Modelling of European Defence Sector Investment: A Systems Dynamics Perspective

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ABSTRACT
This study develops a system dynamics model to analyse the European defence sector's financial and operational dynamics from a firm-centric perspective, addressing gaps in existing macroeconomic analyses. The model captures complex, interconnected relationships between geopolitical tensions, funding mechanisms, and operational constraints over the short-term revealing that defence sector earnings face significant vulnerability to three key factors in ascending order of impact: geopolitical instability, delivery delays, and unwillingness to spend on defence. Moderate stress levels in defence spending and delivery delays have a greater impact on cumulative earnings uncertainty due to complex factor interactions, compared to geopolitical shock probabilities which has a greater impact on the absolute value of cumulative earnings.

For asset managers, the findings emphasise developing prudent risk management strategies that account for the sector's exposure to intra-European political uncertainties and broader geopolitical volatility.

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INTRODUCTION
Europe is confronted with multipronged geopolitical challenges straining its traditional reliance on diplomacy and trade. On the western front, transatlantic ties are undergoing serious recalibration as recent electoral shifts in both the EU and the US cast uncertainty over the future direction of cooperation and burden-sharing (Leblond & Vannier, 2024). Meanwhile, the bloc's eastern border remains volatile, with Russian aggression fundamentally destabilizing the post-Cold War European order. At the same time, Europe's inability to reduce dependence on adversarial actors such as China also reveals lack of diversified strategic partnerships and fragmented policy-making (Fatsiadou, 2025).

Although NATO allies' commitment to increase defence spending to 5% of GDP by 2035 – financed primarily through national and European debt instruments – will provide substantial stimulus for European defence sector growth, the growth of the defence sector faces several challenges. Primary of which is unwillingness of some allies to spend on defence in contrast to their NATO commitments (Reuters, 2025). Sources of this unwillingness are Euroscepticism, populism and fear of higher budget deficits. Secondly, due to decades of underinvestment, the sector lags behind its peers and will realistically face delays in meeting the high deliver demands. Finally, the sector is heavily reliant on imported feedstocks, such as structural metals, critical minerals, and energy sources. These imported goods are extremely vulnerable to geopolitical instability, which are completely stochastic and partly outside the control of the European governments.

SCOPE
Europe's defence sector's growth significantly impacts multiple stakeholders, particularly private sector investors, who will provide crucial funding through both debt and equity instruments motivated by economic returns, portfolio diversification benefits and strategic national interests. This article is targeted towards these private sector investors such as asset managers, offering them a framework to assess risk-reward trade-offs when investing in the emerging European defence sector.

Since this article examines the defence sector at a systemic level, it deliberately excludes many sector-specific intricacies to maintain focus on broader patterns and relationships. For instance, potential capital constraints or financing bottlenecks that could limit sectoral expansion are out of scope.

Furthermore, the model's primary KPI is Cumulative Earnings measured over a six-year trajectory and other valuation metrics such as ROIC, NOPAT, FCF *etc.* are excluded. This simplified approach assumes investment analysts hold prior beliefs about the price trajectory of the sector and can independently derive valuation multiples from the simulated earnings trajectory.

SYSTEM DYNAMICS

SUITABILITY

System Dynamics (SD) originating in engineering and rooted in nonlinear dynamics and feedback control theory, excels at revealing how complex systems evolve over time through feedback loops, time delays, and stock accumulations (Sterman, 2000). This makes it particularly appropriate for analysing the European defence sector, where financial and operational dynamics are characterised by complex, interconnected relationships that mainstream linear econometric models struggle to capture. Additionally, it translates abstract mental models into intuitive frameworks using stocks and flows. Finally, it enables modelling of external factors – geopolitical tensions, funding mechanisms, and scaling delays – to assess their collective impact on profitability and growth.

SYSTEMIC APPROACH

The SD approach for analysing the European defence sector is systemic because rather than focussing on isolated drivers, it is directed towards the interdependencies over time of structural forces such as fiscal policy, supply chains, and geopolitical shocks in a unified framework. Moreover, the model captures emergent behaviour from feedback loops and delays, revealing structural forces that shape long-term performance and investment outcomes.

RESEARCH GAP

Currently available perspectives fail to account for the interplay of uncertainty created by shifting macroeconomic conditions and industrial constraints to enable better decision making.

EUROPEAN COMMISSION ANALYSIS

The European Commission's QUEST macroeconomic model estimates the economic impact of increasing defence spending to 1.5% of GDP by 2028, focusing exclusively on aggregate EU-level effects such as GDP growth, debt levels, and inflation (European Commission, 2025). This top-down approach provides essential policy insights but cannot capture the firm-level profitability dynamics.

GOLDMAN SACHS AND BRUEGEL PERSPECTIVES

Goldman Sachs provides a theoretical framework examining funding mechanisms and spending outlooks, while Bruegel offers broader geopolitical analysis encompassing funding mechanisms and GDP growth implications (Goldman Sachs, 2025) (Breugel, 2025). Both analyses maintain a macroeconomic viewpoint, prioritising aggregate industrial outcomes over the granular, firm-level insights that investors require.

METHODOLOGY

The model is structured to capture the interaction of firm-specific endogenous variables with exogeneous uncertainty over a six-year horizon with quarterly time steps.

CAUSAL LOOP DIAGRAM

Building a causal loop diagram

According to Sterman (2000), the foundation of any SD model is a causal diagram that captures the modeller's understanding of how variables influence one another through directional arrows. Furthermore, a causal diagram only includes those relationships that capture the underlying causal structure at the chosen level of abstraction. Importantly, the links represent causations but not correlations – correlations among variables become apparent after simulation runs.

Links

The diagram contains two types of links which represent different causal relationships. Positive links (marked with a +) indicate direct relationships where variables move in the same direction, *i.e.,* when the cause increases, the effect increases beyond its expected baseline, and when the cause decreases, the effect similarly falls below its baseline. Negative links (marked with a –) work inversely, representing relationships where variables move in opposite directions.

Feedback Loop Types

These individual links combine to form two types of feedback loops.

1. Reinforcing loops are marked with + sign enclosed in a green circular arrow, to signify a feedback loop thar accelerates change in the system
2. Balancing loops marked with – sign enclosed in a red circular arrow, to signify a feedback loop that counteracts change in the system

An overview of the model is provided using the causal loop diagram below (figure 1).

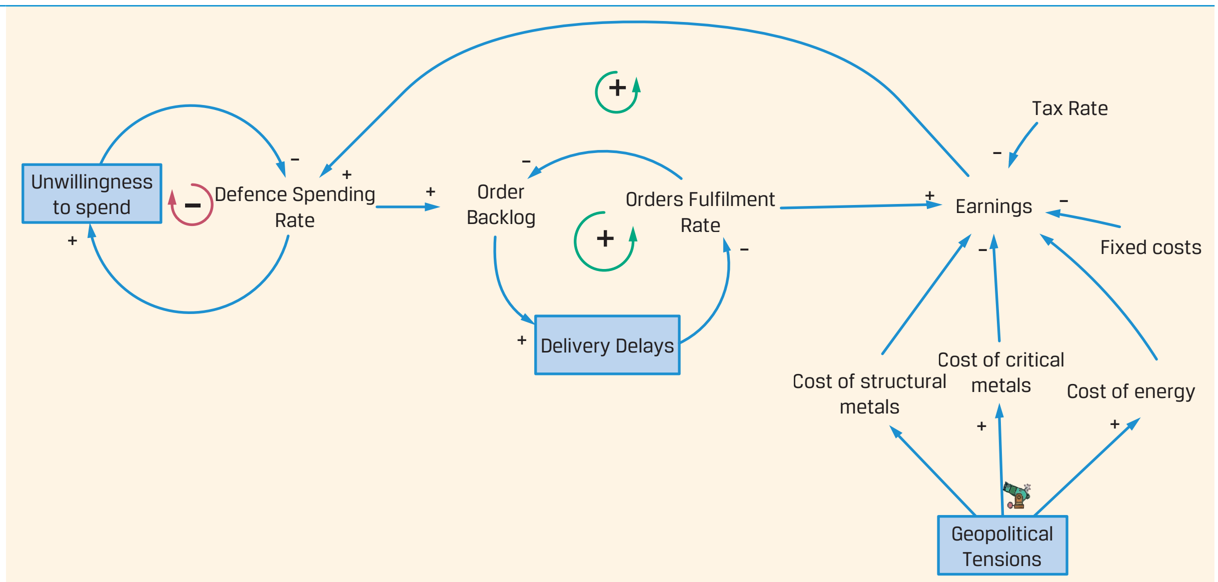
There are three external forces, which are (partly) out of control of the defence sector and the European policy makers.

1. Unwillingness to spend
2. Delivery Delays
3. Geopolitical Tensions

These create important dynamics outlined below

Loop 1: As the Defence Spending Rate increases the *Unwillingness to Spend* increases. With the plan to linearly increase defence spending by NATO allies, public and political resistance to further spending will also rise. This creates a negative feedback loop: higher spending reduces willingness, which over time slows industrial ramp-up and introduces volatility into long-term investment planning.

Figure 1
Causal loop diagram of the model



Loop 2: As *Defence Spending Rate* increases, the *Order Backlog* increases, which leads to increases in *Delivery Delays*. The delays increase due to factors like inability to scale operations commensurate to demand. But, with time the sector is able to increase its *Order Fulfilment Rate* which decreases the Order Backlog. This creates a positive feedback loop.

Loop 3: As the *Order Fulfilment Rate* increases, the *Earnings* increase and as the *Earnings* increase, there is greater interest in the defence sector from investors. This influences the defence spending loop positively.

Loop 4: As *Geopolitical Tensions* increase, cost of various feedstocks increases and that leads to lower *Earnings*, which eventually decreases the *Defence Spending*. This loop is influenced by actors outside control of EU and the defence sector therefore unlike other loops, this loop does not close.

ASSUMPTIONS

Like all analytical frameworks, this model too represents a simplified abstraction of reality and not all variables affecting the European defence sector are incorporated. Assumptions made for modelling are explained below which the reader should consider when interpreting results.

1. Rheinmetall is chosen as a representative of the European defence sector due to its position as one of the largest and fastest-growing defence companies in the EU, driven by the evolving geopolitical landscape. Although headquartered in Germany, Rheinmetall has significant international engagement making it sensitive to external shocks. Moreover, Rheinmetall's broader portfolio and substantial order backlog compared to other European companies like BAE, Saab and Leonardo makes a compelling case to use it as a proxy for the European defence industry's overall dynamics and opportunities (Dyos, 2025) (MacDonogh, 2025).
2. The Cumulative Earnings in the simulations are therefore of Rheinmetall which forms a proxy for the European defence sector.
3. The model assumes defence companies can secure unlimited private funding for organic growth. Therefore, fundraising activities through debt and equity is not modelled
4. The model assumes a singular European funding mechanism will finance the defence spending. This reflects EU's growing capacity for supranational debt issuance and member states' commitment to collectively issue defence bonds (Scope Ratings, 2025).
5. Various structural metals form an important feedstock to the defence sector, specifically hot-rolled coil steel is used as a representative structural metal. This is done because of its heavy use by the defence sector in the production of a wide range of equipment such as armoured vehicles, weapon systems, and structural frames.
6. Various critical metals form an important feedstock to the defence sector, of which cobalt is chosen as representative. This is done because of its use in military electronics and as a thermal alloy. Moreover, 70% of cobalt originates from the D.R. Congo and has significant Chinese processing dominance which presents a major geopolitical risk.
7. Natural gas is chosen as a representative of energy costs because it plays a dominant role in key defence sector activities such as steel processing, forging, and the chemical production of explosives and propellants. Moreover, natural gas is sensitive to geo-political risks due to which it is an ideal indicator of macro energy cost risk.

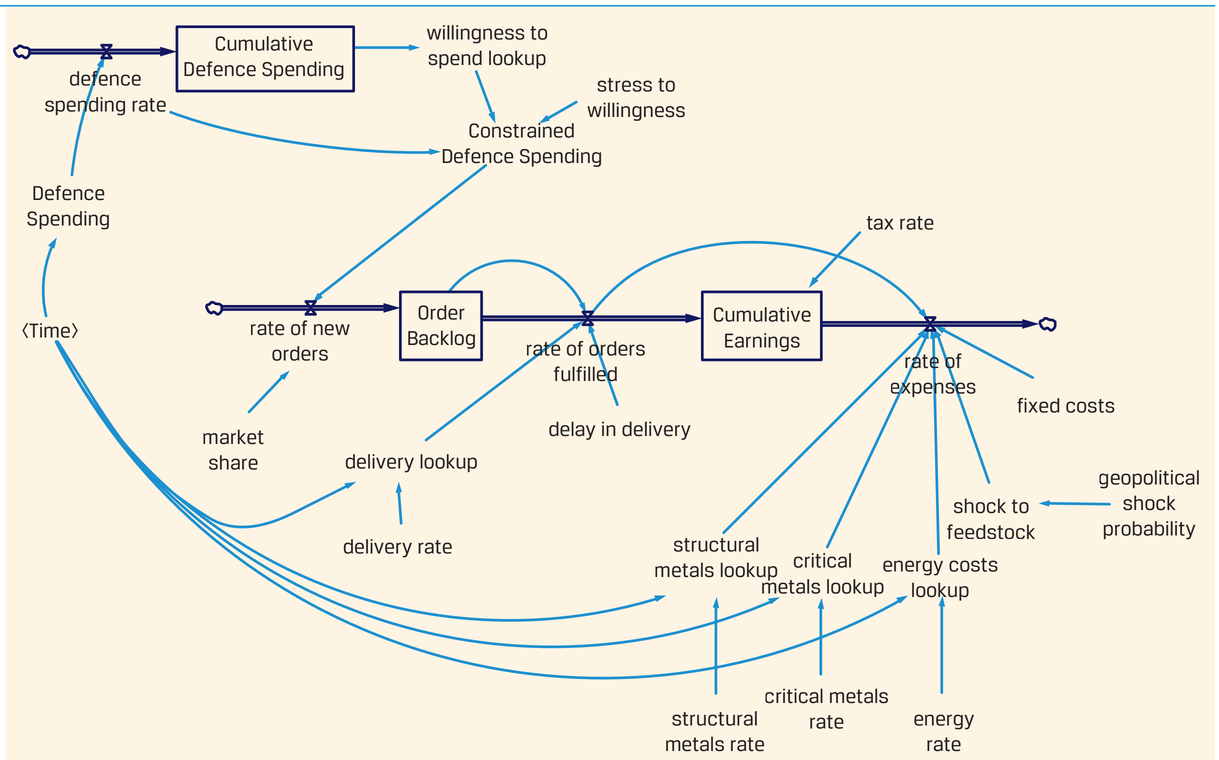
STOCK AND FLOW DIAGRAM

The causal loop diagram which is abstracted at a higher level of detail is translated into a detailed system dynamics stock-and-flow model. Because the stock-and-flow model explicitly models the complexity of the system and various dynamic elements, it is more detailed than the causal loop diagram.

TIME HORIZON

While defence procurement decisions and industrial capacity building traditionally unfold over multi-decade timelines, recent geopolitical shifts primarily the election of Donald Trump and

Figure 2
Stock and Flow diagram of the model



escalating Russian aggression have driven European nations to advocate for accelerated defence build-ups within a five-year timeframe (Cook, 2025). Notwithstanding the rapid response demanded, the defence sector faces structural challenges. More than 40% of companies report difficulty substituting current imports with European alternatives, while ongoing trade tensions and logistics disruptions continue restricting access to essential materials (European Investment Bank, 2025).

This exposes the central dilemma: while structural adaptation typically unfolds over decades, governments are demanding transformation within a shorter time frame. While Europe's strategic autonomy may be achievable long-term, short-term implementation failures could derail the entire effort. Therefore, this article examines risks and emergent behaviour in this transitional phase which is characterised by scaling challenges after a period of prolonged underinvestment (Eijden, 2025).

Although a five-year horizon seems obvious, a horizon of six years (24 quarters) is chosen for the simulation. This is done to capture the ramp-up phase of first five years and the phase of stabilization in the sixth year. Furthermore, by fixing the horizon at exactly five years, dynamics that would spill over just beyond this decisive period would get truncated. Therefore, it is chosen to extend the model to 24 quarters to obtain a more comprehensive view of how the defence sector will behave under fiscal willingness, industrial scaling, and geopolitical shocks.

Time Bounds of the Simulation

The time step is chosen in quarters and not months because months would have been too granular while years would have become too coarse. Furthermore, fiscal planning cycles such as budget allocations, procurement and order backlogs typically occur in quarterly cycles. Therefore, the time step was chosen as quarterly since it strikes an appropriate balance between capturing variation according to familiar time cycles and avoiding unnecessary noise.

EXOGENEOUS PARAMETERS

In SD, two kinds of variables are present (Sterman, 2000):

1. **Exogenous variables** influence other variables in the model but are not themselves altered by the model's internal feedback loops. They are treated as predetermined numerical values or lookup functions, often derived from external data or assumptions. In this definition exogenous is an element of the model construct and should not be interpreted in the everyday sense of being completely independent.
2. **Endogenous variables** conversely change in response to feedback from the model, are calculated by the model itself and can be explained by the structure of the model.

There are four types of exogeneous inputs that drive this model

1. Lookup variables are defined by a set of values (often from data or assumptions) across time and they provide a reference curve that other variables can query at each time step.
2. Constants are fixed values that remain unchanged over the course of the simulation.
3. Control variables are parameters to explore scenarios and allow sensitivity analysis.
4. Conditional variables are stochastic parameters that introduce uncertainty into the model.

Table 1 includes a brief description, characteristics, and the implementation of each of these parameters. Detailed values of these parameters are available on the GitHub repository.

Table 1
Exogeneous Parameters

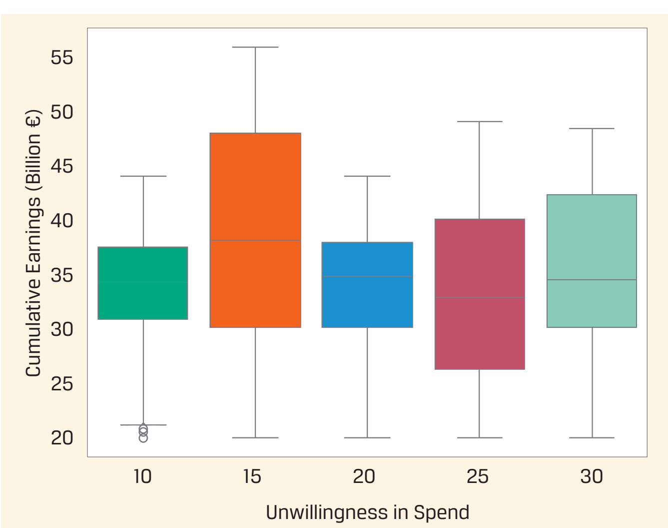
Parameter Name	Description	Characteristic	Type
Defence Spending	Government budget allocated to defence	Linearly increasing with time	Lookup
Willingness to spend	Decline in political willingness with spending	Linearly decreases as cumulative defence spending increases with time	Lookup
Stress to willingness	The greater the stress, the higher the unwillingness to spend	Ranges from 1 to 3	Control
Market share	Share of total defence orders captured by Rheinmetall	15%	Constant
Delivery lookup	With time, order fulfilment efficiency increases	Linearly increasing with time	Lookup
Delay in delivery	Time lag in order fulfilment to account for sensitivity to scale up production	Ranges from 1 to 20 quarters	Control
Critical metals lookup	Cost evolution of critical metals	Estimate obtained from S&P global	Lookup
Structural metals lookup	Cost trend for structural metals	Estimate obtained from S&P global	Lookup
Energy costs lookup	Trend in energy costs	Estimate obtained from S&P global	Lookup
Geopolitical shock probability	Likelihood of external disruption per quarter	Ranges from 5% to 10% per quarter	Control
Shock to feedstock	Multiplier to the feedstock costs if a shock occurs	1 = baseline, no shock. 1.3 reflects mild disruptions that dominate frequency. 3 represents tail events with heavy amplification effects	Conditional/ Random Var.
Fixed costs	Constant baseline production costs based on Rheinmetall Annual Report	57%	Constant
Tax rate	Corporate tax rate	30%	Constant
Time Step	Granularity of simulation	monthly	Constant
Time Bounds	Period of simulation	24 quarters	

RESULTS AND SENSITIVITY ANALYSIS

Even moderate stress can heighten volatility, while elevated shock probabilities rapidly erode profitability and predictability compounded by stochastic interaction effects.

SENSITIVITY OF CUMULATIVE EARNINGS TO UNWILLINGNESS TO SPEND

Figure 3
Distributions of Cumulative Earnings across varying levels of fiscal unwillingness



The plot demonstrates how cumulative earnings respond to different degrees of spending unwillingness arising from fiscal, political, and societal constraints.

At the lowest level of unwillingness (1.0), which reflects a political environment highly supportive of defence spending in response to geopolitical threats, orders are fulfilled more steadily and capital flows are less constrained. This results in relatively low variability in this scenario – suggesting a stable and investable outlook.

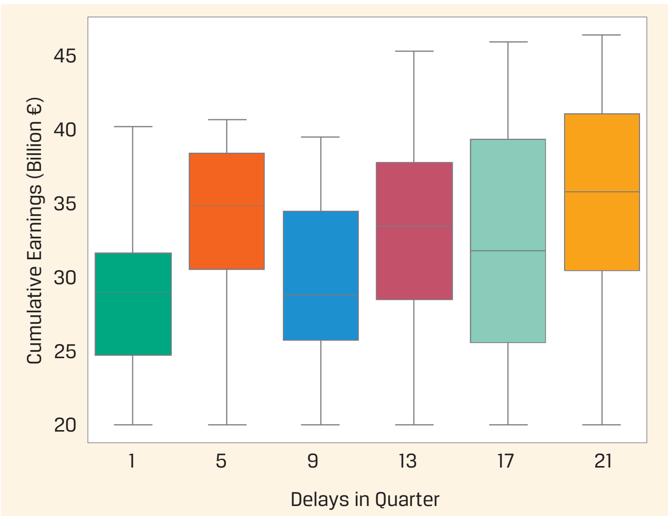
Interestingly, at an unwillingness level of 1.5, median cumulative earnings actually exceed those observed in the baseline case (1.0), despite a noticeably wider interquartile range. This counterintuitive outcome arises as moderate fiscal restraint unintentionally optimizes delivery flows by evenly distributing sharp spikes in order backlog. However, geopolitical sensitivity to feedstock shocks persists which explains the earnings dispersion.

As the unwillingness increases beyond 1.5, earnings decline and stagnate to a low-activity equilibrium. across higher unwillingness levels (2.0 to 3.0). This simulation exhibits that as defence spending is progressively throttled, the rate of new orders slows enough to passively absorb both order backlog fluctuations and feedstock shocks.

Essentially, rising unwillingness to spend erodes the sector's dynamism, dampening both its upside potential and exposure to risk – ultimately resulting in consistently mediocre outcomes.

SENSITIVITY OF CUMULATIVE EARNINGS TO DELAYS IN DELIVERY

Figure 4
Distributions of Cumulative Earnings across varying levels of Delivery Delays



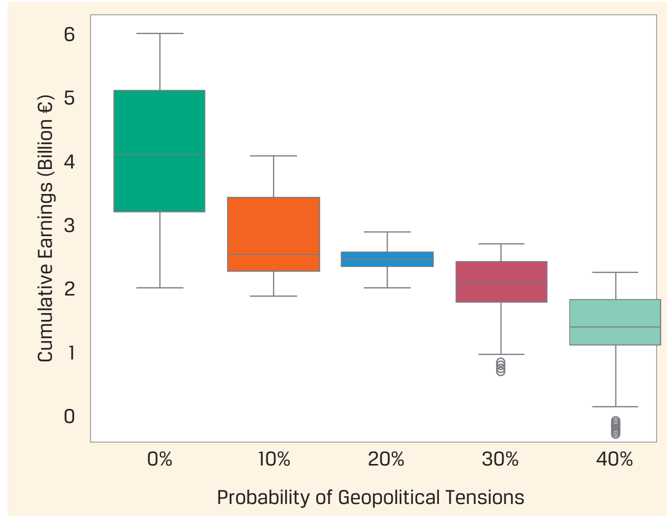
The plot reveals that increased earning uncertainty manifested through wide IQR with incremental delays in delivery. However, median earnings decline non-monotonically. This is evident in the delays of 5, 13, and 21 quarters compared to a 1-quarter delay. These confounding results can be explained due to the model's incorporation of stochastic elements that mirror real-world uncertainties which create complex interactions between timing effects and random shocks. This counterintuitive pattern likely stems from smoother cost realisation profiles, deferred expense recognition, and reduced exposure to early-period volatility – effectively creating a temporal buffer. Although, this enhances median outcomes in various scenarios, it simultaneously increases outcome variability.

This demonstrates that specific supply-chain dynamics can make longer delivery timelines paradoxically beneficial for earnings stability and profitability, albeit at the cost of reduced strategic agility and potential customer satisfaction concerns.

SENSITIVITY OF CUMULATIVE EARNINGS TO GEOPOLITICAL TENSIONS

Higher geopolitical instability directly undermines defence sector earnings primarily through stochastic cost shocks. Without geopolitical shocks (0% scenario), the sector operates efficiently with higher profitability, yet earnings dispersion persists due to the model's inherent feedback loops even in this benign scenario. This reflects a fundamental characteristic of system dynamics due to which the system remains vulnerable to interconnected stochastic variations in elements such as production delays which can compound over time even in stable conditions.

Figure 5
Distributions of Cumulative Earnings across varying levels of Geopolitical Tensions



The plot reveals widening uncertainty and extreme downside risks beyond 20% shock probability, where both expected returns and earnings reliability deteriorate rapidly. This deterioration manifests through negative outliers and potential deep losses approaching zero earnings. Such vulnerability demonstrates the sector's acute sensitivity to feedstock price volatility and cascading cost effects that can fundamentally destabilise profitability under persistent geopolitical stress.

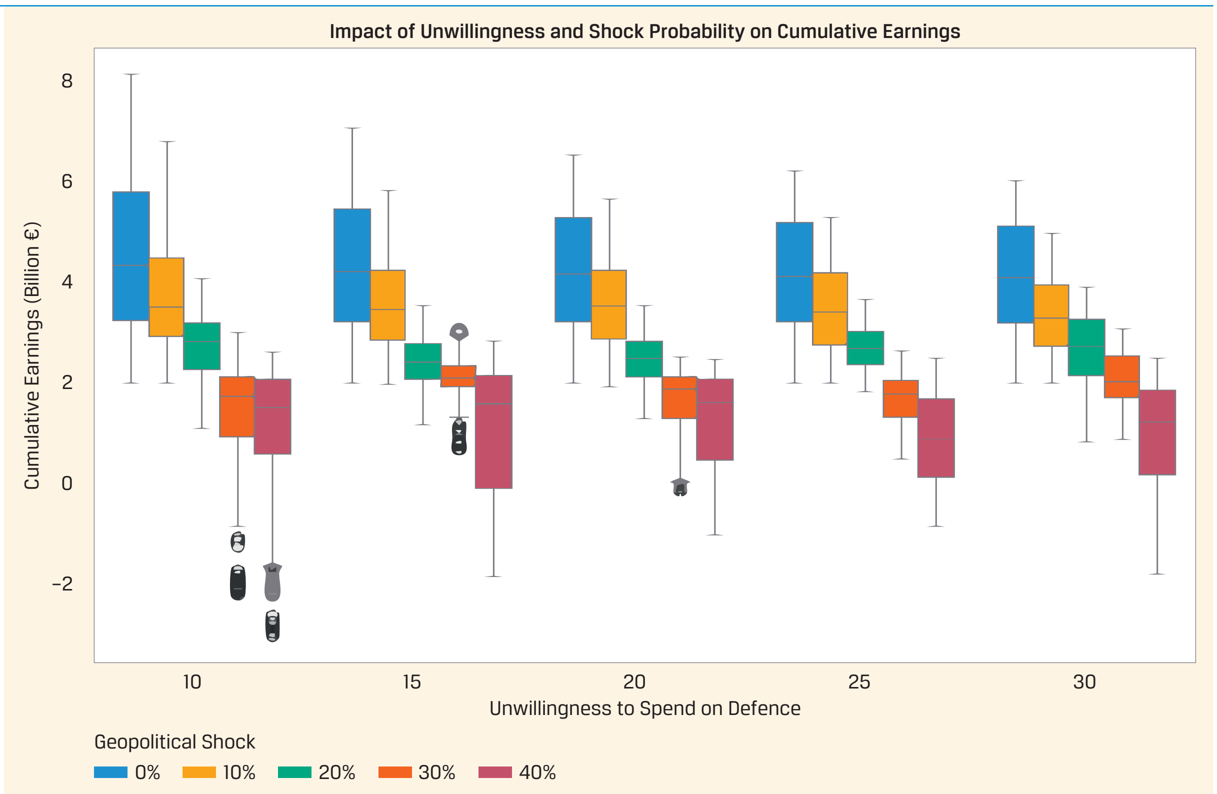
Finally, unlike the previous factors such as unwillingness to spend and delivery delays which produced mixed results and non-monotonic patterns due to system dynamics and nonlinear interactions, geopolitical tensions exhibit a direct and consistently negative impact on earnings.

COMBINED VARIABLE INTERACTION EFFECTS ON CUMULATIVE EARNINGS

This section examines the combined effect of all three external variables namely: unwillingness to defence spending, delivery delays, and geopolitical instability on cumulative earnings. Although the simulation is swept across all scenarios for the three variables, practical visualization limitations prevent displaying three-dimensional results. Given the previous analysis demonstrating that unwillingness to spend and geopolitical instability inflict the greatest damage on sector profitability, these two variables are presented below.

The analysis reveals that earnings decrease systematically as shock probability increases from 0% to 40% within each unwillingness level. Although the previous sections show each factor alone is capable to reduce earnings, their combined interaction creates nonlinear drops and significantly increased volatility. Non-linear effects intensify at higher combinations of unwillingness and geopolitical shock probability, creating severe earnings deterioration. At the most adverse scenario (unwillingness = 3.0, shock = 40%), median earnings approach zero or turn negative with extensive downward outliers, indicating substantial investment risk.

Figure 6
Joint Impact of External Constraints on Cumulative Earnings



Paradoxically, scenarios with low to moderate unwillingness (1.0 to 1.5) exhibit wider interquartile ranges, reflecting greater variability from complex interactions between delivery delays, cost fluctuations due to geopolitics, and order fulfilment dynamics. This creates heightened sensitivity and reduced predictability even in moderate stress conditions. However, at extreme stress levels, the dominant factors overwhelm these interactive effects, resulting in more predictable though consistently poor outcomes.

STRATEGIC IMPLICATIONS FOR DEFENCE SECTOR INVESTMENT

Without strong risk management, exogeneous shocks can erode earnings, turning investment in the upcoming European defence sector a costly, low-return exposure.

UNWILLINGNESS TO SPEND IS STRUCTURALLY DETRIMENTAL

Reduction in defence budgets due to fiscal or political constraints leads to a plateau in cumulative earnings. This pattern aligns with evidence that major European defence contractors already hold historically high order backlogs, therefore fiscal uncertainty's impact is largely on the variability of earnings trajectories (Dyos, 2025). This uncertainty is critical at this juncture because without predictable spending schedules from the national governments, industrial throughput and economies of scale of the capital-heavy defence sector will get constrained.

On the other hand, the findings also suggest that European policymakers should exercise restraint in ramping up the sector too quickly. Premature or excessive demand on a sector that has yet to scale can backfire – amplifying inefficiencies, attracting speculative capital, and placing stress on fragile supply chains. A more measured approach will help sustain the rearmament effort over time by dampening shocks and avoiding unnecessary fiscal strain on national budgets. The latter is politically crucial as fiscal strains can cause second-order risks of public backlash and political fragmentation. Which could eventually jeopardize the long-term legitimacy and continuity of Europe's defence renewal.

GEOPOLITICAL SHOCKS EXACERBATE RISK AND VARIANCE

A surge in geopolitical shock probabilities leads to both a drop in median earnings and a significant increase in volatility. At elevated shock probabilities, several simulations show near-zero or even negative cumulative earnings
A combination of the stressors: high unwillingness and high shock probability makes the sector acutely vulnerable. Earnings collapse, variability surges, and systemic risk amplifies. Notably, some dynamics (*e.g.*, longer delivery delays) can occasionally offset and smooth shocks due to deferred cost realization, but such effects are inconsistent and not broadly reliable.

CONCLUSION

Short-term investment performance in Europe's defence sector depends not only on sustained demand but also on coherent, consistent and balanced political will. Although recent EU initiatives on critical raw materials and defence spending mark important steps toward greater autonomy, their effectiveness will depend on careful implementation. Without translating these acts into robust mitigation measures that strengthen the sector's capacity to absorb and adapt to supply chain disruptions, cost volatility, and delivery constraints, the rearmament drive risks entrenching vulnerabilities rather than resolving them.

For investors, this analysis highlights the critical importance of assessing political commitment continuity alongside traditional financial metrics. Policy reversals at the European level and external shocks from trading partners can fundamentally alter sector profitability regardless of underlying fundamentals.

Investors should therefore develop prudent risk management strategies that account for the inherent vulnerabilities underpinning this sector. While long-term structural growth prospects remain promising for European defence capabilities, investments face significant downside risks if political will diminishes or geopolitical tensions escalate unexpectedly.

Finally, SD offers unique analytical capabilities to formalize mental models while identifying volatility patterns and emergent behaviours across different time horizons. This can complement traditional modelling techniques in the asset management sector. Crucially, SD models reveal the non-linear interactions of market dynamics and policy interventions uncovering risks and opportunities that linear projections would overlook.

LIMITATIONS

This article takes a systemic approach to modelling the defence sector, but capturing every causal relationship would be both impractical and potentially overwhelming for readers. As a result, many of the sector's nuances remain unexplored. I approach this analysis with appropriate humility, recognizing two key limitations. Firstly, the research relies entirely on publicly available sources, which inevitably miss the behind-the-scenes political decisions that shape this industry. Secondly, defence policy falls outside my primary area of expertise.

CODE AVAILABILITY

The source code for the model and all related parameters are available at https://github.com/bhatt-keshav/Defence-Autonomy

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