Mykolas Romeris University

ISSN 1822-8038 (online)
INTELEKTINĖ EKONOMIKA
INTELLECTUAL ECONOMICS
2022 , No 16(2), p. 189–217

AN EMPIRICAL ANALYSIS OF LUXEMBOURG'S POST-COLD WAR DEFENCE EXPENDITURE

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DOI: 10.13165/IE-22-16-2-10

Abstract. *The latest shift in the global balance of power (i.e., Russia invading Ukraine) has reinforced the role of NATO and breathed new life into the discussion on defence expenditure, particularly in respect to NATO's two percent GDP guideline. This paper is interested in the defence expenditure of one of the smallest NATO nations, Luxembourg. The author investigates Luxembourg's post-Cold War military spending via two different methods (graphical analysis and econometric modelling) and in relation to a selection of endogenous and exogenous influence factors. Graphical analysis allows for an explanation of the dichotomy of Luxembourg being, on the one hand, NATO's smallest contributor in terms of defence expenditure as a share of GDP, and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure. In turn, the econometric analysis in this paper proposes an OLS model which explains Luxembourg's defence expenditure as a share of GDP in relation to two endogenous variables (GDP per capita and military personnel) and one exogenous variable (US defence expenditure as a share of GDP). This model has two merits. First, it offers a science-based indication as to how many staff the Luxembourg Armed Forces need to recruit in the future. Second, it exposes the limits of defence expenditure as a share of GDP for evaluating the military effort of a nation. Finally, the limitations of the paper are that the developed model is only applicable to Luxembourg. The author tested it against an updated version of Verlaine's (2022, in press-a, in press-b) small NATO nations, but it failed to produce convincing results.*

Key words. *Defence expenditure, Luxembourg, small NATO nations, OLS model.*

JEL Codes. *H:56, C:11*

1. Introduction

The end of the Cold War introduced a new era in the defence spending of NATO nations. The collapse of the Soviet Union and the dissolution of the Warsaw Pact in 1991 implied that NATO's main rival had suddenly disappeared. NATO countries were eager to profit from the newly gained "peace dividend", and gradually reduced their defence spending in favour of other investments (e.g., public health, education, infrastructure) (Bishop, 2017). This trend has been further accelerated by a neoliberal method of reform in public management (New Public Management), which has redefined the role of the government and introduced (a) greater reliance on markets and private services and (b) new pressures and incentives for efficiency and effectiveness (Cadell, 2007).

However, faced with shrinking budgets on the one hand and new responsibilities (e.g., peacekeeping and stabilisation missions) on the other, the NATO nations agreed at the 2006 Riga Summit to commit a minimum of two per cent of their gross national product (GDP) to defence spending in order to continue to guarantee the Alliance's military readiness (NATO, 2022a). This decision was also made against the backdrop of the rise to power of the Russian Federation and a change in President Putin's rhetoric, particularly in relation to NATO's enlargement process in the East. At the 2014 Wales Summit, as a reaction to the illegal annexation of Crimea by the Russian Federation, the NATO nations reiterated their commitment to the two percent guideline and further agreed to spend twenty percent of their annual defence expenditure on major new equipment (Techau, 2015). Finally, at the 2022 Madrid Summit, following the Russian invasion of Ukraine, the NATO nations issued a membership invitation to Sweden and Finland and reconfirmed the importance of military spending and the two percent GDP baseline (The White House, 2022).

In spite of the commitments undertaken at the Riga, Wales and Madrid Summits, the majority of the NATO nations have not spent two per cent of their GDP on defence in 2022 (see Figure 1). However, most NATO nations do match the twenty percent guideline on equipment expenditure (see Figure 2).

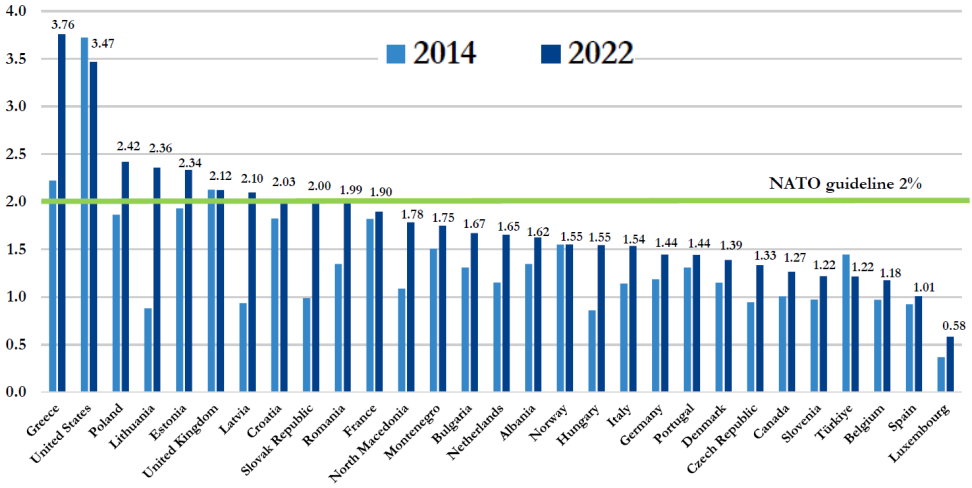

Figure 1: Defence expenditure as a share of GDP (in percentages) (Source: NATO, 2022b)

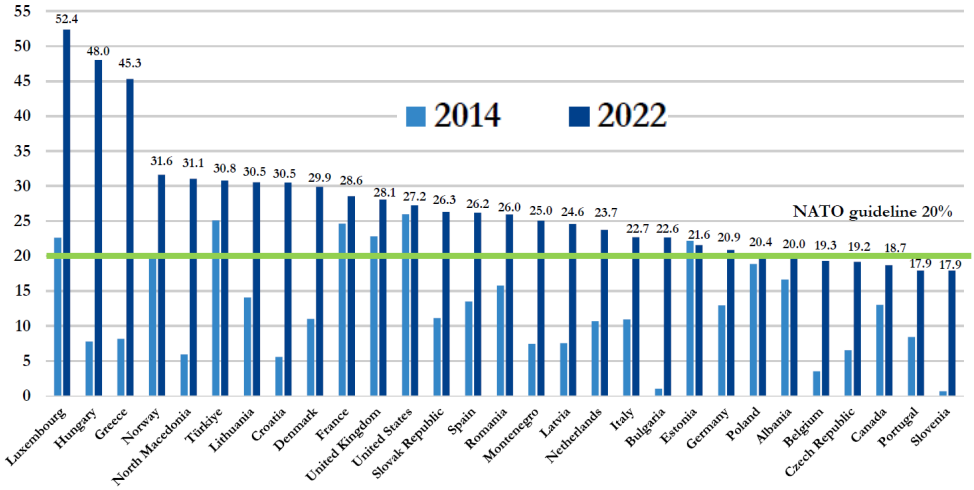

Figure 2: Military equipment as a share of defence expenditure (in percentages) (Source: NATO, 2022b)

2. Research Objective

This paper is specifically interested in the defence expenditure of one of the smallest NATO nations, Luxembourg. Figure 1 shows that Luxembourg spends by far the smallest share of GDP on defence of all NATO nations (0.58% in 2022 and 0.38% in 2014). However, Figure 2 shows that Luxembourg is NATO's top spender in terms of military equipment by share of defence expenditure (52.4% in 2022 and 22.6% in 2014). This discrepancy is intriguing and deserves an

explanation.

The main research question is as follows: What factors influence Luxembourg's defence expenditure, and is it possible to develop a model that can accommodate these factors? The period of interest is the post-Cold War era, from 1989 to 2021. The unit of analysis is Luxembourg's defence expenditure as a share of GDP.

This paper is furthermore interested in whether the developed model holds true for Luxembourg only, or if it is applicable to other similar small NATO member countries. In order to answer this question, the model is tested against an updated version of Verlaine's (2022, in press-a, in press-b) small NATO nations. The author's hypothesis is that Luxembourg occupies a unique position with NATO as result of its socio-economic and geopolitical profile, and that the developed model is too specific to be applied elsewhere.

Finally, the paper tackles the question of why Luxembourg is, on the one hand, NATO's smallest contributor in terms of defence expenditure as a share of GDP, and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure. Table 1 summarises the research questions and hypothesis.

Table 1: Research questions and hypothesis

Main Questions	What factors influence Luxembourg's defence expenditure, and is it possible to develop a model that can accommodate these factors?
	Will the developed model hold true for Luxembourg only, or is it also applicable to other similar smaller NATO member countries?
Sub Question	Why is Luxembourg on the one hand NATO's smallest contributor in terms of defence expenditure as a share of GDP, and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure?
Hypothesis	Luxembourg occupies a unique position within NATO as result of its socio-economic and geopolitical profile, and the developed model is too specific to be applied elsewhere.

3. Literature Review

The author conducted a literature review on the determinants of military spending in general, and on the socio-economic and geopolitical situation of Luxembourg in particular, in view of identifying potentially relevant influence factors for explaining the defence expenditure of Luxembourg.

In terms of the former, a series of contemporary and classical publications caught the attention of the author. Looney and Frederiksen (1990) analysed the impact of expected and unexpected gross national income (GNI) on defence expenditure in six East Asian Countries and concluded that economic strength is a key factor. In a similar vein, Pan et al. (2015) investigated the causal relationship between military spending and economic growth in ten countries in the Middle East. They found that causality was either unidirectional, bidirectional or non-existent depending on the economic and political profile of the country. Desli et al. (2016) came to a similar conclusion when investigating developed, developing and least-developed countries. They found evidence of a positive long-term causality from military spending to economic growth in

the case of developing countries, and from economic growth to military spending in the case of developing and developed countries.

By contrast, Jari (2005) took a more multifactorial perspective and proposed to model defence expenditure in relation to the price of military goods, a state's income, the impact of friendly states' military spending, the impact of hostile states' military spending, and the constraints imposed by changes in the overall strategic parameters of a nation. In fact, Jari (2005) sides with Smith (1977, 1978, 1980, 1989, 1995), who established early on that a host of factors determine military spending, including internal and external security considerations, economic power, geopolitical aspirations, and the ideological orientation of the incumbent government. Wang (2013) also adhered to a multidimensional approach when examining Southeast Asia, and discovered that military spending in this region has been jointly determined by economic, strategic and socio-political factors. He identified surging foreign debt and the rise of China as key forces.

Finally, Odehnal and Neubauer (2020) used a host of economic variables (budget balance, foreign debt, inflation, GDP per capita, growth and current account as a percentage of GDP), security variables (terrorism, cross border conflict, ethnic tension and foreign pressures) and political variables (democratic accountability and a government stability) when assessing military spending within NATO. Their results showed serious inconsistencies in factors affecting the defence expenditure of both old and new NATO nations. In a similar study, Odehnal et al. (2021) investigated military expenditure in relation to a series of socio-economic variables (average military burden, GDP, non-military government expenditure, share of trade balance of GDP and population) in order to identify the potential following behaviour of NATO nations. They found that new NATO nations in particular honour the commitment to spend two percent of GDP on defence.

As to Luxembourg's socio-economic and geopolitical profile, the latest OECD economic forecast on Luxembourg and government reports on Luxembourg's defence strategy offer valuable reference points (OECD, 2019, 2022; DOD, 2017, 2022a, 2022b). Furthermore, as a member of the Luxembourg Armed Forces, the author has access to internal documents such as the five-year road map and the recruitment strategy of the Armed Forces. Naturally, the information contained in the latter documents needs to be treated with some discretion. A short socio-economic and geopolitical profile of Luxembourg is presented below.

Luxembourg is a small and stable high-income economy featuring solid growth, low inflation rates (until 2022) and low unemployment. Its political orientation is neoliberal, with a strong conservationist tendency. The economy proved relatively sheltered from direct negative consequences of the war in Ukraine or the sanctions imposed on Russia, although energy supply (oil and natural gas) is likely to become more of a concern in the future. Luxembourg has a dominant service sector which accounts for a substantial share of its GDP. It has a total population of 645,000 inhabitants, and only a small Armed Force of 900 soldiers. Despite a lurking global recession, the Luxembourg Directorate of Defence (DOD) plans to increase defence expenditure substantially, from $523 million in 2022 to $992 million in 2028. This increase is necessary in order to fulfil the latest NATO capability targets that Luxembourg accepted in 2021, most notably the establishment of a Belgian-Luxembourg reconnaissance battalion and the reinforcement of its stock of war ammunition.

Based on the conducted literature review, the author identified 10 potentially relevant en-

dogenous influence factors and 15 potentially relevant exogenous influence factors for explaining Luxembourg's military spending (see Appendix A and Appendix B). Endogenous factors were selected with reference to the socio-economic information they contain about Luxembourg's economy (GDP in real terms, GDP per capita, inflation and growth rates) and defence apparatus (military personnel, defence expenditure in real terms, defence expenditure per capita, and defence expenditure per category). In turn, exogenous factors were selected based on global economic crises (dotcom bubble, subprime mortgage crisis, COVID-19 pandemic), key NATO decisions (Riga Summit, Wales Summit and Madrid Summit) and international political/armed conflicts in which the Luxembourg Armed Forces intervened with a detachment of soldiers (see Table 2). Furthermore, NATO and US defence expenditure as a share of GDP were included as reference points. All data was retrieved from official sources, including: NATO press releases (NATO, 1992, 1994, 1996, 2001, 2005, 2011, 2015, 2017, 2022b); working documents from the Luxembourg Armed Forces (Armée luxembourgeoise, 2021, 2022); and the databases of the World Bank (2022) and the Luxembourg Institute for Statistics and Economic Studies (STATEC, 2022).

Table 2: Political and armed conflicts in which the Luxembourg Armed Forces intervened

Mission	Period
IFOR	1996
KFOR	2000–2017
ISAF	2003–2012
VJTF	2018 / 2022
eFP	2017–2022
EUTM Mali	2019–2023

4. Methodology

The data from Appendix A and Appendix B was analysed via two different methods: graphical analysis and econometric modelling. The author first conducted a graphical investigation of the selected variables and drew assumptions based on historical facts and socio-economic and geopolitical reasoning. This process was important because data does not speak for itself, but must be interpreted within its context (Mukherjee & Wuyts, 2007). Moreover, graphical analysis helped to visually confirm the choice of endogenous and exogenous influence factors.

Second, the author reverted to econometric modelling in order to test the statistical relevance of the selected endogenous and exogenous influence factors for military spending in the case of Luxembourg. However, there is no consensus among researchers as to what constitutes the best technique for analysing military spending. Some researchers such as Solar (2022) and Kollias et al. (2018) refer to quantile regression analysis and contend that classical regression is likely to underestimate or overestimate the association between economic growth and military expenditure. Others, such as Chairil et al. (2013) and Dunne et al. (2005), put faith in the augmented Solow model and argue that it is less flawed than the often-used Feder-Ram model. More still, such as Odehnal et al. (2021) and Nikolaidou (2008), favour autoregressive distributed lag

(ARDL) models, stressing that these models do not omit important structural changes, as is usually the case with cross-sectional studies of large groups of countries. Yet more authors, such as Dizaji and Farzanegan (2021) and Gomez-Trueba et al. (2020), believe in vector autoregression (VAR), claiming that VAR treats all variables as endogenous and is thus better for revealing the dynamic interactions between the variables.

The author, however, sides with Aziz and Asadullah (2016), Esener and Ipek (2015), Fu et al. (2013) and Albalate et al. (2012), who reverted to ordinary least squares (OLS) regression to analyse the determinants of military spending. Since these studies used similar influence factors to those in this study and produced convincing results, the author sees no reason to reject the OLS technique. In an OLS model, a linear relationship is established between a dependent variable (here: defence expenditure as a share of GDP of Luxembourg) and a selection of independent variables (here: the socio-economic and geopolitical variables of Appendix A and Appendix B). Importantly, in order for the model to be conclusive, it is necessary that the independent variables have appropriate theoretical explanatory power in relation to the dependent variable (Frost, 2020; Wooldridge, 2019). The literature review and graphical analysis presented at the front of this paper work in that direction.

The OLS model used is written as follows:

$$y_t = \beta_0 + \beta_n x_{tn} + u_t$$

where t is the year, n the number of independent variables, β_0 the constant, y the dependent variable, x the independent variables, β the coefficient of the independent variables, and u the residual.

The author followed an incremental approach similar to the Bayesian inference method for building the model, and added step-by-step influence factors (see Clyde et al., 2021). Starting with modelling a simple relationship between defence expenditure as share of GDP (dependent variable) and GDP per capita and military personnel (independent variables), the author gradually added endogenous and exogenous variables over the process. However, the adding order was important. Since endogenous variables contain basic economic information such as capital and labour (which are arguably prerequisites for military spending), they were added first. Exogenous variables were added only once a model based on endogenous variables had been built. In order to interpret the results in percentages, the author used natural logarithms (the log-log model). All computing operations were conducted with the help of the STATA software.

In the final step, the author applied the model to an updated version of Verlaine's (2022, in press-a, in press-b) small NATO nations in order to test whether the model holds true for other similar smaller NATO member countries. Verlaine's (2022, in press-a, in press-b) differentiation between big, middle and small NATO powers appears particularly pertinent for this study because it defines "similarity" in terms of the size of the military apparatus (based on military personnel), and not in terms of country size (area or population), geographical location or GDP, as most defence studies do (see Solar, 2022; Dunne et al., 2019; Neubauer & Odehnal, 2018; Kollias et al., 2018; Aziz & Asadullah, 2016; Esener & Ipek, 2015, Fu et al., 2013). Indeed, in view of the peculiar socio-economic and geopolitical profile of Luxembourg, conventional definitions may be ill-placed. Hence, the model was tested on the following NATO nations: Latvia, Estonia, Slovenia, Albania, Montenegro and North Macedonia.

Importantly, the period of investigation had to be adapted for the selected nations because

they only joined NATO in the twenty-first century. Furthermore, finding reliable data for their "pre-NATO" period was an issue. Consequently, the period of investigation was adapted as follows: from 2004 to 2022 for Latvia, Estonia and Slovenia; from 2009 to 2022 for Albania; and from 2014 to 2022 for Montenegro and North Macedonia.

5. Analysis

5.1 Graphical Analysis

Figure 3 shows the evolution of Luxembourg's defence expenditure as a share of GDP from 1989 to 2022. The overall trend is of a decreasing nature. However, within the overall trend, the author identifies four sub-trends. The first is from 1989 to 1995 and is decreasing. The second is from 1996 and 2001 and is increasing. The third is from 2002 to 2008 and is decreasing. The fourth is from 2009 to 2022 and is increasing. Importantly, each sub-trend is likely to have a different origin and thus requires a separate explanation.

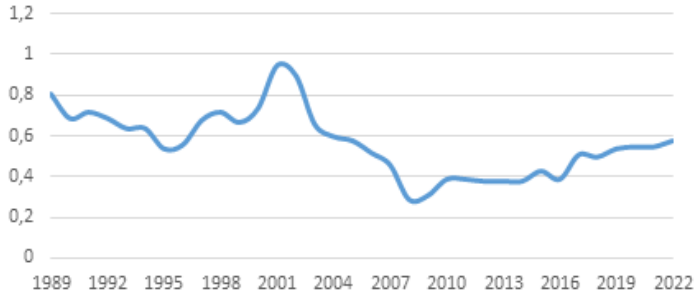

Figure 3: Evolution of the defence expenditure of Luxembourg as a share of GDP (in percentages)

The first sub-trend reflects the effects of both the end of the Cold War and the New Public Management reform in the public sector (see the introduction of this paper). The second sub-trend reflects the rise in violent intrastate conflicts in the 1990s (e.g., Somalia in 1992, Rwanda in 1994, Bosnia in 1995 and Kosovo in 1999) and the subsequent shift in NATO's role towards peace enforcement and peacekeeping missions (Hanlon, 2013). In 1996, Luxembourg contributed to ISAF with a contingent of 22 soldiers, which represented a significant effort for the Luxembourg Armed Forces, especially after prolonged years of austerity (Armée luxembourgeoise, 2022). In fact, ISAF marked a turning point in the strategic orientation of the Luxembourg Armed Forces. As a NATO member, Luxembourg had to contribute its share to NATO's new peace enforcement and peacekeeping role. However, the ISAF experience showed that Luxembourg was ill-prepared to take on such missions and needed to upgrade its military capabilities. This upgrade translated into both a rise in defence expenditure and a rise in military personnel (see Figure 3 and Figure 4). Once the necessary capabilities were built, Luxembourg took on two more NATO peace-

keeping/stabilisation missions: KFOR (2000–2017) and ISAF (2003–2012).

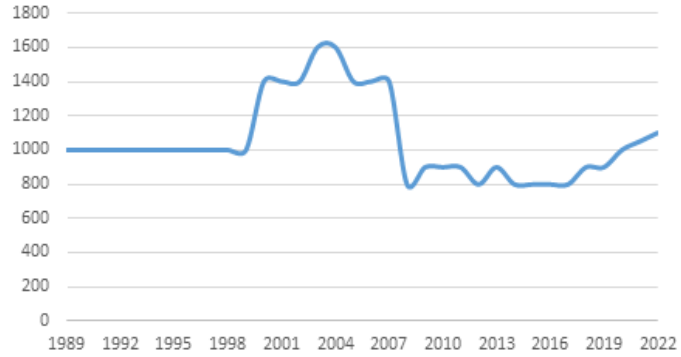

Figure 4: Evolution of the headcount of the Luxembourg military (in real numbers*)*

The third sub-trend is more of a mystery. The author assumes that the stark cut in defence expenditure is linked to an overinvestment in defence expenditure in order to quickly build up the capability for taking on NATO peacekeeping and stabilisation missions. The fact that a substantial share of Luxembourg's KFOR and ISAF contribution was conducted under a decreasing defence budget (viewed as a share of GDP) supports this rationale. However, it must be noted that the defence budget only shrank when viewed as a share of GDP. In real terms, Luxembourg's defence budget actually increased from 1989 to 2022 (see Figure 5). From this perspective, the overinvestment theory changes to a narrative of maintaining newly built capabilities based on a budget of roughly $200 million during the period from 2002 to 2008.

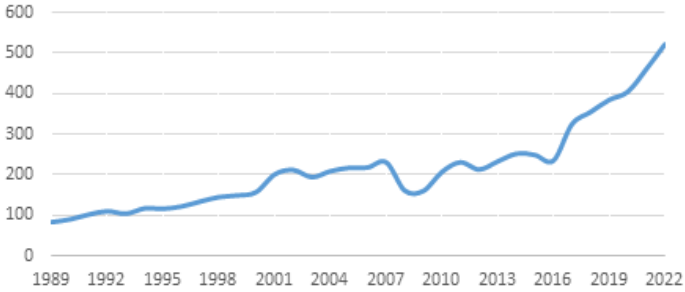

Figure 5: The evolution of Luxembourg's defence expenditure (in million USD)

However, neither the overinvestment theory nor the maintenance narrative can account for the stark drop in military personnel from 2004 to 2008 (see Figure 4). Rather, the opposite. Why were staff that had been recruited in order to take on NATO peacekeeping and stabilisation missions reduced? A more inward perspective is needed to explain the drop in military personnel.

The Luxembourg Armed Forces are composed of professional soldiers (officers and NCOs) and volunteers (privates), with a ratio of roughly one to two-and-a-half (1:2.5). Although conscription was abolished in 1967, for some careers such as the police, the customs or the postal service, a compulsory military service of three years was maintained. This ensured that the Luxembourg Armed Forces recruited enough volunteers (privates) to fulfil their national and international duties. However, political reforms in the late 1990s and early 2000s succinctly abolished compulsory military service for those careers. This decision had an important effect on the personnel strength of the Luxembourg Armed Forces, as recruiting enough volunteers (privates) was no longer guaranteed. Thanks to opening up the volunteer (private) career to EU citizens with their residence in Luxembourg in 2003, it was possible to address a growing sector of the Luxembourg population (young EU citizens) and stabilize military headcount around a baseline of 900 soldiers. More recently, expanding the civilian career within the Luxembourg Armed Forces has allowed the country to break the frontier of 1,100 employees.

Finally, the fourth sub-trend reflects the effects of the illegal annexation of Crimea by the Russian Federation in 2014 and the subsequent reaction by NATO. In contrast to the 2006 appeal to raise defence spending to two percent of GDP, which was paid only little attention by Luxembourg, it appears as if NATO's 2014 appeal had a stronger effect. Luxembourg's military spending almost doubled from 2014 to 2022 (in terms of both real expenditure and as a share of GDP) (see Figure 3 and Figure 5). Moreover, following the latest press brief of the DOD, Luxembourg is planning to reach a one percent GDP baseline by 2028 (DOD, 2022b). Although this is still far away from the two percent GDP baseline requested by NATO, it does confirm a positive sub-trend. In terms of international commitments, Luxembourg has taken on both a NATO commitment (VJTF and eFP) and an EU commitment (EUTM Mali). However, operating on two fronts represents a big effort for the Luxembourg Armed Forces because military headcount has not increased since 2008, as opposed to the military budget, which has more than doubled in the same period (see Figure 4 and Figure 5).

Comparing Luxembourg's defence expenditure with NATO's defence expenditure allows the author's reasoning to be crosschecked. However, since there are important differences between the defence spending of European countries and the US, it is useful to use three variables when investigating NATO's defence expenditure: NATO Europe, NATO Total and the US. Figure 6 shows that NATO Total defence expenditure is embedded between US defence expenditure and NATO Europe defence expenditure. Although all three variables have an overall decreasing trend, there is an important increasing sub-trend in US and NATO Total defence expenditure from 2001 to 2009. This sub-trend can be explained by the 9/11 attacks on the World Trade Centre in 2001 and the subsequent US War on Terror. Crucially, NATO Europe did not follow the increasing sub-trend and continued its decreasing path, dropping below the two percent benchmark from 2005 onwards. The reason that NATO Total defence expenditure followed the US trend is explained by the stark discrepancy between NATO Europe and US military spending.

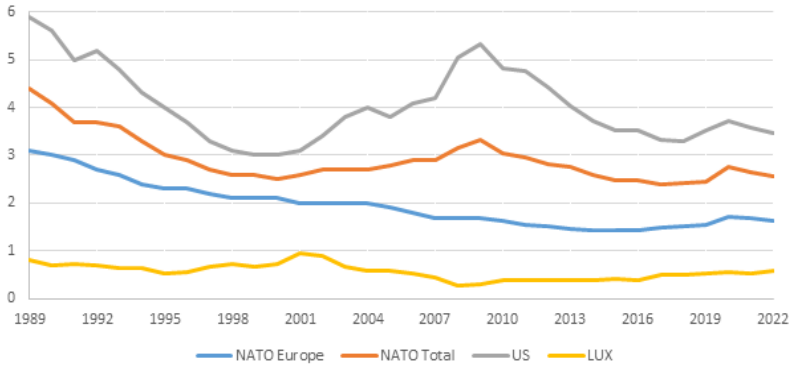

Figure 6: The evolution of defence expenditure as a share of GDP (in percentages)

However, the important question for this study is: Which trend does Luxembourg follow? Based on Figure 6, it appears that Luxembourg neither follows the NATO Europe trend nor the NATO Total and US trend. One possible explanation for this is that Luxembourg has a unique socio-economic and geopolitical profile that significantly differs from the profiles of most NATO nations. Indeed, with a territory of only 2,586 km^2, a population of 645,000, a military apparatus of 1,100 employees (military and civilian) and a GDP of $72,500 million in 2022, Luxembourg is one of the smallest NATO nations (OECD, 2022; STATEC, 2022; Thull, 2022). Moreover, lacking essential defence assets such as combat aircrafts, battleships and tanks, Luxembourg must be considered a no-capability NATO nation (see Verlaine, in press-a, in press-b). The crucial point is that as a no-capability NATO nation, Luxembourg does not have the ability to protect its national territory and relies entirely on the protection of NATO. However, following military theory, the ability to effectively protect national territory is an indispensable prerequisite for the proper functioning of a defence alliance (Odehnal et al., 2021; Wukki & Sandler, 2019). In fact, Luxembourg is a typical NATO free rider – that is, a member nation that underinvests in defence but profits from the collective protection of the Alliance (see George and Sandler, 2022; Jakobsen, 2018).

Finally, the question of why Luxembourg is on the one hand NATO's smallest contributor in terms of defence expenditure as a share of GDP and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure can be explored by breaking down Luxembourg's defence expenditure by category (see Figure 7). Figure 7 shows that expenditure on military personnel in Luxembourg has an overall negative trend, whereas expenditure on military equipment in Luxembourg has an overall positive trend. Moreover, 2008 appears to have been a pivotal year, as expenditure on military personnel significantly dropped while expenditure on military equipment significantly increased. This indicates a strategic shift in Luxembourg's defence orientation towards more capital-intensive and labour-saving military capabilities

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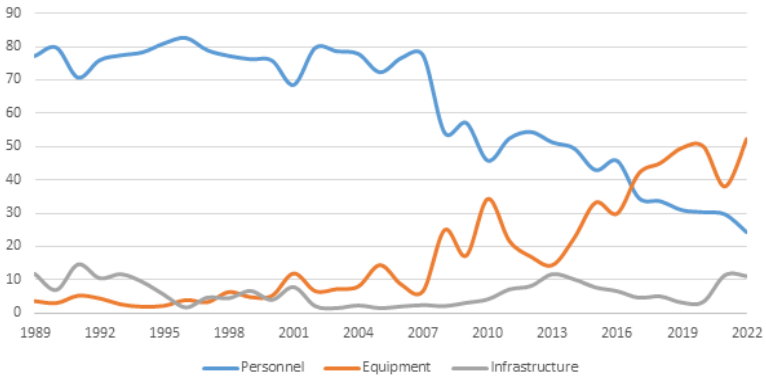

Figure 7: Luxembourg's defence expenditure by category (in percentages)

The fact that expenditure for military personnel has progressively been dropping since 2008 while military headcount has actually stagnated since 2008 can be explained by the stark growth in real terms defence expenditure from 2009 to 2022 (see Figure 5). A rising defence budget and a stagnating military headcount allowed new investments into equipment and infrastructure. Importantly, military headcount from 2008 to 2022 was similar to military headcount from 1989 to 1999 (see Figure 4). However, real terms defence expenditure did not grow as starkly from 1989 to 1999 as it did from 2008 to 2022 (see Figure 5). This explains why Luxembourg dedicated 80% of its defence budget to military personnel in 1989 and only 25% in 2022.

In order for this analysis to be complete, the important growth in real terms of defence expenditure needs to be explained. Comparing real terms defence expenditure with real terms GDP shows that both experienced important growth from 1989 to 2022 (see Figure 5 and Figure 8). A similar picture can be drawn when comparing defence expenditure per capita and GDP per capita from 1989 to 2022 (see Figure 10 and Figure 9). The value of using a per capita indicator (as opposed to a real terms indicator) is that it is able to take into account the variance of the population. From 1989 to 2022, Luxembourg's population almost doubled, growing from 377,000 inhabitants in 1989 to 645,000 inhabitants in 2022. However, over the same period, its GDP multiplied by a factor of seven (rising from $10,392 million in 1989 to $73,000 million in 2022) and its GDP per capita by a factor of four (rising from $27,500 in 1989 to $115,000 in 2022) (see Figure 8 and Figure 9).

Figure 8: The evolution of Luxembourg's GDP (in million USD)

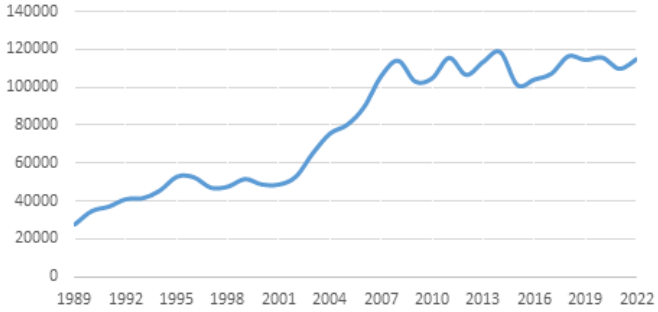

Figure 9: The evolution of Luxembourg's GDP per capita (in USD)

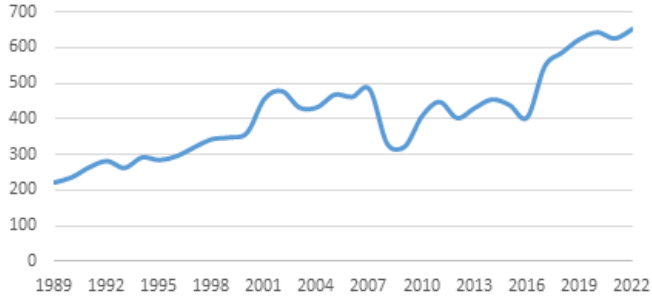

Figure 10: The evolution of Luxembourg's defence expenditure per capita (in USD)

Importantly, when comparing GDP and GDP per capita, a specificity of the Luxembourg economy needs to be taken into account. In Luxembourg, a significant share of employment is occupied by cross-border workers (28% in 1995 and 44% in 2022) (STATEC, 2022). While cross-border workers contribute to Luxembourg's overall wealth (in real terms GDP), they are not accounted for in GDP per capita (as their place of residence is outside of Luxembourg). Thus,

one can make a case for GDP per capita not being the best indicator in the case of Luxembourg.

In conclusion, graphical analysis offers an answer to the question of why Luxembourg is on the one hand NATO's smallest contributor in terms of defence expenditure as a share of GDP and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure. This dichotomy is explained by a strategic (re)orientation towards more capital-intensive and labour-saving military capabilities, induced by recruiting issues. This strategic shift has furthermore been enabled by the stark growth of real terms defence expenditure, which was made possible by a fast-growing economy (in real terms GDP).

5.2 Econometric Modelling

The author started by investigating if the data in Appendix A and Appendix B is stationary or non-stationary. Non-stationary data is a problem for modelling because the estimate of the mean will change through time, which creates biased results (Hamilton, 2020). Based on the graphical analysis, the author suspects that several variables from the dataset are non-stationary and have a unit root trend. Stationarity can be tested against with the Dickey-Fuller test and remedied by using first difference (Hamilton, 2020). The null hypothesis of the Dickey-Fuller test is that there is a trend in the variable. Table 3 shows which variables in the dataset have a unit root problem and thus needed first difference transformation.

In the first step, the author regressed the dependent variable (FD defence expenditure as a share of GDP) on the first set of endogenous variables: GDP per capita and military personnel. GDP per capita was chosen over real terms GDP because it also takes into account the variance of the population. Table 4 shows the key results. *R*-squared is at 51%, which is perfectly acceptable for the model under construction. Furthermore, the *F*-test confirmed that all variables are jointly significant. The null hypothesis of the *F*-test is that at least one of the variables is equal to zero. The null hypothesis must be rejected (*p*-value at 0.0000).

Table 3: Dickey-Fuller test and first difference for variables with a unit root problem

Variable (in ln)	Statistics	p-value
Defence expenditure as a share of GDP	−1.760	0.4003
Defence expenditure in real terms	−0.258	0.9313
Defence expenditure per capita	−1.415	0.5750
GDP per capita	−2.347	0.1574
GDP in real terms	−2.098	0.2453
Military personnel	−1.775	0.3929
Defence expenditure by share of military personnel	0.787	0.9914
Defence expenditure by share of military equipment	−1.023	0.7447
Defence expenditure by share of infrastructure	−2.474	0.1219
US defence expenditure as a share of GDP	−2.112	0.2397
FD* defence expenditure as a share of GDP	−5.094	0.0000
FD defence expenditure in real terms	−5.577	0.0000
FD defence expenditure per capita	−5.649	0.0000

FD GDP per capita	−4.953	0.0000
FD GDP in real terms	−5.005	0.0000
FD military personnel	−6.345	0.0000
FD defence expenditure by share of military personnel	−7.731	0.0000
FD defence expenditure by share of military equipment	−8.123	0.0000
FD defence expenditure by share of infrastructure	−7.069	0.0000
FD US defence expenditure as a share of GDP	−3.415	0.0105

***FD = first difference**

Table 4: Test results for the model under construction

FD defence expenditure as a share of GDP (in ln)				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.9350494	0.2127994	−4.39	0.000
FD military personnel	0.9554739	0.3318530	2.88	0.007
_constant	0.0292256	0.0207219	1.41	0.169

R-squared = 0.5034

F-test = 0.0000

Continuing the development of the model, the author added a second set of endogenous variables: defence expenditure by share of military personnel, defence expenditure by share of equipment, and defence expenditure as share of infrastructure. All possible combinations were tested; however, none of the variables worked with the model and added only noise. At this point, it is worth mentioning that defence expenditure per share of military personnel was significant at 10% (p-value at 0.084). However, this study adheres strictly to the conventional 5% significance level. As a consequence, the variable of defence expenditure per share of military personnel could not be included into the model.

The author then added the last set of endogenous variables: inflation rates, growth rates, and defence expenditure per capita. Again, all possible combinations were tested. However, as before, none of the variables worked with the model and added only noise.

In a further step, the author added the first set of exogenous variables: NATO Europe defence expenditure as a share of GDP, NATO Total defence expenditure as a share of GDP, and US defence expenditure as a share of GDP. Again, all possible combinations were tested. However, only the variable US defence expenditure as a share of GDP worked with the model (see Table 5). All variables in the model were significant at 5%, and R-squared improved to 59%. In addition, the F-test confirmed that all variables were jointly relevant (p-value at 0.0000).

Finally, the author turned to the last set of exogenous variables, the dummy variables. The dummy variables were organised into three categories – economic crises, military missions and key NATO decisions – and added by category to the model. The economic crises category included the variables subprime mortgage crisis, dotcom bubble and COVID-19 pandemic. The military missions category contained the variables IFOR, KFOR, ISAF, VJTF, eFP and EUTM. The key NATO decisions category included the variables Riga Summit, Wales Summit and Madrid

Summit. For each category, all possible combinations were tested. However, none of the variables worked with the model and added only noise. Consequently, the author stuck with the model as shown in Table 5. This is also the final model.

Table 5: Test results for the final model

FD defence expenditure as a share of GDP (in ln)				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.8152650	0.2024304	−4.03	0.000
FD military personnel	0.7851928	0.3141609	2.50	0.018
FD US def exp as a share of GDP	−0.6196505	0.2498145	−2.48	0.019
_constant	0.0142862	0.0200682	0.71	0.482

R-squared = 0.5904

F-test = 0.0000

The author tested the final model against the following assumptions: autocorrelation, serial correlation, heteroscedasticity and omitted variables. Fist, autocorrelation (or first-order serial correlation) was assessed with the Durbin–Watson test. The result of the Durbin–Watson test was 2.29903, meaning that the variables in the model are negatively autocorrelated. However, since this value is between the acceptable range of 1.5 and 2.5, the autocorrelation is statistically not relevant (SAP, 2016). The alternative Durbin–Watson test confirms the test results of the Durbin–Watson test. The value of chi-squared was 0.716 and the *p*-value for chi-squared was 0.3974. There is thus no reason to reject the null hypothesis (null hypothesis: there is no autocorrelation).

Second, heteroscedasticity was checked with the Breusch–Pagan test. The value of chi-squared was 0.13 and the *p*-value for chi-squared was 0.7175. There is thus no reason to reject the null hypothesis (null hypothesis: there is no heteroscedasticity). Third, higher-order serial correlation was verified with the Breusch–Godfrey test. The author checked for five lags. The choice of five lags is justified on the basis that the government in Luxembourg is elected for five years, and that a policy decision should take (and show) effect within these five years. Table 6 shows the results of the Breusch–Godfrey test. At all five lags, the *p*-value is greater than 0.05. There is thus no reason to reject the null hypothesis (null hypothesis: no serial correlation).

Table 6: Breusch–Godfrey statistics for the final model

Lag	Chi-squared	*p*-value
1	0.823	0.3643
2	5.317	0.0700
3	5.319	0.1499
4	6.034	0.1966
5	6.062	0.3002

Fourth, omitted variables were checked with the Ramsey RESET test and the link-test. In the case of the former, the *p*-value of the *F*-statistics was 0.0689. There is thus no reason to reject

the null hypothesis (null hypothesis: the model has no omitted variables). For the link-test, Table 7 shows the test result. Both hat and hat-squared are statistically significant (p-value at 0.000 and 0.044, respectively). Consequently, there is no reason to suspect that the model has omitted variables. Based on the test results, there is no reason to reject the final model.

Table 7: Link-test statistics for the final model

FD defence expenditure as a share of GDP (in ln)				
Variable	Coefficient	Standard deviation	*t* statistics	*p*-value
_hat	0.8498666	0.1589697	5.35	0.000
_hatsq	−1.669718	0.7948175	−2.10	0.044
_constant	0.0191202	0.0182202	1.05	0.302

R-squared = 0.6461

In the last stage, the author applied the final model to an updated version of Verlaine's (2022, in press-a, in press-b) small NATO nations, namely Latvia, Estonia, Slovenia, Albania, Montenegro, and North Macedonia (see Table 8). However, the model did not work with any of the selected countries. Indeed, from the three independent variables (GDP per capita, military personnel and US defence expenditure as a share of GDP), only GDP per capita was significant in the case of Albania (p-value at 0.001). As a consequence, the author's final model must be rejected for all small NATO nations except Luxembourg.

Table 8: The final model applied to small NATO nations

LATVIA*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	0.0081402	0.166873	0.49	0.633
FD military personnel	0.3004667	0.5089213	0.59	0.564
FD US def exp as a share of GDP	.1121787	0.488113	0.23	0.822
_constant	0.30339	0.357087	0.85	0.410
ESTONIA*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.0103918	0.0077134	−1.35	0.199
FD military personnel	−0.1031036	0.1272546	−0.81	0.431
FD US def exp as a share of GDP	0.2941843	0.2541789	1.16	0.266
_constant	0.265478	0.195971	1.35	0.197
SLOVENIA*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	0.0052038	0.0105263	0.49	0.629
FD military personnel	0.3651111	0.3449563	1.06	0.308
FD US def exp as a share of GDP	0.959054	0.314861	0.30	0.765

_constant	−0.017361	0.228283	−0.47	0.645
ALBANIA*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.0327055	0.0069455	−4.71	0.001**
FD military personnel	0.2252011	0.1950845	1.15	0.278
FD US def exp as a share of GDP	0.4893332	0.3243806	1.51	0.166
_constant	0.0088981	0.0207482	0.43	0.678
MONTENEGRO*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.0058273	0.0087878	−0.66	0.544
FD military personnel	06863107	0.2617441	2.62	0.059
FD US def exp as a share of GDP	0.4111468	0.674432	0.61	0.575
_constant	0.0260357	0.262624	0.99	0.378
NORTH MACEDONIA*				
Variable (in ln)	Coefficient	Standard deviation	*t* statistics	*p*-value
FD GDP per capita	−0.0208465	0.0140461	−1.48	0.212
FD military personnel	−0.2712295	1.23783	−0.22	0.837
FD US def exp as a share of GDP	1.371667	0.8673085	1.58	0.189
_constant	0.0496502	0.0433769	1.14	0.316

*FD Defence expenditure as a share of GDP (in ln)

**Significant at 1%

6. Discussion

Regression analysis has produced a working model for Luxembourg (see Table 5) which establishes a correlation between defence expenditure as a share of GDP and two endogenous variables, namely GDP per capita and military personnel, and one exogenous variable, namely US defence expenditure as a share of GDP. The results of the model are interpreted below.

First, GDP per capita has a negative effect on defence expenditure as a share of GDP. For any 1% increase in GDP per capita, defence expenditure as a share of GDP is expected to decrease by 0.81% (ceteris paribus). Graphical analysis helps to understand this result. The GDP per capita of Luxembourg has experienced enormous growth over the period from 1989 to 2022, rising from $27,556 in 1989 to $115,000 in 2022 (see Figure 9). In fact, this growth is so important that it "out scales" the growth in real terms defence expenditure (which rose from $84 million in 1989 to $523 million in 2022) when used in a composite index such as defence expenditure as a share of GDP (see Figure 5 and Figure 1). According to the author's model, if the GDP per capita of Luxembourg grows in the future in a way similar to how it did in the past, defence expenditure as a share of GDP will decrease, even if real terms defence expenditure continues to increase.

Second, the number of military personnel has a positive effect on defence expenditure as a share of GDP. For any 1% increase in military personnel, defence expenditure as a share of GDP is

expected to increase by 0.78% (ceteris paribus). In other words, a 100% increase in military personnel (that is, 1,100 employees) is expected to increase defence expenditure as a share of GDP by 78% (that is, from 0.58% to 1.0324%). This information is important, particularly in relation to the latest plan of the DOD to reach a one percent GDP baseline by 2028 (DOD, 2022b). Indeed, following this model, a one percent GDP baseline correlates with recruiting 1,100 new employees (military and civilian) with other factors held constant.

Third, US defence expenditure as a share of GDP has a negative effect on Luxembourg's defence expenditure as a share of GDP. For any 1% increase in US defence expenditure as a share of GDP, Luxembourg's defence expenditure as a share of GDP is expected to decrease by 0.62% (ceteris paribus). At first sight, this appears to be a spurious correlation – that is, a situation in which two variables are correlated but do not have a causal relationship (see Vigen, 2015; Harvard Business Review, 2015). However, there is a logical explanation in this case. The US is a very high capability NATO nation with the biggest defence budget, defence technological and industrial base (DTIB) and military capabilities in the world. By contrast, Luxembourg is a no-capability NATO nation that lacks essential military capabilities such as size, budget, defence industry, etc. (see Hartley and Belin, 2020; Hartley 2020; Verlaine, in press-a, in press-b). In fact, the US and Luxembourg have diametrically opposing defence profiles and military priorities, which is ultimately reflected in their defence expenditure as a share of GDP. On the one hand, the US is the driving force in NATO and stretches its protective umbrella over the other member nations and even beyond; Ukraine and Taiwan being the most recent examples (see Antezza et al., 2022; US Department of State, 2022). On the other hand, Luxembourg is the typical NATO free rider, which does not have the ability to protect its national territory and relies entirely on the protection of the Alliance.

The model is useful in two ways. First, it offers a science-based indication as to how many staff the Luxembourg Armed Forces needs to recruit in the future. This is of particular relevance in the light of the DOD target to reach a one percent GDP baseline by 2028. So far, the Armed Forces have based their estimations on a purely operational needs approach, which is essentially connected to their NATO capability targets. For example, following General Steve Thull (2022), the Luxembourg Armed Forces will need to recruit 100 soldiers in relation to the 2028 Belgian-Luxembourg battalion. Although this method works, it is one-dimensional and cannot account for factors other than overt operational needs. Most importantly, it lacks empirical backing. This study, on the other hand, takes a multidimensional perspective and offers an OLS regression model in which defence expenditure as a share of GDP correlates with GDP per capita, military personnel and US defence expenditure as a share of GDP. Based on this model, a one percent GDP baseline correlates with recruiting 1,100 new employees (military and civilian), with other factors held constant.

Second, this model shows that a composite index such as defence expenditure as a share of GDP is not the best method to evaluate the military effort of a nation. The main reason for this is that it cannot account for the socio-economic and geopolitical peculiarities of a nation. In the case of Luxembourg, the stark growth in GDP per capita combined with an economy that relies heavily on cross border workers to generate its wealth are key influence factors that go unobserved in defence expenditure as a share of GDP. A similar argument has been brought forward by the DOD in order to justify its one percent baseline target (DOD, 2022a). The DOD

argues that Luxembourg's GDP per capita is 2.66 times higher than the EU average, and that this circumstance masks important achievements such as the doubling of its real terms defence expenditure over the past ten years. The DOD further contends that its military investments are high and must be seen in the context of its limited capabilities, highlighting that Luxembourg has only a small air, land and space component and no naval component.

Finally, this model is not useful for other small NATO nations. None of the independent variables (GDP per capita, military personnel and US defence expenditure as a share of GDP) are significant for small NATO nations, except GDP per capita in the case of Albania. This is a strong indication that Luxembourg is an outlier in the small NATO nations group. In fact, Verlaine (in press-a, in press-b) makes a similar argument when investigating the policy and practice of military acquisition within NATO and the EU, holding that Luxembourg is not only a small NATO nation but also a no-capability NATO nation that lacks essential military attributes. The author further claims that Luxembourg faces particular challenges in relation to defence acquisition, which are mainly due to internal factors such as a limited in-house capability, low-volume orders, small budgets, weak review and audit mechanisms, no defence industry and no military school.

7. Conclusion

This paper has proposed a series of endogenous and exogenous influence factors that can potentially explain Luxembourg's defence expenditure in the post-Cold War era (see Appendix A and Appendix B). In the first step, the author investigated the data with the help of graphs and made assumptions based on historical facts and socio-economic and geopolitical reasoning. Importantly, this graphical analysis offered an answer to the question of why Luxembourg is on the one hand NATO's smallest contributor in terms of defence expenditure as a share of GDP and on the other hand NATO's top spender in terms of military equipment by share of defence expenditure. This dichotomy is the result of the strategic reorientation of Luxembourg's defence policy towards more capital-intensive and labour-saving military capabilities, induced by recruiting issues. Furthermore, this policy shift has been enabled by stark growth in real terms defence expenditure, which was made possible by a fast-growing economy (real terms GDP).

In the second step, the author examined the data through regression analysis and developed an OLS model that explains Luxembourg's post-Cold War defence expenditure as a share of GDP in relation to two endogenous factors, namely GDP per capita and military personnel, and one exogenous factor, namely US defence expenditure as a share of GDP. This model has two merits. First, it offers a science-based indication as to how many personnel the Luxembourg Armed Forces need to recruit in the future in view of reaching the set target of a one percent GDP baseline. Second, the model highlights that a composite index such as defence expenditure as a share of GDP is not the best method to evaluate the military effort of a nation. The reason for this is that it cannot account for the socio-economic and geopolitical specificities of a nation.

However, this model also has clear limits: it does not work for other small NATO nations. Even though the model confirms the author's hypothesis that Luxembourg occupies a unique position within NATO as result of its socio-economic and geopolitical profile, further research on small NATO nations is necessary. One potential avenue could be to investigate Verlaine's (2022, in press-a, in press-b) small NATO nations group through a different econometric method such as quantile regression analysis, ARDL or VAR modelling and augmented Solow models. On the

one hand, this would help to confirm the author's research results. On the other hand, and most importantly, it could contribute to generating a better understanding of what influence factors determine the military spending of small NATO nations, and in the process could tackle the lack of consensus among researchers as to what constitutes the best technique to analyse military spending.

Disclaimer

The views represented in the article are those of the author and do not reflect the official position of the Luxembourg Armed Forces.

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APPENDIX A: Endogenous Influence Factors

Year	DE* by share of GDP (%)	DE (million $)	DE per capita ($)	DE by share of personnel (%)	DE by share of equipment (%)	DE by share of infrastructure (%)	Military Personnel	GDP (million $)	GDP per capita ($)	Inflation (%)	Growth (%)
1989	0.81	84	223	77.10	3.80	11.90	1000	10392	27556	3.37	9.8
1990	0.69	91	238	79.60	3.20	7.00	1000	13229	34645	3.25	5.3
1991	0.72	103	266	70.60	5.40	14.80	1000	14322	37007	3.12	8.6
1992	0.69	111	283	75.80	4.60	10.60	1000	16066	40965	3.15	1.8
1993	0.64	105	264	77.30	2.80	11.80	1000	16487	41479	3.59	4.2
1994	0.64	118	293	78.20	2.10	9.40	1000	18326	45481	2.19	3.8
1995	0.54	117	286	80.90	2.40	5.50	1000	21588	52831	1.87	1.4
1996	0.56	123	297	82.50	4.10	1.70	1000	21777	52571	1.18	1.4
1997	0.68	135	322	78.80	3.50	4.70	1000	19732	47042	1.37	5.7
1998	0.72	146	344	77.10	6.50	4.50	1000	20209	47584	0.96	6.0
1999	0.67	150	349	76.10	5.00	6.70	1000	22236	51654	1.03	8.5
2000	0.74	158	362	75.70	5.40	4.00	1400	21264	48735	3.15	8.2
2001	0.95	202	457	68.40	12.10	7.90	1400	21272	48719	2.66	2.5
2002	0.90	213	478	79.50	6.80	2.10	1400	23616	52930	2.07	3.8
2003	0.66	195	432	78.50	7.40	1.50	1600	29557	65455	2.05	1.6
2004	0.60	210	433	77.70	8.20	2.30	1600	34685	75716	2.23	3.6
2005	0.58	218	468	72.20	14.60	1.50	1400	37347	80289	2.49	3.2
2006	0.52	219	462	76.50	8.70	2.00	1400	42414	89739	2.67	5.2
2007	0.46	232	483	77.30	6.80	2.40	1400	50888	106018	2.31	8.4
2008	0.29	162	331	54.00	25.10	2.10	800	55850	114293	3.40	-1.3
2009	0.31	161	323	57.00	17.40	3.10	900	51371	103198	0.37	-4.4
2010	0.39	208	409	45.63	34.45	4.16	900	53212	104965	2.27	4.9
2011	0.39	232	448	52.29	21.86	7.18	900	60005	115761	3.41	2.5
2012	0.38	214	403	54.23	17.11	8.20	800	56678	106749	2.66	-0.4
2013	0.38	234	431	51.10	14.57	11.81	900	61739	113625	1.73	3.7
2014	0.38	253	455	49.31	22.61	10.26	800	66104	118823	0.63	4.3
2015	0.43	250	439	42.77	33.33	7.79	800	57744	101376	0.47	4.3
2016	0.39	236	405	45.56	30.07	6.64	800	60691	104278	0.29	4.6
2017	0.51	326	547	34.40	42.06	4.64	800	64023	107361	1.73	1.8

2018	0.50	356	586	33.42	45.18	5.05	900	70885	116597	1.53	3.1
2019	0.54	386	623	30.76	49.71	3.16	900	71105	114685	1.74	2.3
2020	0.55	406	642	30.13	50.15	3.42	1000**	73264	115873	0.82	-1.3
2021	0.54	403	625	29.48	38.18	11.53	1050**	68500	110000	2.65	6.5
2022	0.58	523	651	24.11	52.37	11.22	1100**	73000	115000	6.60	2.4

*Defence Expenditure
**based on Thull (2022)

(Source: NATO, 1992, 1994, 1996, 2001, 2005, 2011, 2015, 2017, 2022b; World Bank, 2022)

APPENDIX B: Exogenous Influence Factors

Year	DE NATO EU by share of GDP (%)	DE NATO Total by share of GDP (%)	DE US by share of GDP (%)	Sub prime	Dot Com	COVID-19
1989	3.10	4.40	5.90	0	0	0
1990	3.00	4.10	5.60	0	0	0
1991	2.90	3.70	5.00	0	0	0
1992	2.70	3.70	5.20	0	0	0
1993	2.60	3.60	4.80	0	0	0
1994	2.40	3.30	4.30	0	0	0
1995	2.30	3.00	4.00	0	0	0
1996	2.30	2.90	3.70	0	0	0
1997	2.20	2.70	3.30	0	0	0
1998	2.10	2.60	3.10	0	1	0
1999	2.10	2.60	3.00	0	1	0
2000	2.10	2.50	3.00	0	1	0
2001	2.00	2.60	3.10	0	0	0
2002	2.00	2.70	3.40	0	0	0
2003	2.00	2.70	3.80	0	0	0
2004	2.00	2.70	4.00	0	0	0
2005	1.90	2.80	3.80	0	0	0
2006	1.80	2.90	4.10	0	0	0
2007	1.70	2.90	4.20	1	0	0
2008	1.69	3.16	5.04	1	0	0
2009	1.70	3.31	5.32	1	0	0
2010	1.63	3.04	4.81	1	0	0
2011	1.55	2.97	4.77	0	0	0
2012	1.53	2.82	4.42	0	0	0
2013	1.47	2.76	4.03	0	0	0
2014	1.43	2.59	3.73	0	0	0
2015	1.42	2.48	3.52	0	0	0
2016	1.44	2.48	3.52	0	0	0
2017	1.48	2.40	3.31	0	0	0
2018	1.51	2.41	3.29	0	0	0
2019	1.54	2.45	3.52	0	0	0
2020	1.72	2.75	3.72	0	0	1
2021	1.69	2.65	3.57	0	0	1
2022	1.64	2.57	3.47	0	0	1

*Defence Expenditure

(Source: NATO, 1992, 1994, 1996, 2001, 2005, 2011, 2015, 2017, 2022b)

IFOR	KFOR	ISAF	VJTF	eFP	EUTM	Riga06	Wales14	Madrid22
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0
0	1	1	0	0	0	0	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	1	0	0	0	1	0	0
0	1	0	0	0	0	1	0	0
0	1	0	0	0	0	1	1	0
0	1	0	0	0	0	1	1	0
0	1	0	0	0	0	1	1	0
0	1	0	0	1	0	1	1	0
0	0	0	1	1	0	1	1	0
0	0	0	0	1	1	1	1	0
0	0	0	0	1	1	1	1	0
0	0	0	0	1	1	1	1	0
0	0	0	1	1	1	1	1	1