.32	19.02	14	I (2)**
growthrate	–94.16	–6.86	0.07	0.26	13	–273.32	–11.67	0.00	0.00	14	I (0)**	–103.37	–7.19	0.07	0.89	13	–470.86	–153.44	0.00	0.00	14	I (0)**
lnhomeownershiprate	–174.71	–9.34	0.05	0.14	11	–0.11	–0.13	1.25	81.28	10	I (0)**	–52.96	–5.14	0.10	1.77	11	–0.70	–0.39	0.56	65.05	10	I (0)**
lnhouseholddebttogdp	0.33	0.47	1.44	117.78	14	–1.75	–0.92	0.53	13.87	11	I (2)**	–5.35	–1.49	0.28	16.59	14	–2.05	–0.98	0.48	42.28	11	I (2)**
lnipi	1.32	1.63	1.23	109.59	2	0.48	1.19	2.49	351.86	11	I (2)**	–7.55	–1.94	0.26	12.06	2	–0.20	–0.27	1.35	334.30	11	I (2)**
lnpricetorent	–0.43	–0.38	0.88	39.86	1	–8.78	–2.04	0.23	3.02	1	I (1)*	–1.09	–0.63	0.57	64.21	1	–12.28	–2.47	0.20	7.44	1	I (2)**
lnrealconstructioncosts	–6.83	–1.71	0.25	4.07	1	–84.30	–6.49	0.08	0.29	0	I (1)**	–6.99	–1.77	0.25	13.18	1	–86.21	–6.56	0.08	1.06	0	I (1)**
lnrealgoldtry	0.68	0.45	0.66	32.18	1	–4.23	–1.39	0.33	5.90	5	I (2)**	–9.36	–2.15	0.23	9.80	1	–79.70	–6.31	0.08	1.16	0	I (1)**
lnrealgrossminimumwage	0.63	0.54	0.86	49.41	0	–6.37	–1.78	0.28	3.87	5	I (2)**	–7.54	–1.93	0.26	12.12	0	–100.82	–7.10	0.07	0.91	0	I (1)**
lnrealhpi	–5.26	–1.58	0.30	4.78	3	–14.47	–2.69	0.19	1.70	2	I (1)**	–6.17	–1.75	0.28	14.77	3	–18.50	–3.03	0.16	4.99	2	I (1)*
lnrealrent	–3.25	–1.27	0.39	7.53	3	–8.49	–2.04	0.24	2.97	2	I (1)*	–7.23	–1.80	0.25	12.79	3	–13.35	–2.58	0.19	6.86	2	I (2)**
lnrealusdtry	–0.66	–0.54	0.82	34.07	2	–31.69	–3.97	0.13	0.82	2	I (1)**	–1.12	–0.57	0.51	53.35	2	–75.50	–6.14	0.08	1.22	2	I (1)**
lnunemployment	–3.44	–1.06	0.31	7.07	4	–19.37	–3.11	0.16	1.27	3	I (1)**	–16.83	–2.89	0.17	5.48	4	–29.34	–3.81	0.13	3.23	3	I (1)**
creditgrowthrate	–11.89	–2.38	0.20	2.28	2	–0.22	–0.32	1.45	103.91	10	I (0)*	–24.31	–3.49	0.14	3.75	2	–156.80	–8.85	0.06	0.59	1	I (0)**
lnrealcreditvolume	1.03	1.57	1.52	153.62	3	–17.33	–2.91	0.17	1.54	2	I (1)**	–3.03	–1.16	0.38	28.40	3	–28.81	–3.79	0.13	3.16	2	I (1)**
lnpricetoincome	–0.88	–0.63	0.72	25.83	3	–0.65	–0.38	0.59	20.91	6	I (2)**	–2.05	–0.85	0.41	35.51	3	–5.12	–1.59	0.31	17.75	6	I (2)**
lnxmgyo	0.04	0.04	0.85	42.99	0	–9.14	–2.13	0.23	2.69	4	I (1)*	–3.16	–1.20	0.38	27.51	0	–98.88	–7.01	0.07	1.01	0	I (1)**

Variables	Model: Intercept											Model: Trend & Intercept										
	Level					First difference					Result	Level					First difference					Result
	MZa	MZt	MSB	MPT	*k*	MZa	MZt	MSB	MPT	*k*		MZa	MZt	MSB	MPT	*k*	MZa	MZt	MSB	MPT	*k*	
lnyouthunemployment	–3.79	–1.22	0.32	6.57	13	–5.55	–1.52	0.27	4.83	14	I (2)**	–3.90	–1.28	0.33	21.93	13	–13.33	–2.55	0.19	7.03	14	I (2)**
mir	0.07	0.06	0.92	49.28	2	–112.36	–7.50	0.07	0.22	1	I (1)**	–2.35	–1.01	0.43	35.67	2	–114.08	–7.55	0.07	0.80	1	I (1)**
Model	Intercept											Trend & Intercept										
Level of significance	MZa		MZt		MSB		MPT					MZa		MZt		MSB		MPT				
1%	–13.80		–2.58		0.17		1.78					–23.80		–3.42		0.143		4.03				
5%	–8.10		–1.98		0.23		3.17					–17.30		–2.91		0.17		5.48				
10%	–5.70		–1.62		0.28		4.45					–14.20		–2.62		0.19		6.67				

Note: The null hypothesis is the existence of unit root for the NG-Perron modified unit root test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. *k* denotes the lag length using the GLS-detrended spectral autoregression and it is chosen using Schwarz' information criteria for each case (with a maximum of 14 lags). The critical values are from Ng and Perron (2001). Stationarity values of the variables were determined according to 5% significance level.

Table S7a. Zivot-Andrews unit root test results for the ıntercept model

Variables	Level				First difference				Result
	Lag(s)	λ	Test statistics	T_b	Lag(s)	λ	Test statistics	T_b	
lnbist100	0	0.4	–3.31	2009M04	0	0.2	–15.34	2006M03	I (1)**
lnbpkm2	2	0.9	–3.90	2017M06	1	0.5	–15.52	2011M04	I (0)*
lncpi	4	0.9	–1.74	2017M06	3	0.8	–8.01	2016M12	I (1)**
lnrealgdp	4	0.5	–3.57	2012M02	4	0.4	–4.20	2010M03	I (1)*
growthrate	2	0.2	–8.16	2005M09	4	0.6	–10.32	2012M05	I (0)**
lnhomeownershiprate	4	0.8	–2.04	2016M02	4	0.5	–4.12	2011M02	I (1)*
lnhouseholddebttogdp	3	0.3	–5.65	2008M11	4	0.2	–5.53	2006M05	I (0)**
lnipi	2	0.3	–3.46	2008M04	1	0.4	–17.76	2009M04	I (1)**
lnpricetorent	4	0.2	–4.22	2006M07	4	0.3	–4.65	2007M06	I (0)*
lnrealconstructioncosts	4	0.3	–3.58	2008M07	3	0.3	–8.23	2008M07	I (1)**
lnrealgoldtry	2	0.6	–4.52	2013M04	1	0.5	–11.20	2011M10	I (0)**
lnrealgrossminimumwage	4	0.8	–4.94	2016M03	0	0.8	–15.19	2015M12	I (0)**
lnrealhpi	3	0.3	–3.02	2007M08	2	0.4	–4.57	2010M03	I (1)**
lnrealrent	3	0.6	–3.18	2013M07	2	0.5	–4.89	2011M06	I (1)**
lnrealusdtry	4	0.2	–3.67	2006M07	3	0.3	–8.18	2008M09	I (1)**
lnunemployment	4	0.5	–4.67	2010M09	3	0.4	–5.65	2009M05	I (0)**
creditgrowthrate	0	0.2	–14.11	2006M03	4	0.2	–11.65	2005M11	I (0)**
lnrealcreditvolume	3	0.2	–2.01	2006M07	2	0.4	–7.33	2009M04	I (1)**
lnpricetoincome	4	0.9	–7.22	2018M10	4	0.5	–4.44	2012M02	I (0)**
lnxmgyo	1	0.4	–3.22	2009M07	0	0.4	–13.48	2008M12	I (1)**
lnyouthunemployment	4	0.5	–4.30	2010M11	3	0.4	–6.30	2009M05	I (0)*
mir	2	0.4	–4.66	2008M12	1	0.2	–9.52	2005M08	I (0)**
Level of significance	10%			5%			1%		
Critical values									
λ = 0.1	–3.40			–3.68			–4.30		
λ = 0.2	–3.47			–3.77			–4.39		
λ = 0.3	–3.46			–3.76			–4.39		
λ = 0.4	–3.44			–3.72			–4.34		
λ = 0.5	–3.46			–3.76			–4.32		
λ = 0.6	–3.47			–3.76			–4.45		
λ = 0.7	–3.51			–3.80			–4.42		
λ = 0.8	–3.46			–3.75			–4.33		
λ = 0.9	–3.38			–3.69			–4.27		

Note: The null hypothesis is the existence of unit root that concludes the series are random walk for ADF test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. Critical values are due to Zivot and Andrews (2002). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S7b. Zivot-Andrews unit root test results for the trend model

Variables	Level				First difference				Result
	Lag(s)	λ	Test statistics	T_b	Lag(s)	λ	Test statistics	T_b	
lnbist100	0	0.2	–3.81	2005M08	0	0.3	–15.13	2008M02	I (0)*
lnbpkm2	2	0.9	–5.24	2017M06	1	0.2	–15.47	2006M02	I (0)**
lncpi	4	0.8	–4.16	2016M12	3	0.7	–7.68	2015M07	I (0)*
lnrealgdp	4	0.8	–3.03	2017M01	4	0.3	–2.69	2007M10	I (2)**
growthrate	2	0.3	–8.01	2008M02	4	0.2	–10.15	2005M11	I (0)**
lnhomeownershiprate	4	0.7	–3.34	2015M03	4	0.6	–2.69	2013M03	I (2)**
lnhouseholddebttogdp	3	0.6	–4.80	2013M03	4	0.2	–6.24	2006M10	I (0)**
lnipi	2	0.4	–2.75	2009M01	1	0.3	–17.12	2008M07	I (1)**
lnpricetorent	4	0.2	–4.06	2006M08	4	0.4	–4.80	2010M03	I (0)*
lnrealconstructioncosts	4	0.7	–3.08	2015M03	3	0.4	–7.44	2009M03	I (1)**
lnrealgoldtry	2	0.5	–3.24	2011M03	1	0.2	–10.57	2006M01	I (1)**
lnrealgrossminimumwage	4	0.6	–4.39	2013M12	0	0.2	–15.25	2006M04	I (0)*
lnrealhpi	3	0.3	–2.52	2008M06	2	0.7	–4.01	2015M01	I (1)*
lnrealrent	3	0.8	–2.68	2016M04	2	0.3	–4.35	2008M02	I (1)*
lnrealusdtry	4	0.5	–3.77	2010M10	3	0.8	–8.04	2017M01	I (1)**
lnunemployment	4	0.6	–3.18	2013M10	3	0.5	–4.87	2010M12	I (1)**
creditgrowthrate	0	0.3	–13.67	2007M12	4	0.8	–11.59	2017M05	I (0)**
lnrealcreditvolume	3	0.6	–3.84	2013M11	2	0.3	–7.11	2007M05	I (1)**
lnpricetoincome	4	0.9	–7.02	2017M06	4	0.2	–5.03	2005M11	I (0)**
lnxmgyo	1	0.2	–2.96	2005M08	0	0.3	–13.24	2008M02	I (1)**
lnyouthunemployment	4	0.7	–3.45	2015M08	3	0.5	–5.55	2011M03	I (1)**
mir	2	0.6	–4.30	2012M11	1	0.2	–9.52	2006M07	I (0)*
Level of significance	10%			5%			1%		
Critical values									
λ = 0.1	–3.36			–3.65			–4.27		
λ = 0.2	–3.49			–3.80			–4.41		
λ = 0.3	–3.58			–3.87			–4.51		
λ = 0.4	–3.66			–3.94			–4.55		
λ = 0.5	–3.68			–3.96			–4.56		
λ = 0.6	–3.66			–3.95			–4.57		
λ = 0.7	–3.57			–3.85			–4.51		
λ = 0.8	–3.50			–3.82			–4.38		
λ = 0.9	–3.35			–3.68			–4.26		

Note: The null hypothesis is the existence of unit root that concludes the series are random walk for ADF test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. Critical values are due to Zivot and Andrews (2002). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

Table S7c. Zivot-Andrews unit root test results for the trend & ıntercept model

Variables	Level				First difference				Result
	Lag(s)	λ	Test statistics	T_b	Lag(s)	λ	Test statistics	T_b	
lnbist100	0	0.3	–3.88	2007M11	0	0.4	–15.66	2009M03	I (1)**
lnbpkm2	2	0.8	–5.22	2017M03	1	0.4	–15.55	2009M01	I (0)**
lncpi	4	0.8	–4.09	2016M08	3	0.8	–7.96	2016M12	I (0)*
lnrealgdp	4	0.5	–3.51	2012M02	4	0.4	–5.04	2010M03	I (1)**
growthrate	2	0.5	–8.18	2011M11	4	0.6	–10.29	2012M05	I (0)**
lnhomeownershiprate	4	0.6	–5.40	2013M02	4	0.5	–4.21	2011M02	I (0)**
lnhouseholddebttogdp	3	0.9	–4.97	2017M06	4	0.2	–6.27	2006M05	I (0)**
lnipi	2	0.3	–3.44	2008M04	1	0.4	–18.06	2009M02	I (1)**
lnpricetorent	4	0.2	–5.07	2006M07	4	0.4	–5.11	2008M12	I (0)**
lnrealconstructioncosts	4	0.3	–3.78	2008M07	3	0.3	–8.24	2008M07	I (1)**
lnrealgoldtry	2	0.6	–4.59	2013M01	1	0.5	–11.17	2011M10	I (0)*
lnrealgrossminimumwage	4	0.8	–5.42	2016M03	0	0.2	–15.22	2006M10	I (0)**
lnrealhpi	3	0.3	–3.04	2007M08	2	0.4	–4.78	2009M04	I (1)**
lnrealrent	3	0.7	–3.28	2014M04	2	0.4	–5.23	2010M03	I (1)**

End of Table S7c

Variables	Level				First difference				Result
	Lag(s)	λ	Test statistics	T_b	Lag(s)	λ	Test statistics	T_b	
lnrealusdtry	4	0.4	–3.76	2010M07	3	0.3	–8.14	2008M09	I (1)**
lnunemployment	4	0.5	–4.66	2010M09	3	0.4	–5.68	2009M05	I (0)*
creditgrowthrate	0	0.2	–14.14	2006M02	4	0.8	–11.79	2016M09	I (0)**
lnrealcreditvolume	3	0.6	–3.76	2013M10	2	0.4	–7.31	2009M04	I (1)**
lnpricetoincome	4	0.8	–7.63	2017M04	4	0.2	–5.63	2005M11	I (0)**
lnxmgyo	1	0.2	–3.35	2006M03	0	0.4	–13.98	2008M12	I (1)**
lnyouthunemployment	4	0.5	–4.41	2011M07	3	0.4	–6.42	2009M05	I (0)*
mir	2	0.6	–4.33	2013M07	1	0.2	–9.60	2006M10	I (0)*
Level of significance	10%			5%			1%		
Critical values									
λ = 0.1	–3.45			–3.75			–4.38		
λ = 0.2	–3.66			–3.99			–4.65		
λ = 0.3	–3.87			–4.17			–4.78		
λ = 0.4	–3.95			–4.22			–4.81		
λ = 0.5	–3.96			–4.24			–4.90		
λ = 0.6	–3.95			–4.24			–4.88		
λ = 0.7	–3.86			–4.18			–4.75		
λ = 0.8	–3.69			–4.04			–4.70		
λ = 0.9	–3.46			–3.80			4.41		

Note: The null hypothesis is the existence of unit root that concludes the series are random walk for ADF test. In the tables, superscripts **, * denote the rejection of the null hypothesis at 1%, and 5% significance levels, respectively. Critical values are due to Zivot and Andrews (2002). Three lag selection information criteria are performed in order to confirm the results in this study, namely Akaike Information Criterion (AIC), Schwarz Information Criterion (SIC), and Hannan-Quinn Information Criterion (HQIC). Stationarity values of the variables were determined according to 5% significance level.

2. Summary of unit root tests

Table S8. Evaluation of the unit root tests

Variables	ADF unit root tests		PP unit root tests		KPSS unit root tests		DF-GLS unit root tests	
	Model: Intercept	Model: Trend & Intercept	Model: Intercept	Model: Trend & Intercept	Model: Intercept	Model: Trend & Intercept	Model: Intercept	Model: Trend & Intercept
lnbist100	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)
lnbpkm2	I (0)	I (1)	I (0)	I (0)	I (1)	I (1)	I (2)	I (2)
lncpi	I (1)	I (1)	I (1)	I (1)	I (1)	I (2)	I (0)	I (1)
lnrealgdp	I (2)	I (2)	I (1)	I (1)	I (1)	I (0)	I (0)	I (2)
growthrate	I (0)	I (0)	I (0)	I (1)	I (0)	I (0)	I (0)	I (0)
lnhomeownershiprate	I (2)	I (2)	I (1)	I (1)	I (1)	I (1)	I (0)	I (0)
lnhouseholddebttogdp	I (0)	I (0)	I (0)	I (1)	I (2)	I (2)	I (1)	I (2)
lnipi	I (1)	I (1)	I (1)	I (0)	I (1)	I (0)	I (2)	I (2)
lnpricetorent	I (0)	I (0)	I (1)	I (0)	I (0)	I (2)	I (1)	I (2)
lnrealconstructioncosts	I (1)	I (1)	I (1)	I (1)	I (0)	I (1)	I (1)	I (1)
lnrealgoldtry	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (2)	I (1)
lnrealgrossminimumwage	I (1)	I (1)	I (1)	I (1)	I (1)	I (0)	I (1)	I (1)
lnrealhpi	I (1)	I (1)	I (1)	I (1)	I (0)	I (2)	I (1)	I (1)
lnrealrent	I (1)	I (1)	I (1)	I (1)	I (0)	I (0)	I (1)	I (2)
lnrealusdtry	I (1)	I (1)	I (1)	I (1)	I (0)	I (1)	I (1)	I (1)
lnunemployment	I (1)	I (1)	I (1)	I (1)	I (1)	I (0)	I (1)	I (1)
creditgrowthrate	I (0)	I (0)	I (0)	I (0)	I (0)	I (1)	I (0)	I (0)
lnrealcreditvolume	I (1)	I (1)	I (1)	I (1)	I (1)	I (2)	I (1)	I (1)
lnpricetoincome	I (0)	I (0)	I (0)	I (0)	I (0)	I (2)	I (2)	I (1)
lnxmgyo	I (0)	I (1)	I (0)	I (1)	I (1)	I (0)	I (1)	I (1)
lnyouthunemployment	I (1)	I (1)	I (1)	I (2)	I (0)	I (1)	I (1)	I (1)
mir	I (0)	I (0)	I (0)	I (1)	I (1)	I (1)	I (1)	I (1)

End of Table S8

Variables	ERS point optimal unit root tests		Ng-Perron modified unit root tests		Zivot-Andrews unit root tests			I (0)	I (1)	I (2)	Result
	Model: Intercept	Model: Trend & Intercept	Model: Intercept	Model: Trend & Intercept	Model: Intercept	Model: Trend	Model: Trend & Intercept				
lnbist100	I (1)	I (1)	I (1)	I (1)	I (1)	I (0)	I (1)	1	14	0	I (1)
lnbpkm2	I (1)	I (1)	I (2)	I (2)	I (0)	I (0)	I (0)	6	5	4	I (0)
lncpi	I (1)	I (1)	I (1)	I (1)	I (1)	I (0)	I (0)	3	11	1	I (1)
lnrealgdp	I (2)	I (2)	I (2)	I (2)	I (1)	I (2)	I (1)	2	5	8	I (2)
growthrate	I (0)	I (0)	I (0)	I (0)	I (0)	I (0)	I (0)	14	1	0	I (0)
lnhomeownershiprate	I (0)	I (0)	I (0)	I (0)	I (1)	I (2)	I (0)	7	5	3	I (0)
lnhouseholddebttogdp	I (2)	I (2)	I (2)	I (2)	I (0)	I (0)	I (0)	6	2	7	I (2)
lnipi	I (1)	I (1)	I (2)	I (2)	I (1)	I (1)	I (1)	2	9	4	I (1)
lnpricetorent	I (1)	I (2)	I (1)	I (2)	I (0)	I (0)	I (0)	7	4	4	I (0)
lnrealconstructioncosts	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	1	14	0	I (1)
lnrealgoldtry	I (1)	I (1)	I (2)	I (1)	I (0)	I (1)	I (0)	2	11	2	I (1)
lnrealgrossminimumwage	I (1)	I (1)	I (2)	I (1)	I (0)	I (0)	I (0)	4	10	1	I (1)
lnrealhpi	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	1	13	1	I (1)
lnrealrent	I (1)	I (2)	I (1)	I (2)	I (1)	I (1)	I (1)	2	10	3	I (1)
lnrealusdtry	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	1	14	0	I (1)
lnunemployment	I (1)	I (0)	I (1)	I (1)	I (0)	I (1)	I (0)	4	11	0	I (1)
creditgrowthrate	I (0)	I (0)	I (0)	I (0)	I (0)	I (0)	I (0)	14	1	0	I (0)
lnrealcreditvolume	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	0	14	1	I (1)
lnpricetoincome	I (2)	I (2)	I (2)	I (2)	I (0)	I (0)	I (0)	8	1	6	I (0)
lnxmgyo	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	I (1)	3	12	0	I (1)
lnyouthunemployment	I (1)	I (1)	I (2)	I (2)	I (0)	I (1)	I (0)	3	9	3	I (1)
mir	I (1)	I (1)	I (1)	I (1)	I (0)	I (0)	I (0)	6	9	0	I (1)

3. Comparison of the results

Table S9. A comparison of NARDL and RNN results

Model	MSE	MAE
3-M-GRU-2-L	***0.00002***	0.003833
3-M-LSTM-4-L	0.000027	***0.003798***
3-M-NARDL	0.731512	0.616502
6-M-RNN-4-L	***0.000027***	***0.004562***
6-M-NARDL	0.733928	0.617281
9-M-LSTM-2-L	***0.000085***	***0.008108***
9-M-NARDL	0.725424	0.601415
12-M-RNN-3-L	***0.000185***	***0.010086***
12-M-NARDL	0.729208	0.605129

Note: MSE and MAE denote mean squared error and mean average error, respectively. The table presents the RNN models with the lowest MSE and MAE, and compares the model outcome to NARDL model forecasting results.