EJE EUROPEAN JOURNAL OF ECONOMICS

ISSN: 2669-2384
VOLUME 2, ISSUE 2

Change, Persistence and Convergence in NATO Member Defense Spending

T. Daniel Coggin

Florence, SC, USA
dcoggin1948@gmail.com

ABSTRACT

This study presents an analysis and quantitative summary of 18 NATO member country defense spending over the period 1953-2020. Using recently developed econometric techniques, we explore the time series properties of change, persistence and convergence in two indicators of NATO defense spending data typically used in the literature: real (2019) US dollars and Percent of GDP. Our two indicator variables display a *mix* of positive, negative and zero trends over the sample period. The *only* NATO countries with ≥ 2% defense spending after the 2006 and 2014 Summits are: Greece, Turkey, UK, USA and Poland. Using the *fractional* difference-based persistence tests of Martins and Rodrigues, we find only UK, Hungary and Poland dollar Defense Spending reject the null of a *constant* fractional difference (unit root) for the entire sample period; while seven NATO members reject the null of a *constant* fractional difference (unit root) for Percent of GDP. The mixed set of positive, negative and zero trends render the popular *relative convergence* test of Phillips and Sul inappropriate for our data. Using the more appropriate *weak sigma-convergence* test of Kong, Phillips and Sul, we find mixed evidence for convergence of our indicator variables. Our quantitative results present a mixed picture of statistical consistency and coherence for NATO defense spending. Our tests of persistence suggest major changes in the defense policies and spending of NATO members will have a *lasting* effect in most cases. The emergence and growth of serious threats and potential threats from Russia (and now potentially China as well) will require the NATO allies to address these issues.

Keywords: NATO, Defense Spending, Persistence, Convergence, Weak Sigma-Convergence, Two Percent Guideline

Cite this article as: Coggin, T. D. (2022). Change, Persistence and Convergence in NATO Member Defense Spending. *European Journal of Economics*, *2*(2), 51-65. https://doi.org/10.33422/eje.v2i2.253

1. Introduction and Background

The April 2022 *SPIRI Fact Sheet* reported, "In 2021 world military expenditure surpassed the two trillion US dollar mark for the first time, reaching $2113 billion in 2020 $US. Global spending in 2021 was 0.7 per cent higher than in 2020 and 12 per cent higher than in 2012" (Lopes Da Silva, *et al.*, 2022). By comparison, NATO (North Atlantic Treaty Organization) defense spending was estimated to be $1.2 trillion in 2021 (*Investment Watch*, 2021). We note that we will use the terms "defense spending" and "military spending" interchangeably in this study. NATO was founded in the aftermath of the Second World War to secure peace in Europe, to promote cooperation among its members and to guard their freedom, all of this in the context of countering the threat posed at the time by the Soviet Union (NATO, 2022). Since its formation in 1949, NATO has faced a number of challenges. In addition to its humanitarian and peacekeeping efforts, NATO has made major military interventions from 1990 in Kuwait through 2011 in Libya. The 2014 Russian annexation of Crimea and 2022 invasion of Ukraine have resurrected Russia as an ominous threat to future European security.

Wolkronowski (2018) defines defense expenditures as all current and capital expenditure on armed forces as well as military and civilian personnel, including pensions of military personnel and social services for staff, service and maintenance supply, military research and development and military assistance. Civil defense and current expenditure on previous military activities such as veteran benefits, demobilization, etc. are excluded. Dunne, *et al.* (2003) notes that there are a wide variety of models of the *demand* for military expenditure based on different theories about the decision-making process and the influence of various military, political and economic factors [see also Smith (1989), Dunne, *et al*. (2005) and Alozious (2022)]). This study does *not* focus on these important issues. This study also does *not* focus on the *determinants* of military expenditures [see Odehnal and Neubauer (2020)] or the relationship between defense spending and *economic growth* [see Gadea, *et al*. (2004), Utrero-Gonzalez, *et al*. (2019) and Santamaria, *et al*. (2021)].

The purpose of this study is to use state-of-the-art econometric methods to examine the *observed statistical time series properties* of NATO member states' defense spending from its inception to 2020. It will seek to determine if they are changing, persistent and converging. Our study is not the first to examine these issues. Amara (2007) used econometric unit root tests to examine the stability of key defense spending ratios and found mixed results. Using recent econometric methods Amara (2008) investigated the timing of *structural breaks* in NATO defense spending and found mixed evidence that they were coordinated across member countries. Blum and Potrafke (2020) found that NATO countries that have lower military spending to GDP growth rate and a large change in government are less likely to comply with the 2014 NATO goal of 2% of GDP military expenditure.

2. Data and Basic Statistics

2.1. Sample Countries

Our sample of countries includes 18 NATO member states. The time period covers the formation of NATO until 2020, the most recent data available. We did not include countries that joined after 1999 in order to have at least 20 years of time series data. This choice of time period is somewhat arbitrary, but is consistent with having enough time periods to observe and analyze change and persistence in the data. Iceland is a charter member but is omitted because it has no standing army and only a negligible defense budget. To add some perspective and context to our study, Table 1 presents our sample of 18 countries ranked by population and GDP in 2020, taken from the World Bank *DataBank*. The (rank) correlation between these ranks is 0.897.

Table 1.
Rank in 2020

	Population	**GDP**
USA	1	1
Turkey	2	9
Germany	3	2
France	4	4
UK	5	3
Italy	6	5
Spain	7	7
Canada	8	6
Poland	9	10
Netherland	10	8
Belgium	11	11
Denmark	12	13

Greece	13	16
Czech Republic	14	14
Portugal	15	15
Hungary	16	17
Norway	17	12
Luxembourg	18	18
Rank Correlation ($r_{Population,\ GDP}$) =	0.897	

Source: World Bank Data Bank. Population=Total Population; GDP=Current $US.

2.2. Indicator Variables

The focus of our study is on two versions of defense (military) spending that have been used in the prior literature: defense spending as a Percent of GDP and real (inflation-adjusted) Defense Spending in 2019 US dollars. Defense spending as a Percent of GDP can be viewed as a measure of *relative* defense spending, while dollar Defense Spending can be viewed as a measure of *absolute* defense spending. Both variables are taken from the *SPIRI* (Stockholm International Peace Research database, https://milex.sipri.org/sipri).

2.3. Basic Time Series Statistics

Table 2 presents descriptive statistics (means, standard deviations and sample periods) for our sample of indicator variables. Panel One presents data for dollar Defense Spending and Panel Two presents data for defense spending as Percent of GDP. We tried to obtain data from 1949-2020 to cover the period of the formation of NATO up to the present. As indicated in the first column of Table 2, no indicator variable had complete data available for all countries from 1949. We therefore picked the longest time period available with complete data for all countries: 1953 for Defense Spending and 1954 for Percent of GDP. Data for former Warsaw Pact members Hungary, Poland and Czech Republic begin in 1999, their first year in the NATO alliance. We also included two subperiods in Table 2: 2006-2020 and 2014-2020 to recognize the 2006 Riga Summit pledge to spend 2% of GDP annually on defense and the 2014 Wales Summit [see Dowdy (2017) for a discussion].

Table 2.
Descriptive Statistics for Defense Spending

Panel One. Real $US(x000)

	Belgium	Canada	Denmark	France	Germany	Greece	Italy	Luxembourg	Netherlands	Norway	Portugal	Spain	Turkey	UK	USA	Hungary	Poland	Czech Republic
1953-2020																		
Mean	5833	14430	3617	42164	43834	5046	22140	166	10152	3937	3269	12751	7293	52797	568216			
SD	1471.7	3325.4	715.5	8395.1	10865.4	2273.4	8115.6	97.7	1955	1523.3	987.8	5409.1	4936.9	6541.9	128740			
1953-2005																		
Mean	6079	13163	3499	40374	44328	4739	20497	130	10012	3362	3025	11516	5588	51235	516494			
SD	1574.3	2256.8	747.9	8669.2	12131.9	2361.3	8393.9	66.4	2138.4	1120	980.2	5484.3	3802.8	6348.6	88545.2			
2006-2020																		
Mean	4968	18908	4030	48489	42088	6132	27945	294	10647	5971	4128	17114	13316	58315	750968			
SD	359.9	2537.7	370.2	1775.3	3757	1550.6	2679	82.2	985.2	872.1	293	1462.3	3612.9	3639	65470.4			
2014-2020																		
Mean	4740	20571	4043	49461	44490	5142	25991	354	10482	6702	4050	16225	16055	55273	705024			
SD	274.2	2684.4	533.6	1615.6	4343.3	297.1	1837.1	84.2	1222.6	711.7	355.9	997.7	3715.1	1912.2	33455.9			
1999-2020																		
Mean																1515	8082	2671
SD																347.1	2230.0	451.0
1999-2005																		
Mean																1646	5782	3047
SD																195.8	416.9	227.3
2006-2020																		
Mean																1454	9156	2496
SD																389.5	1872	424.0
2014-2020																		
Mean																1616	10847	2469
SD																500.0	1306	453.2

[Panel Two continues below}

Panel Two. Percent of GDP

	Belgium	Canada	Denmark	France	Germany	Greece	Italy	Luxembourg	Netherlands	Norway	Portugal	Spain	Turkey*	UK	USA	Hungary	Poland	Czech Republic
1954-2020																		
Mean	2.305	2.171	2.020	3.154	2.454	3.897	2.008	0.965	2.449	2.609	3.023	1.789	3.285	5.865	5.865			
SD	1.031	1.324	0.601	1.259	1.109	1.056	0.561	0.537	1.095	0.803	1.348	0.554	0.773	2.273	2.273			
1954-2005																		
Mean	2.678	2.449	2.233	3.510	2.812	4.255	2.178	1.091	2.803	2.909	3.344	2.090	3.633	5.038	6.400			
SD	0.860	1.384	0.510	1.213	1.004	0.920	0.523	0.545	1.005	0.645	1.370	0.377	0.517	1.867	2.299			
2006-2020																		
Mean	1.013	1.208	1.284	1.920	1.215	2.658	1.421	0.527	1.270	1.569	1.911	1.309	2.219	2.270	4.011			
SD	0.105	0.127	0.105	0.078	0.072	0.233	0.109	0.100	0.099	0.172	0.129	0.081	0.298	0.239	0.587			
2014-2020																		
Mean	0.930	1.239	1.224	1.904	1.204	2.590	1.347	0.567	1.224	1.693	1.863	1.253	2.254	2.053	3.486			
St Dev	0.073	0.147	0.120	0.078	0.097	0.151	0.111	0.112	0.107	0.171	0.155	0.077	0.403	0.118	0.171			
1999-2020																		
Mean																1.238	1.911	1.367
SD																0.251	0.115	0.350
1999-2005																		
Mean																1.517	1.893	1.814
SD																2.160	0.086	0.033
2006-2020																		
Mean																1.108	1.920	1.159
SD																0.185	0.139	0.189
2014-2020																		
Mean																1.111	2.019	1.069
SD																0.255	0.124	0.146

Note: Turkey data from 1960; Hungary, Poland and Czech Republic data from 1999.

Our brief discussion of Table 2 will focus on comparing the *changes* in dollar Defense Spending and Percent of GDP. In Panel One for Defense Spending we see that every NATO country *increased* its real mean US dollar amount after the 2006 and 2014 Summits *except* Belgium, Germany, Hungary and Czech Republic., Panel Two shows that 13 of the 15 existing NATO members had a mean value ≥ 2% for Percent of GDP *before* the 2006 RIGA and 2014 Wales Summits (1954-2005). Only Luxembourg and Spain failed to meet that threshold. However, the only NATO countries with ≥ 2% of GDP defense spending *after* the 2006 and 2014 Summits are: Greece, Turkey, UK, USA and Poland.

Trends are also of interest in analyzing persistence and convergence. As will be discussed below, trends are central to the definition and measurement of convergence [see Sul (2019, Chapter 7) for a full discussion]. For this reason, we apply the time series regression test of Perron and Yabu (2009a) to the slopes of time trends that is valid whether the time is series is trend-stationary or has an autoregressive unit root. The test is the (standard normal) t-test on the trend in a time series regression of the individual indicator variable onto a constant term and a deterministic time trend. The complete details of the test are presented in Perron and Yabu (2009a). Table 3 presents the results of the t-tests on the slopes of the deterministic time trends for our two panels of defense spending indicators for the full periods of available data. The null hypothesis for these t-tests is that the slope of the time trend estimate (β in their notation) is zero. In column one of Table 3 we see the trend(β) t-statistics for ln (natural log) Real $US Defense Spending. Only five countries (Denmark, Italy, Norway, Turkey and Poland) have (positive) trend slopes significantly different from zero. In column two of Table 3 we see the t-statistics for Percent of GDP. The trend slopes for Percent of GDP are almost uniformly negative, with seven significantly so (Belgium, Denmark, France, Germany, Italy, Spain and UK).

Table 3.
Perron-Yabu (2009a) deterministic trend (β) t-stat

	1953-2020 lnReal $US(x000) t-stat	**1954-2020 % GDP t-stat**
Belgium	0.269	-2.82*
Canada	1.085	-1.773
Denmark	2.050*	-11.956*
France	1.498	-3.176*
Germany	1.469	-2.637*
Greece	1.424	-0.847
Italy	2.398*	-2.071*
Luxembourg	1.523	-1.494
Netherlands	1.830	-1.568
Norway	3.602*	-1.834
Portugal	1.672	-0.384
Spain	0.535	-2.087*
Turkey	3.504*	-0.250
UK	0.300	-2.483*
USA	0.501	-1.550
Hungary	0.521	0.236
Poland	29.746*	1.420
CzechRepublic	0.339	-1.024

H(0): β=0, two-sided test, standard normal.
*Reject H(0) at 0.05 level.
Turkey data from 1960; Hungary, Poland and Czech Republic data from 1999.

It is possible, indeed probable, that there might be structural changes, breaks or shifts in our time series data spanning over 60 years in most cases. In order to test this hypothesis, we use the trend (slope) break test of Perron and Yabu (2009b), who use the terms *shift* and *break*, and *trend* and *slope* interchangeably. Their model builds on Perron and Yabu (2009a) and tests for an unknown shift (break) in the trend of a time series with a stationary or and integrated noise component. The null hypothesis for this model is that there is *no* break in the slope of the time trend estimate (β in their notation). The null hypothesis is tested with a statistic they derive and label the W_{RQF}-statistic. The complete details of the test are presented in Perron and Yabu (2009b). The results of the Perron and Yabu (2009b) trend break tests are presented in Table 4. We note that with only 22 years of data, we chose not to test for a trend break (sharp structural change) in Hungary, Poland and Czech Republic. In column one of Table 4 we see that there are only two cases of a significant statistical break in the trends of Real $US Defense Spending: Greece (1978) and Italy (1991). In column two of Table 4 we see that there are four cases of a significant statistical break in the trends of Percent of GDP: Canada (1968), France (1971), Luxembourg (1965) and Netherlands (1965).

Table 4.
Perron-Yabu (2009b) trend break test

	1953-2020 lnReal $US(x000) W_{RQF}-stat	**Break Date**	**1954-2020 % GDP W_{RQF}-stat**	**Break Date**
Belgium	1.612		1.037	
Canada	1.829		33.88*	1968
Denmark	1.678		0.496	
France	1.434		3.147*	1971
Germany	1.707		0.115	
Greece	2.827*	1978	1.127	
Italy	2.436*	1991	1.382	
Luxembourg	0.807		3.776*	1965
Netherlands	1.281		17.596*	1965
Norway	0.232		1.893	
Portugal	1.947		0.518	
Spain	1.666		1.128	
Turkey	0.260		0.183	
UK	0.097		1.632	
USA	0.100		0.528	
Hungary	NA		NA	
Poland	NA		NA	
CzechRepublic	NA		NA	

H(0): No break in trend function.
*Reject H(0) at 0.05 level.
Turkey data from 1960.

3. Persistence and Some Tests

So far, we have examined basic statistics and the existence of trends and breaks in NATO member country defense spending. Another important property of time series data is *stationarity*. Stationarity implies the existence of a *constant mean* (and variance) in time series data. As more fully discussed in Phillips (2001) and Clark and Coggin (2011, 2018), if time series data are *not* (covariance) stationary the sample mean has *no* asymptotic limit. Thus, technically speaking, there is *no* "mean value" for a *nonstationary* time series. To put it another way, such a time series is called *persistent*. More precisely, we have a persistent time series process if the effect of a *shock* (i.e., a change or intervention) will influence the future predictions of the time series for a long time. Thus the longer the time of influence the longer the *memory* and the persistence. An I(1) process is an *integrated* time series requiring a first-difference to achieve stationarity, where the differencing or memory parameter d=1. We consider an I(1) process (i.e., a *unit root* process) as an example of highly persistent process where the information that comes from the shocks never dies out.

The important point for policy makers is shocks (i.e., major changes) to a highly persistent variable will likely have major and *lasting* effect. In order to test for the existence of persistence in the NATO data and possible changes, we use the recent tests of Kjriwal, Perron and Zhou (2013) and Martins and Rodrigues (2014). We note that with only 22 years of data, tests for changes in persistence in Hungary, Poland and Czech Republic should not be viewed as definitive.

3.1. Kjriwal, Perron and Zhou test

Kjriwal, Perron and Zhou (2013), hereafter KPZ, studied issues related to testing for multiple structural changes in the persistence of a univariate time series based on sup-Wald tests on the difference between the sum of squared residuals under the null hypothesis of a unit root and those under the alternative hypothesis that the process displays *changes* in persistence over the sample. The null hypothesis of KPZ is that the process has an autoregressive unit root against the alternative hypothesis that the process *alternates* between stationary and unit root regimes. Complete details are given in KPZ. We apply their *Udmax* test, which does not assume the location of the persistence break(s) are known. However, KPZ recommend performing a unit root test on the time series of interest *before* applying *Udmax* since the null hypothesis is that the process is I(1) *throughout* the sample. In results not reported here and consistent with prior research in this area [see Amara (2007) and Gadea, *et al*. (2004)], using DF-GLS unit root tests we found no rejections of the unit root hypothesis for the full sample period in our data except for UK Defense Spending (in 2019 US dollars). We therefore did not apply *Udmax* to those data. Panel One of Table 5 presents the results of the KPZ tests on our NATO data. In column one of Panel One of Table 5 we see *none* of the NATO member countries reject the full-sample unit root null for the dollar Defense Spending data. In column two of Panel One of Table 5 we see only two of the NATO member countries reject the unit root null for the Percent of GDP data: Belgium (break in 1985) and Portugal (break in 1972).

3.2. Martins and Rodrigues Test

Another recent test for a change in persistence is that by Martins and Rodrigues (2014), hereafter MR. This is a general test that is not restricted to the I(0)/I(/1) framework, and can identify *fractional* changes in d (the order of differencing to achieve stationarity) from $I(d_1)$ to $I(d_2)$, where $d_1 \neq d_2$, and $(-1/2< d_1,d_2<2)$. Fractional differencing is more fully discussed in MR, Phillips (2001) and Clark and Coggin (2018). Specifically, MR propose regression-based (t-statistic) procedures that allow *sequential* testing for a persistence change in fractionally integrated models. Based on the analysis and recommendations in MR, we use the squared t-test version, which they denote ζ^2. Under the null hypothesis, H(0), it is assumed that the fractional integration parameter d_t is constant over the sample, i.e.: $d_t = d_0$. The alternative hypothesis takes two forms: H(1a) an *increase* in d_t or H(1b) a *decrease* in d_t over the range of the sample data. Complete details are given in MR. As noted above, our pretesting suggests that all our data series have a unit root for the entire sample period except UK dollar Defense Spending. Thus we will use H(0): $d_0=1$ (unit root) in our MR tests.

In columns one and two of Panel Two of Table 5 we see that the ζ^2 t-tests for UK dollar Defense Spending suggest a *decrease* in the factional d estimate over the sample period; while the ζ^2 t-tests for Hungary and Poland suggest an *increase* in the fractional d estimate over the sample period. The ζ^2 t-tests in columns three and four of Panel Two for Belgium, Germany,

Netherlands, UK and USA Percent of GDP suggest a *decrease* in the factional d estimate over the sample period; while the ζ^2 t-tests for Hungary and Poland Percent of GDP suggest an *increase* in the fractional d estimate over the sample period.

The results in Table 5 indicate a *refinement* in the ability of our persistence tests to detect a change going from the I(1)/I(0) model of KPZ to the fractional $I(d_1)/I(d_2)$ model of MR. That is, the ζ^2 t-tests of MR detected a change in the persistence of UK, Hungary and Poland dollar Defense Spending. Only UK suggests a decrease. The ζ^2 t-tests detected changes in the persistence in Percent of GDP for: Belgium, Germany, Netherlands, UK, USA, Hungary and Poland. Only Belgium, Germany, Netherlands, UK, USA suggest a decrease. In summary, the majority of our persistence tests for real Defense Spending and Percent of GDP suggest no change (or an increase) in the unit root null or constant d hypothesis. Thus our tests of persistence suggest major changes in the defense policies and spending of NATO members will have a *lasting* effect in most cases.

Table 5.
Persistence tests

Panel One. KPZ Test			
	1953-2020 lnReal$US *Udmax*	**1954-2020 % GDP *Udmax***	**Break Date**
Belgium	9.497	14.518*	1985
Canada	3.091	1.960	
Denmark	6.383	2.475	
France	7.294	2.811	
Germany	1.481	3.155	
Greece	8.145	2.503	
Italy	4.633	7.974	
Luxembourg	3.621	0.606	
Netherlands	3.056	0.000	
Norway	4.551	5.299	
Portugal	1.924	13.902*	1972
Spain	4.851	1.975	
Turkey	4.801	2.423	
UK	NA	4.449	
USA	4.300	6.053	
CzechRepublic	4.516	9,590	
Hungary	4.473	6.092	
Poland	5.200	5.198	

H(0): Unit root in full sample; H(1): Process alternates between I(1)/I(0).
*Reject H(0), 0.05 level, Udmax>10.87.

[Panel Two continues below}

Panel Two. MR Test				
	1953-2020 lnReal$US		**1954-2020 % GDP**	
	ζ^2-stat H(1):Decrease	**ζ^2-stat H(1):Unknown Change**	**ζ^2-stat H(1):Decrease**	**ζ^2-stat H(1):Unknown Change**
Belgium	1.336	1.336	21.442†	21.442†
Canada	0.583	2.646	1.100	1.100
Denmark	0.115	0.116	1.810	1.810
France	2.155	2.155	1.357	1.891
Germany	4.238	4.238	28.726†	28.726†
Greece	0.522	1.356	0.786	1.029
Italy	0.900	0.900	1.289	1.289
Luxembourg	1.392	1.392	2.473	2.473
Netherlands	4.788	4.788	499.997†	499.997†
Norway	2.273	2.273	5.960	5.960
Portugal	3.106	3.106	1.979	1.979
Spain	1.811	1.811	1.058	1.058
Turkey	0.819	0.819	5.179	5.179
UK	7.468†	7.468†	25.854†	25.854†
USA	4.142	4.142	11.631†	11.631†
CzechRepublic	1.477	8.401	1.095	1.803
Hungary	1.687	6.339††	3.315	11.448††
Poland	0.821	9.683††	1.135	12.072††

H(0): No change in memory estimate d=1.
†Reject H(0) in favor of an Decrease in d.
††Reject H(0) in favor of an Increase in d.
Turkey data from 1960; Hungary, Poland and Czech Republic data from 1999.

4. Econometric Convergence Tests and Results

As discussed by Sul (2019a) and elsewhere, the notion of "convergence" has a prominent place in the social science literature, and has also been applied to NATO defense spending. Arvanitidis, *et al*. (2017) found evidence of defense policy convergence using β and σ-convergence methodologies as well as from Markov chains. Guris, *et al*. (2017) used linear and nonlin*e*ar unit root (stochastic) convergence tests for NATO members and found mixed results for the period 1953-2014. Ucler and Bulut (2021) provide a useful review of the convergence literature for NATO military expenditures. They used stochastic convergence tests for NATO members and found weak and mixed results for the period 1993-2018. Coggin (2021) found evidence of weak σ-convergence for military spending as a percent of GDP for a sample of 15 EU member countries for the period 1990-2020.

4.1. Problems with the β-Convergence and PS Relative Convergence Models

Sul (2019a, Chapter 7; 2019b) discusses some general problems and pitfalls in tests of convergence. As explained in Sul (2019a, 2019b), the β-convergence model of Barro and Sala-i-Martin (1991, 1992) can result in a "statistical illusion." That is, even in some cases where the cross-sectional variance of y_{it} *increases*, β-convergence *still* holds. Furthermore, the relative convergence tests of Phillips and Sul (2007a, 2007b, 2009), hereafter PS, become problematic when the panel data of interest have sign changes or do *not* display deterministic or stochastic *trends*. Specifically, when panel data include distinct stochastic trends, the nonstationarity in the data assists in identifying club membership. *Otherwise applying the relative convergence model and testing for "convergence clubs" does not work*. This suggests a strategy of *pretesting data* for the existence of trends before selecting a convergence model. As shown in Table 3, our indicator variables display a *mix* of positive, negative and zero trends. Thus we do not present PS tests for convergence clubs here because, as explained above, they are not appropriate for our data. The PS relative convergence regression *only* works when y_{it} has a (non)stochastic trend. This result is fully detailed in Kong, Phillips and Sul (2019, 2020) and Sul (2019a, 2019b) and is relatively new to the econometric literature on convergence.

4.2. Kong, Phillips and Sul Weak σ-Convergence Test

In response to the problems associated with the relative convergence model of PS, Kong, Phillips and Sul (2019, 2020), hereafter KPS, develop the *weak σ-convergence* model in which *cross-section variation* in panel data *decreases* over time. The complete details are available in their papers, but we give a brief outline here.

KPS note that weak σ-convergence is directly related to the definition of convergence suggested by Milton Friedman (1992) who quoted Harold Hotelling, "*The real test of a tendency to converge would be in showing a consistent diminution of variance.*" Assume we want to test convergence of a cross-sectional panel variable y_{it} (country i at time t). KPS discuss and propose a simple t-test of the parameter estimate, φ, in the linear trend regression:

$$K^y_{nt} = a + \varphi t + u_t,$$

where K^y_{nt} is the sample cross-section variance of y_i, a is the regression intercept, t is a linear time-trend and u_t is a zero-mean random error term. As a test of weak σ-convergence, they use the Newey-West (Bartlett kernel) corrected t-statistic on φ, t_φ. They propose the following decision rule for the null hypothesis of No weak σ-convergence:

$$t_\varphi < -1.65 \rightarrow \textit{accept weak σ-convergence}$$

$$-1.65 < t_\varphi < 1.65 \rightarrow \textit{fluctuating } y_i$$

$$1.65 < t_\varphi \rightarrow \textit{σ-divergence}$$

Thus weak σ-convergence is consistent with the original concept and meaning of convergence. That is, if cross-sectional variance is overall *decreasing* over time, weak σ convergence holds.

As described and presented in the results for Table 3 above, the estimated statistical trends of our defense spending indicators are a mix of positive, negative and zero. As discussed above, this presents a serious problem for estimating the relative convergence model of PS and also suggests that the weak σ-convergence model of KPS is the appropriate model for our data. As noted in Sul (2019b), many empirical researchers have traditionally used the notion of weak σ convergence, but they didn't define it as such and know how to test it properly. Our study is among the first to correctly apply the KPS weak σ convergence model (see also Coggin, 2021). The results are presented in Table 6.

Based on the t-statistic decision rule for the null hypothesis of No weak σ-convergence presented above, we find real dollar Defense Spending *fluctuating* (between weak σ-convergence convergence and no weak σ-convergence) for our 1953-2020 sample of NATO members and for our three newer 1999-2020 members (Hungary, Poland, Czech Republic). In order to include Turkey in a full period Percent of GDP convergence model, we use data for 1960-2020. We *accept* weak σ-convergence for Percent of GDP for our 1960-2020 sample of NATO members; and find σ-*divergence* for our 1999-2020 sample of NATO members.

Table 6.
Weak σ-convergence tests

	1953-2020 t-stat lnReal$US	1960-2020 t-stat % GDP
Belgium		
Canada		
Denmark		
France		
Germany		
Greece		
Italy		
Luxembourg		
Netherlands		
Norway		
Portugal		
Spain	NA	NA
Turkey		
USA		
t-stat	-0.497	-8.368
Hungary		
Poland		
CzechRepublic		
t-stat	1.386	5.141

Note: Hungary, Poland and Czech Republic data from 1999.

5. Summary and Conclusion

This study presents an analysis and quantitative summary of change, persistence and convergence for 18 NATO member defense spending over the period 1953-2020 (where the data permit). Specifically, we examine two indicators of defense spending that have been used in the literature: real $US and Percent of GDP. With regard to *change*, our analysis of dollar Defense Spending revealed that every NATO country *increased* its real mean US dollar amount after the 2006 and 2014 Summits *except* Belgium, Germany, Hungary and Czech Republic. Our analysis of Percent of GDP revealed that the *only* NATO countries with ≥ 2% defense spending after the 2006 and 2014 Summits are: Greece, Turkey, UK, USA and Poland. Another dimension of change concerns *trends* in our NATO data. Our analysis of dollar Defense Spending found only five countries (Denmark, Italy, Norway, Turkey and Poland) have (positive) trend slopes significantly different from zero. The trend slopes for Percent of GDP are almost uniformly negative, with seven significantly so (Belgium, Denmark, France, Germany, Italy, Spain and UK. We found only two cases of a significant *statistical break* in the trends of dollar Defense Spending: Greece (1978) and Italy (1991); and four cases of a significant statistical break in the trends of Percent of GDP: Canada (1968), France (1971), Luxembourg (1965) and Netherlands (1965).

Our tests of *persistence* focused on the *stationarity* of the NATO defense data over time, using the recent tests of Kjriwal, Perron and Zhou (2013) and Martins and Rodrigues (2014). Specifically, a persistent time series is one containing a *unit root*. Applying the KPZ test we found *none* of the NATO member countries reject the full-sample (constant) unit root null for the dollar Defense Spending data; and only two of the NATO member countries reject the unit root null for the Percent of GDP data: Belgium (break in 1985) and Portugal (break in 1972). The MR persistence test permits a more refined measure of persistence which allows *fractional differences* in the stationarity measure *d*. The tests of MR detected a *change* in the persistence of UK, Hungary and Poland dollar Defense Spending. Only UK suggests a decrease. The MR test detected *changes* in the persistence in Percent of GDP for: Belgium, Germany, Netherlands, UK, USA, Hungary and Poland. Only Belgium, Germany, Netherlands, UK and USA suggest a decrease.

In response to problems with existing econometric measures of *convergence*, Kong, Phillips and Sul developed the *weak σ-convergence* model in which cross-section variation in panel data decreases over time. We found real Defense Spending *fluctuating* (between weak σ-convergence convergence and no weak σ-convergence) for our 1953-2020 sample of NATO members and for our three newer 1999-2020 members (Hungary, Poland, Czech Republic). We accepted weak σ-convergence for Percent of GDP for our 1960-2020 sample of NATO members and found σ-*divergence* for our 1999-2020 sample.

Our quantitative results present a mixed picture of statistical consistency and coherence for NATO defense spending. A NATO Summit was held in June 2022 in Madrid in part to celebrate the 40th anniversary of Spain's NATO membership. The meeting was scheduled to occur several months after the February 2022 Russian invasion of Ukraine, a major escalation of the Russo-Ukrainian war that began with the invasion and annexation of Crimea in 2014. Several key announcements were made in response to the renewed and greatly expanded Russian threat [see Belam (2022) for a summary]. Finland and Sweden were invited to join the alliance. With regard to defense spending, NATO Secretary General Stoltenberg proclaimed NATO's target that 2% of GDP of each country be spent on defense will in the future be seen as "more of a floor than a ceiling." Based on our results presented here, that will be a tall order. Our tests of persistence suggest major changes in the defense policies and spending of NATO members will have a *lasting* effect in most cases. It appears that the growing threat from Russia (and now potentially China as well) will require no less.

References

Alozious, J. 2022. "NATO's Two Percent Guideline: A Demand for Military Expenditure Perspective." *Defense and Peace Economics*, 33:475-488. https://doi.org/10.1080/10242694.2021.1940649.

Amara, J. 2007. "Evaluating NATO Long Run Defense Burdens Using Unit Root Tests." *Defense and Peace Economics*, 18:157-181. https://doi.org/10.1080/10242690600789254.

Amara, J. 2008. "NATO Defense Expenditures Common Goals or Diverging Interests? A Structural Analysis." *Defense and Peace Economics*, 19:449-469. https://doi.org/10.1080/10242690701823259.

Arvanitidis, P., Kollias, C. and Messis, P. 2017. "Converging Allies?" *Peace Economics, Peace Science and Public Policy*, 23:216-0040. https://doi.org/10.1515/peps-2016-0044

Barro, R.J. and X. Sala-i-Martin. 1992. "Convergence." *Journal of Political Economy* 100:223-251. https://doi.org/10.1086/261816.

Belam, M. 2022. "NATO 2022 Madrid Summit: Wat Has Been Agreed?" *The Guardian*. https://www.theguardian.com/world/2022/jun/30/nato-2022-madrid-summit-what-has-been-agreed.

Blum, J. and N. Potrafke. 2020. "Does a Change of Government Influence Compliance with International Agreements? Empirical Evidence for the NATO Two Percent Target." *Defense and Peace Economics*, 31:743-761. https://doi.org/10.1080/10242694.2019.1575141.

Clark, S.P., and T.D. Coggin. 2011. "Are U.S. Stock Prices Mean Reverting? Some New Tests Using Fractional Integration Models with Overlapping Data and Structural Breaks." *Empirical Economics*, 40:373–391. https://doi.org/10.1007/s00181-010-0338-y.

Clark, S.P., and T.D. Coggin. 2018. "A Study of Fractionally Integrated Time Series using Descriptive Methods." *Applied Economics,* 50:172-186. https://doi.org/10.1080/00036846.2017.1321839.

Coggin, T. D. 2021. "An Analysis of Progress Toward EU Macroeconomic and Environmental Indicator Convergence." *European Journal of Economics,* 1:39-53. https://doi.org/10.33422/eje.v1i2.77.

Dowdy, J. 2017. "More Tooth, Less Tail: Getting Beyond NATO's 2 Percent Rule." McKinsey & Company, https://www.mckinsey.com/industries/public-and-social-sector/our-insights/more-tooth-less-tail-getting-beyond-natos-2-percent-rule.

Dunne, P. 1996. "Economic effects of military expenditure in developing countries: A survey." In *The Peace Dividend*, edited by N.P. Gleditsh, O. Bjerkholt, A. Cappelen, R. Smith and P. Dunne. Amsterdam: North Holland, 439-464. https://doi.org/10.1108/S0573-8555(1996)0000235025.

Dunne, J.P., E. Nikolaidou, and N. Mylonidis. 2003. "The demand for military spending in the peripheral economies of Europe." *Defense and Peace Economics*, 14:447-460. https://doi.org/10.1080/1024269032000085215.

Dunne, J.P., R.P. Smith, and D. Willenbockel. 2005. "Models of Military Expenditure: A Critical Review." *Defense and Peace Economics*, 16:449-461. https://doi.org/10.1080/10242690500167791.

Friedman, M. 1992, "Do Old Fallacies Ever Die?" *Journal of Economic Literature,* 30:2129-2132.

Gadea, M.D. E. Pardos and C. Perez-Fornies. 2004. "A Long-Run Analysis of Defence Spending in the NATO Countries (1960–99)." *Defense and Peace Economics,* 15:231–249. https://doi.org/10.1080/1024269042000189273.

Guris, S., B. Girus and M. Tirasoglu. 2017."Do military expenditures converge in NATO countries? Linear and nonlinear unit root test evidence." *Theoretical and Applied Economics*, 24:237-248.

Investment Watch. September 2021. "This is how much NATO countries spend on defense." https://www.investmentwatchblog.com/this-is-how-much-nato-countries-spend-on-defense/.

Kejriwal, M., P. Perron, J. Zhou, 2013. "Wald Tests for Detecting Multiple Structural Changes in Persistence." *Econometric Theory*, 29:289-323. https://doi.org/10.1017/S0266466612000357.

Kong, J., P.C.P. Phillips, and D. Sul. 2019. "Weak σ-convergence: Theory and applications." *Journal of Econometrics,* 209:185-207. https://doi.org/10.1016/j.jeconom.2018.12.022.

Kong, J., P.C.B Phillips, and D. Sul. 2020. "Testing Convergence Using HAR Inference", in Li, T., Pesaran, M.H. and Terrell, D. (Eds.) *Essays in Honor of Cheng Hsiao* (*Advances in Econometrics, Vol. 41*), Emerald Publishing Limited, 25:72. https://doi.org/10.1108/S0731-905320200000041002.

Martins, L.F, and P.M.M Rodrigues. 2014. "Testing for Persistence Change in Fractionally Integrated Models: An Application to World Inflation Rates." *Computational Statistics & Data Analysis,* 76: 502–22. https://doi.org/10.1016/j.csda.2012.07.021.

NATO, 2022, "What Is NATO?" https://www.nato.int/wearenato/why-was-nato-founded.html.

Lopes, D., T. Nian, L. Beraud-Sudreau, A. Marksteiner, and X. Liang. April 2022. "Trends in World Military Expenditure, 2021." *SIPRI Fact Sheet.* Solna, Sweden.

Odehnal, J. and N. Neubauer. 2020. "Economic, Security, and Political Determinants of Military Spending in NATO Countries." *Defence and Peace Economics*, 31:517-531, https://doi.org/10.1080/10242694.2018.1544440.

Perron, P., and T. Yabu. 2009a. "Estimating Deterministic Trends with an Integrated or Stationary Noise Component." *Journal of Econometrics,* 151:56-69. https://doi.org/10.1016/j.jeconom.2009.03.011.

Perron, P., and T. Yabu. 2009b. "Testing for Shifts in Trend With an Integrated or Stationary Noise Component." *Journal of Business & Economic Statistics,* 27:369-396. https://doi.org/10.1198/jbes.2009.07268.

Phillips, P.C.B, 2001. "Descriptive Econometrics for Non-stationary Time Series with Empirical Illustrations." *Journal of Applied Economics,* 16:389–413. https://doi.org/10.1002/jae.600.

Phillips, P.C.B., and D. Sul. 2007a. "Transition Modeling and Econometric Convergence Tests." *Econometrica,* 75:1771-1855. https://doi.org/10.1111/j.1468-0262.2007.00811.x.

Phillips, P.C.B., and D. Sul. 2007b. "Some Empirics on Economic Growth under Heterogeneous Technology." *Journal of Macroeconomics,* 29:455-469. https://doi.org/10.1016/j.jmacro.2007.03.002.

Phillips, P.C.B., and D. Sul. 2009. "Economic Transition and Growth." *Journal of Applied Econometrics,* 24:1153-1185. https://doi.org/10.1002/jae.1080.

Santamaria, P.G-T., A.A. Garcia and T.C. Garcia. 2021. "A Tale of Five Stories: Defence Spending and Economic Growth in NATO´s Countries." *PLoS ONE* 16(1): e0245260. https://doi.org/10.1371/journal.pone.0245260.

Smith, R. 1989. "Models of military expenditure." *Journal of Applied Econometrics*, 4**:** 345-359. https://doi.org/10.1002/jae.3950040404.

Sul, D., 2019a. *Panel Data Econometrics*. Routledge. https://doi.org/10.4324/9780429423765.

Sul, D., 2019b. "Econometrics Of Convergence & Cross-sectional Dependence." *Power Point* presentation available at https://personal.utdallas.edu/~dxs093000/book/panel.htm.

Ucler, G. and U. Bulut. 2021. "Re-examination of the Convergence in Military Expenditures across NATO Countries: Do Different Approximations in Modeling Structural Breaks Matter?" *Applied Economics Journal,* 28:43–62.

Utrero-Gonzales, N., J. Hromcova and F.J. Callado-Munoz. 2019. Defence Spending, Institutional Environment and Economic Growth: Case of NATO. *Defense and Peace Economics,* 30:525-548. https://doi.org/10.1080/10242694.2017.1400292.

Wolkronowski, J. 2018. "NATO defense expenditures in 1949-2017." SHS Web of Conferences 57, 01032. https://doi.org/10.1051/shsconf/20185701032.