Examining Driving Forces of Arms Production: Security Demand or Economic Needs—World's Largest Defense Companies[1]

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Abstract: Arms production differs from that of general products because it involves both government and market factors. The needs of various actors vary; therefore, arms production is driven by internal security demands and external economic needs. This study identifies the complex factors behind arms production using fuzzy-set qualitative comparative analysis (fsQCA) to examine the configurations influencing arms production among the 77 largest defense companies. The results indicate that economic needs alone are neither necessary nor sufficient conditions for arms production. Arms production primarily stems from a country's security needs, including domestic government procurement and demand for arms imports. Furthermore, a country's economic scale and R&D strength contribute to increased arms sales.

Keywords: Arms production; Arms transfer; Defense spending; Fuzzy-set qualitative comparative analysis (fsQCA)
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Introduction

Unlike general commodities, weapons display the characteristics of public goods and are closely tied to government policies. Research indicates that defense spending and international arms trade are closely linked to a country's arms production (Daniel Albalate, Germà Bel, and Ferran Elias, 2012; Johannes Blum, 2018; 2019; Justin George and Todd Sandler, 2018; Johannes Blum and Niklas Potrafke, 2019; Paul Levine and Ron Smith, 1997). Arms production is driven by demand and supply. Demand is influenced by market size, defense spending, and GDP, and supply is shaped by international pressure (Paul Dunne and Ron Smith, 2016). In other words, a country's arms production equals domestic government purchases plus arms exports (Paul Dunne, Sam Perlo-Freeman, and Ron Smith, 2018). Identifying the factors that determine a country's arms production is the focus of this study. It has certain practical significance for our understanding of degree of countries' self-sufficiency in military matters and the formulation and improvement of a country's defense industry policy.

The rest of the article is organized as follows. Section 2 reviews the literature on the relationship between defense companies' arms sales, defense spending, and arms trade. Section 3 introduces the fsQCA research methodology and relevant data. Section 4 presents the empirical analysis of the driving factors behind arms production. Section 5 presents the conclusion.

Literature Review

Since the end of the Cold War, most studies on weapons production have focused on the evolution of arms market concentration (Dunne et al., 2007; Keith Hartley, 2007; Dunne and Smith, 2016; Stephanie Neuman, 2010), dual-use technology development (François-Xavier Meunier and Célia Zyla, 2016; Manuel Acosta et al., 2018), defense procurement (Stefan Markowski and Hall Peter, 1998; Stefan Markowski, 1998), R&D intensity, and the reduction of unit costs (Maria Garcia-Alonso and Paul Levine, 2007) to explore the characteristics of the international arms market. While there are qualitative analyses of the global defense industry and quantitative studies of arms firms in individual countries, comparative studies on international arms production and sales remain limited. States play a key role in the arms industry by influencing the quantity and quality of domestic arms production. This is driven by defense procurement for defense spending and arms import and export trade (Dunne and Smith, 2016).

On the one hand, defense spending is closely linked to national weapons production. Military spending includes arms purchases and other categories, with increased spending driving domestic arms production (Markowski, 1998; William Nordhaus, John Oneal, and Bruce Russett, 2012). Reductions in military spending lead to changes in weapons production and the restructuring of the defense industry (Ron Smith, 2013). Ron Smith and Paul Dunne (2018) argued that the short-run elasticity of arms sales to military spending is 1.56, and the long-run elasticity is 1. Military spending accounts for 92% of the growth in arms sales, and domestic arms procurement equals domestic arms production plus arms imports minus arms exports (Johannes Blum, 2019). On the other hand, although all countries need arms, not all can produce them domestically (Irina Tulyakova, Victor Dengov, and Elena Gregova, 2021). Few countries are fully self-sufficient in arms production, and domestically produced weapons often require supplementation with imported weapons or components (Jurgen Brauer, 2007). Hugo Meijer (2018), drawing on neoclassical realism, proposed a framework that integrates international and domestic factors to explain differences in arms transfers among large countries. He constructed indicators of arms export and import dependence as proxies for the domestic defense and technology industrial base (DTIB). He compares the arms transfer policies of the U.S., UK, France, and Russia with respect to China. Garcia-Alonso and Levine (2007) developed a model in which buyers and sellers optimize the quantity and price of arms under specific policies, extending it to the determinants of market structure in the military sector. They argue that arms-producing countries are increasingly willing to import arms.

Arms transfers differ from general trade in goods and services because they involve economic considerations and military capabilities, international relations, political security, and defense security. A country's arms transfer decisions are driven by its strategic and political objectives and are influenced by complex factors such as different trade actors, interests, and needs (Robert Beeres et al., 2022; Xin-Yi Wang, Bo Chen, and Yu Song, 2023). Economically, beyond market size, the profit motive encourages military companies to "lobby" governments to increase arms exports. At the same time, the risk of proliferating knowledge and technology impacts the arms transfer decisions of governments and companies (Samuel Perlo-Freeman, 2018). From a security and strategic perspective, a country's domestic and international security environment can either encourage increased arms trade in the pursuit of national stability or constrain it due to security risks, with the benefits of arms exports being offset by negative security effects (Vincenzo Bove and Tobias Böhmelt, 2021).

Military budgets are also a key determinant of arms trade (Blum, 2019), as they reflect a country's military capabilities and influence domestic resource allocation decisions. There is a clear link between defense spending and arms trade, with higher military spending increasing arms sales and imports (Ron Smith and Ali Tasiran, 2010). Military spending positively and negatively affects arms exports (Ron Smith, Anthony Humm, and Jacques Fontanel, 1985). Vincenzo Bove, Claudio Deiana, and Roberto Nisticò (2018) argued that arms imports are a significant component of the defense budget, with factors such as national security, price, income, and international political relations affecting the optimal balance between domestic production and arms imports. On the supply side, states sell weapons for economic and strategic reasons. Michael Seitz, Alexander Tarasov, and Roman Zakharenko (2015) developed a quantitative model examining welfare gains from trade, conflict, and defense spending, exploring the causal link between trade and conflict and the relationship between conflict and defense spending. Oliver Pamp and Paul Thurner (2017) linked defense spending to arms imports and exports, showing that arms imports and exports strongly impact defense spending. Their findings reveal a negative relationship between arms exports and defense spending in democratic countries. Oliver Pamp, Florian Dendorfer, and Paul Thurner (2018) constructed a theoretical model to assess the impact of arms trade on domestic military budgets. They investigated whether a substitution effect exists between arms exports and military spending. Their conclusions suggest that arms exports reduce domestic military spending, assuming suppliers anticipate positive security externalities.

Existing literature focuses on the demand functions for national defense spending and the determinants of the international arms trade. However, defining an arms industry or market solely based on product, use, and geographic space is challenging due to secrecy issues and varying arms production measures (Dunne and Smith, 2016; Smith and Tasiran, 2010). As a result, empirical studies that combine arms sales data with defense spending and international arms transfers are relatively scarce (Smith and Dunne, 2018). Dunne et al. (2007) developed a theoretical model to determine the defense industry's base and size by analyzing the arms industry's structure by investigating the factors influencing arms purchases. Filiz Yesilyurt et al. (2014) examined the arms industry structure using the International Standard Industrial

Classification (ISIC) 2027 for Arms and Ammunition as the output data. To explain arms production, the researchers analyzed military expenditure, arms exports and imports, and GDP per capita for 15 countries from 1997 to 2002. Their findings show that intra-industry trade promotes defense technology development, and arms imports help advance arms technology in importing countries. However, Michael Brzoska (2019) indicated the lack of global data on national weapons production, citing three main limitations: (1) the difficulty in distinguishing between weapons and civilian production and direct and indirect weapons production; (2) the challenge of harmonizing national definitions and classifications of weapons in the ISIC; and (3) the reluctance of governments to disclose national weapons production data. Instead, the closest available estimate of global weapons production comes from SIPRI's data on sales of the world's 100 most significant arms production and military service companies.

Thus, the value of corporate arms sales within national jurisdictions serves as a more suitable indicator of a country's arms production data. Scholars are encouraged to investigate the economics of arms at the firm level (Smith and Dunne, 2018). In this context, Blum (2019) argued that arms orders for the armed forces and arms exports determine sales. Blum combines sales data from the world's 100 most significant arms production and military service companies in SIPRI with national trends in arms transfer values (TIV), using data from 21 countries between 2002 and 2016 and 195 arms companies. The relationship between arms supply from companies and domestic and foreign demand for military goods has been empirically examined. The results show that defense spending and exports increase arms sales, while arms imports complement arms sales.

Although existing literature advances data analysis to address limitations in examining the causes of arms production, it faces drawbacks in the quantitative time-series analysis of individual firms' development over time. Furthermore, given the complex causal relationships among arms production, arms trade, and defense expenditure, methodological limitations persist even with panel models. This study aims to address these gaps in the literature, as detailed below. This study makes a significant contribution to three key areas. First, while existing literature examines factors influencing defense expenditure and arms trade, empirical studies on arms production across countries remain limited due to data constraints.

This study fills this gap by using Stockholm International Peace Research

Institute: SIPRI arms industry data to analyze production patterns in countries hosting large, top-ranked arms companies, providing a more detailed view of defense economics. Second, while research focuses on arms production in individual countries or firms from the perspectives of R&D, scale, and ownership, this study introduces an international perspective. It offers new insights into the arms production dynamics of countries with varying supply and demand characteristics, broadening the scope of current literature. Third, while previous studies use time-series or case study methods to examine the relationship between post-Cold War reductions in defense expenditure, arms production demand, and the link between arms imports/exports and production, these methods are limited by ongoing structural changes in the arms industry, such as mergers and acquisitions (Aude Fleurant and Nan Tian, 2018). The present study overcomes these challenges by adopting a novel methodological framework combining qualitative and quantitative techniques. It uses fuzzy-set qualitative comparative analysis (fsQCA), based on Boolean algebra and set theory, to explore the complex interactions between defense expenditure, arms transfers, and other key variables driving arms production, offering a more nuanced understanding of the underlying causal mechanisms.

Methodology and Data

Fuzzy qualitative comparative analysis

This study employs fuzzy set Qualitative Comparative Analysis (fsQCA) as its primary methodological approach, motivated by the unique characteristics of the arms industry and the research objectives. fsQCA offers three key advantages: (1) it handles complex causal relationships by identifying multiple pathways (e.g., high arms production resulting from either high defense spending with strong R&D or low defense spending with active arms trade); (2) it integrates qualitative and quantitative insights, combining case-oriented depth with set-theoretic rigor to explore both "how" and "why" behind observed patterns; and (3) it effectively analyzes mixed data types, capturing the interplay between firm-specific factors (e.g., specialization) and national-level factors (e.g., defense budgets) to provide a holistic understanding of arms production dynamics.

Specifically, the general linear approach assumes that the effects between variables occur independently and employs regression analysis to evaluate the net effect between variables (Charles Ragin, 2006). In contrast, qualitative comparative analysis (QCA), introduced by Charles Ragin (1998), combines qualitative and quantitative methods using a set-theoretic approach to examine the causal complexity resulting from combinations of conditions.

QCA is a diversity-oriented method that identifies multiple paths to understand the structure of the relationship. It is well-suited for analyzing random yet complex phenomena, particularly in small-N cases—situations too large for traditional qualitative analysis but too small for statistical analysis (Sascha Kraus, Domingo Ribeiro-Soriano and Miriam Schüssler, 2018). Unlike methods that decompose cases into independent variables, QCA transforms cases into combinations of attributes represented as sets based on Boolean algebra principles (Alois Ganter and Achim Hecker, 2014). This approach defines combinations of causes or conditions as multiple pathways leading to an outcome. The methodology focuses on the necessary and sufficient relationships between conditions and outcomes. For necessity, outcomes are subsets of causal conditions, whereas for sufficiency, causal conditions are subsets of outcomes (Nicolas Legewie, 2013).

QCA is further categorized into csQCA, mvQCA, and fsQCA based on the types of research data it analyzes, handling dichotomous, multi-valued, and continuous variables, respectively. Kraus et al. (2018) reviewed 77 journal articles on fsQCA in business management research from 2005 to 2016, concluding that fsQCA has strong potential for applied research, particularly in exploring causal configurations of firm performance and business model innovation. Stefan Verweij and Barbara Vis (2021) offered valuable insights into political science by comparing three QCA strategies incorporating temporal dimensions and using a descriptive approach to examine case configurations over time in other fields.

In military politics, Katharina Meissner and Patrick Mello (2022) applied fsQCA to examine the negative externalities of UN sanctions under various conditions, finding that long-term, comprehensive sanctions often have significant adverse effects, while authoritarian targets with economic instruments can remain largely unaffected. Mohamed Dawood Shamout (2020) used fsQCA to analyze the sufficient and necessary conditions for supply chain sensitivity (performance). Babette Never and Joachim Betz (2014) explore the causal relationship between environmental performance and domestic climate policy performance in emerging economies. Similarly, Mohammad Asif Salam, Murad Ali, and Konan Anderson Seny Kan (2017) investigated how supply chain uncertainty impacts operational performance.

Collectively, fsQCA has been applied across diverse fields, including political science, sociology, marketing, and business management, offering new perspectives for qualitative and quantitative analysis in small- and medium-sized samples. This study uses fsQCA as the research method, given that the indicators are continuous variables, and conducts the analysis using fsQCA 3.0 software. (1) The process begins by calibrating the variables into fuzzy sets, defining points for full non-membership, crossover point, and full membership. (2) The analysis generates a truth table to evaluate outcomes based on frequency and consistency values. Frequency reflects the number of observations for each possible combination, and consistency measures how well cases align with the set-theoretic relationship. Coverage evaluates the empirical relevance of a consistent subset, functioning similarly to a coefficient of determination (Shamout, 2020). (3) The study generates and assesses solutions for the necessity and sufficiency of conditions, determining whether they are present, absent, or irrelevant. These solutions are categorized into core variables that exhibit strong causal conditions and peripheral variables that exhibit weaker causal effects. Finally, the analysis summarizes the driving paths of arms production by interpreting the solutions based on consistency and coverage values.

Research Design

The QCA relies on a full interaction model that considers all possible combinations of conditions; thus, the data matrix expands exponentially with the number of condition variables. Consequently, the number of samples limits the number of condition variables that can be analyzed. Axel Marx (2010) demonstrated that the upper limit of condition variables is seven when the sample size is less than 50. Based on this guideline and the theoretical framework of this study, four conditional variables are selected in addition to the three necessary conditions—defense spending, arms imports, and arms exports. These additional variables include the degree of specialization in arms production, Major Episodes of Political Violence, the size of the economy, and the trade globalization index. The research design incorporates these factors.

Arms industries typically operate as oligopolies, characterized by a limited number of suppliers due to the high costs associated with R&D investment, training, capital, and compliance with stringent standards (Levine et al., 1994; Wang et al., 2023). According to Yesilyurt et al. (2014), Smith and Dunne (2018), and Blum

(2019), in an open economy, arms producers manufacture arms “on demand,” aligning production with domestic orders and approved exports rather than maintaining stockpiles. The supply of arms from domestic suppliers equals the sum of domestic demand for military goods and arms exports minus arms imports. The formula representing this relationship is as follows:

Domestic arms supply = Domestic arms demand + Arms export − Arms import

Domestic supply is represented by total arms sales, whereas arms demand is reflected by the national defense budget. Conversely, domestic arms demand equals domestic supply minus exports and plus imports. Therefore, the formula is as follows:

Domestic arms demand = (Domestic arms supply − Arms export) + Arms import

However, the impact of arms imports on arms production remains debatable, with some scholars arguing whether they have a substitution or complementary effect. Unlike general consumer goods, in which intra-industry trade typically reduces domestic production, arms imports can benefit arms production because of unique characteristics such as offset agreements. These imports contribute to consumption, help reduce costs, and provide access to technology. Studies have indicated that the positive effects of arms imports on arms production outweigh the negative impact on demand (Dunne, 1995; Mathews, 1991).

In this study, domestic security needs are expressed not only through domestic demand for arms purchases but also through arms imports. Economic needs are represented by foreign arms trade purchase orders. The formula is as follows:

Domestic arms supply = Domestic security needs + External economic needs = (Defense expenditure + Arms imports) + Arms exports

Based on the above formula for the direct effects, this study considers several indirect effects as conditional variables. (1) The size of the economy (logarithm of GDP) is used as a conditional variable, considering the high fixed costs of arms production, the learning curve, and economies of scale, along with the need for economic volume to support the maintenance of production technology and R&D investment (Yesilyurt et al., 2014). (2) Considering that firms can benefit from their specialization through learning, knowledge transfer, and accumulation (Acosta et al., 2018), the degree of specialization in arms production is represented as the ratio of arms sales to total sales, which is considered one of the conditional variables. (3) The trade globalization index reflects the degree of openness in a country's international trade in goods and services, the diversity of trading partners, and trade rules, tariffs, and agreements. Significant episodes of political violence measure the occurrence of domestic and international warfare. These are incorporated into the analysis as conditional variables.

Data sources

For the data source, the value of arms sales is selected as the outcome variable for arms production because arms are produced on demand; arms sales reflect the demand for arms by domestic and foreign governments (Blum, 2019). The SIPRI Military Expenditure database is used for defense spending while the SIPRI Arms Transfers database is used for arms imports and exports (Trend Indicator Value, TIV). The TIV value is based on production costs and value chain accounting, explaining the quantity of arms transfers rather than the contract price, which can be zero in the case of military assistance (Bove, Deiana, and Nisticò, 2018). Using the SIPRI Arms Industry database, this study compiles data on arms sales of the 100 largest arms-producing and military services companies for the six years from 2015 to 2020. It also gathers data on defense spending, arms transfers, and other control variables for countries in which the corresponding company ownership and control structures are located. The final sample comprises 77 arms-producing companies from 16 countries. The data on arms-producing companies, national defense spending, and arms transfers are sourced from the SIPRI database. Major Episodes of Political Violence (MEPV) data from 2015 to 2018 are from the Center for Systemic Peace. GDP data are from the World Bank WDI database. The trade globalization index data are from the KOF globalization index measured by Savina Gygli et al. (2019). For the QCA analysis, all data were taken as annual averages.

Measurement and calibration

Fuzzy qualitative analysis (fsQCA) requires the transformation of continuous variables into sets, which necessitates calibration of the original data, assigning grades based on variable values and converting them into fuzzy sets. In this study, we use the direct calibration method proposed by Charles Ragin (2009) and Peer Fiss (2011), specifying the values of an interval-scale variable that correspond to three qualitative breakpoints defining a fuzzy set: the threshold for full membership, the crossover point, and the threshold for full non-membership. This study adopts the case percentile calibration approach, using the 95% quantile as full membership, the 5% quantile as full non-membership, and the median as the crossover point. These three benchmarks are employed to transform the original ratio or interval-scale values into fuzzy membership scores, using transformations based on the log odds of full membership. Given the significant gaps in the MEPV indicator, this variable is normalized before direct calibration to ensure data consistency across countries. The study uses the nonlinear stepwise logistic function of fsQCA 3.0 for calibration. The calibrated qualitative anchors and statistical descriptions of each variable are presented in Table 1.

Table 1 Calibration and descriptive statistics of the variables

Variables	Fuzzy-set calibration			Mean	St. d	Min	Max
	Full membership	Crossover	Full non-membership				
Arm sales	26611.12	2654.79	1112.72	0.40	0.29	0.03	1
Export	10280.8	2470.83	0.83	0.55	0.38	0.05	0.95
Import	1488.94	577.83	49.67	0.43	0.27	0.04	1
Miles	705934	68994.5	11093.37	0.56	0.34	0.03	0.95
Specialization	98.1	65.5	9.42	0.50	0.35	0.03	0.96
KOFTrGI	78.76	55.35	42.48	0.55	0.29	0.05	0.99
lnGDP	10.98	10.65	7.71	0.60	0.33	0.04	0.95
MEPV	1	0.5	0	0.11	0.18	0.05	0.95

Analysis of the driving path of arms production

Necessity analysis of a single condition

Before conducting the fsQCA analysis, a necessity analysis of individual conditions is required to logically determine whether any necessary conditions lead to the occurrence of the results. According to set theory, consistency indicates the degree to which cases with a given condition are consistently associated with the results. Table 2 presents the fuzzy-set analysis of the necessary conditions. When the consistency exceeds 0.9, the condition is considered essential for the qualitative results. Coverage reflects how a given condition explains the outcome instances, i.e., the proportion of cases covered. It also assesses the relevance of causal conditions; the smaller the coverage, the fewer combinations of conditions lead to the outcome (Ragin, 2006). Table 2 shows that the necessity of defense spending for high arms production is the highest, with a consistency of 0.787, followed by the size of the economy. However, the consistency of all the conditional variables is less than 0.9, meaning none is necessary for high arms production. Therefore, all conditional variables can be retained, and the combination of conditions can be considered.

Table 2 Fuzzy-set analysis of the necessary conditions

Outcome variable: arm sales		
Conditions	**Consistency**	**Coverage**
Export	0.712475	0.521894
Import	0.651722	0.612893
Miles	0.787524	0.558139
Specialization	0.649448	0.519221
KOFTrGI	0.688434	0.500709
lnGDP	0.776478	0.514975
MEPV	0.193632	0.694639

Constructing the truth table

The truth table algorithm in fsQCA consists of two main steps. First, after calibrating the variables, the fuzzy sets form the data matrix of the truth table. The truth table lists all possible combinations of conditions, with some combinations containing many cases and others having none, depending on the actual cases. Next, meaningful condition combinations are selected based on the consistency threshold of the grouping and the minimum number of cases. Consistency is represented by the ratio of the number of instances of a given combination of conditions and outcomes to the number of instances of the same combination of conditions. The consistency should be as close to 1 as possible to indicate the degree of correspondence between the condition combination and the set-theoretic relationship reflected by the actual cases. The consistency level should not be lower than 0.75, and the frequency threshold should not be lower than 1, meaning each combination must have at least one case with an affiliation score greater than 0.5 (Charles Ragin, 2009). In this study, combinations without actual cases are removed, and the case frequency threshold is set to 1. The truth table results are presented in Table 3. Eight possible configurations exist, containing 30 arms-producing companies. Companies and their respective countries are presented in Table 4. Based on the consistency level, the consistency threshold for the first five configurations exceeds 0.75, while the consistency threshold for the first four configurations exceeds 0.8.

Table 3 Truth Table

Configuration	Export	Import	Miles	KOFTrGI	lnGDP	Specialization	MEPV	Consistency
1	0	1	1	0	0	0	0	0.926859
2	0	1	0	0	0	1	1	0.83218
3	0	0	0	1	1	1	0	0.820306
4	0	1	0	1	0	1	0	0.806162
5	0	0	0	1	0	0	0	0.76527
6	0	0	0	1	0	1	0	0.727197
7	0	0	0	1	1	0	0	0.724684
8	0	1	0	1	0	0	0	0.721429

Table 3 shows that high exports do not preclude high arms production in any configuration. High imports appear in four configurations: 1, 2, 4, and 8, whereas high defense spending is present only in the first configuration, which has a high level of consistency. The trade globalization condition is absent in configurations 1 and 2. Economic size appears in configurations 3 and 7, and the degree of specialization in arms production appears in configurations 2, 3, 4, and 6. The political violence condition appears only in configuration 2. Comparing and synthesizing the configurations reveals a substitution relationship between defense expenditure, company specialization, and political violence in configurations 1 and 2. In contrast, configurations 3 and 4 exhibit an alternative relationship between the economic scale and arms imports.

An analysis of the cases corresponding to each configuration in Table 4 shows that the differences in arms production among companies from the same country, such as British and Korean arms companies, stem from their degree of specialization. BAE Systems, LIGNex1, and Korea Aerospace Industries have specializations of 96%, 100%, and 66%, respectively. Hanwha Aerospace, Rolls-Royce, Babcock International Group, Serco Group, and Meggitt specialize in areas ranging from 24% to 55%. Thus, the degree of specialization in arms production influences the arms production capabilities of defense companies. When analyzing the countries corresponding to each condition, China, India, and South Korea exhibit high arms imports. China also has high defense spending, whereas Switzerland, the UK, South Korea, Italy, Japan, Israel, Poland, Turkey, Ukraine, and Singapore demonstrate high trade globalization. Switzerland and the UK have large economies, and India experiences high levels of political violence. These conditions are sufficient to support high arms production in the corresponding countries.

Table 4 All cases of possible configurations

Configuration	Company[2]	Country
1	NORINCO (0.67,0.86) AVIC (0.67,0.85) CETC (0.67,0.79) CASIC (0.67,0.75) CSGC (0.67,0.61)	China
2	Hindustan Aeronautics Limited (0.53,0.51) Indian Ordnance Factories (0.53,0.27) Bharat Electronics Limited (0.53,0.08)	India
3	Saab (0.85,0.51)	Sweden
	BAE Systems (0.57,0.92)	United Kingdom
4	LIG Nex1 (0.58,0.09)	South Korea

[2] Values in parentheses represent original and unique coverage, with original coverage greater than 0.5 for each case.

	Korea Aerospace Industries (0.51,0.1)	
5	Fincantieri (0.58,0.2)	Italy
	Mitsubishi Heavy Industries (0.52,0.54) Kawasaki Heavy Industries (0.52,0.32) Fujitsu (0.52,0.05) IHI Corp. (0.52,0.07)	Japan
6	Leonardo (0.56,0.72)	Italy
	Elbit Systems (0.53,0.53) Israel Aerospace Industries (0.53,0.51) Rafael (0.53,0.42)	Israel
	Ukr Oboron Prom (0.65,0.07)	Ukraine
	PGZ (0.76,0.07)	Poland
	ASELSAN (0.62,0.08)	Turkey
7	Rolls-Royce (0.57,0.56) Babcock International Group (0.57,0.52) Serco Group (0.57,0.09) Meggitt (0.57,0.03)	United Kingdom
	ST Engineering (0.71,0.13)	Singapore
8	Hanwha Aerospace (0.58,0.23)	South Korea

Standard Analyses: Configuration analysis

Based on the Boolean algebra algorithm, fsQCA standard analysis logically reduces the condition combinations in the truth table to simple combinations, identifying which conditions are sufficient for the outcome. After standard analysis, this study set the consistency threshold to 0.8 (the minimum being 0.75). The frequency threshold is set to 1. Three types of solutions are obtained: complex, parsimonious, and intermediate. Each solution treats the remainder combinations differently. The complex solution excludes logical remainders and counterfactuals, while the parsimonious solution includes any remainder that logically simplifies solutions, regardless of whether it constitutes an easy or difficult counterfactual case. The intermediate solution incorporates only easy counterfactual cases into the solution. Following Fiss (2011), the intermediate solution is considered optimal. Additionally, the algorithm classifies configurations into core and peripheral conditions. Conditions that appear in both the intermediate and parsimonious solutions are core, while those that appear only in the intermediate solutions are peripheral conditions. Therefore, comparing the intermediate and parsimonious solutions in a nested manner helps identify the optimal solution[3]. Combining the parsimonious solutions, Table 5 presents four intermediate solution configurations for high arms production. Each configuration is sufficient, though not necessary, for the outcome, and all are logically equivalent, meaning they can substitute each other.

Table 5 Analysis of high arms production configurations

Condition	Outcome variables: arm sales			
	1	2	3	4
Export	⊗	⊗	⊗	⊗
Import	●	⬤	⊗	⬤
Miles	⬤	⊗	⊗	⊗
KOFTrGI	⨂	⨂	●	●
lnGDP	⊗	⊗	⬤	⊗
Specialization	⊗	⬤	⬤	⬤
MEPV	⊗	●	⊗	⊗
Raw coverage	0.25114	0.15627	0.296621	0.204029
Unique coverage	0.11176	0.023067	0.09909	0.0013
consistency	0.92686	0.83218	0.820306	0.806162
solution coverage	0.439571			
solution consistency	0.766573			

Following Peer Fiss (2007) for the configurations, ● denotes the presence of

[3] COMPASSS: Comparative Methods for Systematic Cross-Case Analysis, https://compasss.org/software/.

the condition, ⊗ denotes the absence of the condition, ● and ⊗ denote the presence and absence for the core condition, respectively. Table 5 shows that four configurations promote high arms production. Overall consistency measures the extent to which the affiliation of the configurations is a subset of the outcome affiliation, which is 0.766, significantly greater than the 0.75 level suggested by Ragin (2009). Therefore, the configurations are deemed adequate for analysis. Overall coverage measures the proportion of the outcome's affiliation explained by the configurations, with a coverage of 0.43. This means that the four configurations explain 43% of the results. The level of agreement for each of the four configurations ranges from 0.806 to 0.926, indicating that each configuration is a sufficient combination of conditions. Raw coverage measures the proportion of the outcome's affiliation explained by each configuration, with values ranging from 0.204 to 0.296. This means that each configuration explains between 20% and 29% of the results. Unique coverage measures the proportion of an outcome's affiliation, explained by the configuration itself without overlap from the others. The strength of the interpretation of results based on each configuration is high.

Among the configurations, high defense spending, high arms imports, high specialization of arms-producing companies, low trade globalization, and large economic size are the core conditions. The cases they cover differ based on different combinations of core conditions. These configurations can be categorized into three groups: domestic procurement-oriented (configuration 1), import-oriented (configurations 2 and 4), and R&D-oriented (configuration 3). The specific analysis is as follows.

Configuration 1: Domestic procurement-oriented

Configuration 1, which is domestic procurement-oriented, indicates high defense spending and low trade globalization as the core conditions; high arms imports support this and the remaining conditions exhibit low levels. The five Chinese defense companies—NORINCO, AVIC, CETC, CASIC, and CSGC—are highly affiliated with this configuration. Although high defense spending is a core condition in the parsimonious solution, including two-thirds of U.S. arms-producing companies with high arms production, its consistency is only 0.56. The absence of trade globalization is another core condition, encompassing all arms companies in China, India, and Russia, with a consistency level of 0.6. Neither core condition explains the outcome at a consistency level of 0.75; however, configuration 1's unique coverage and consistency level are the highest among the groups. Furthermore, the presence of arms imports is a crucial factor. China and the U.S., two military powers, account for more than half of the world's military expenditure (SIPRI, 2022). Notably, U.S. military expenditure is three times that of China, yet China's arms imports are more than twice those of the U.S.

Therefore, by combining all conditional analyses, the cases provide more explanatory power. Configuration 1 shows that arms-producing companies heavily depend on domestic procurement and arms imports for arms production, with low levels of trade globalization. This configuration explains a quarter of high-arm production cases. It reveals that the relationship between arms imports and production is complementary rather than substitutive. This suggests that governments prefer domestic procurement to ensure technological autonomy and security in arms supply, while R&D and assembly production is also supported through imports (Dunne and Smith, 2016).

Configurations 2 and 4: Import-oriented

Arms imports serve as an indicator of a country's reliance on external sources for advanced military technology and equipment. This reliance can influence domestic production capabilities, particularly in countries with limited indigenous R&D capacity. In configurations 2 and 4, the core conditions are high arms imports and arms-producing specialization. These core conditions explain the high arms production in companies such as Indian Ordnance Factories, Hindustan Aeronautics Limited, Bharat Electronics Limited in India as well as LIG Nex1 and Korea Aerospace Industries in South Korea. The arms import rankings indicate that India, China, and South Korea are the top three countries with the highest arms imports. Additionally, LIG Nex1, Indian Ordnance Factories, and Hindustan Aeronautics Limited exhibit a high degree of specialization in arms production, with specialization levels exceeding 90%.

Arms production ranges from simple maintenance to fully independent R&D and production, with most economies exhibiting the former (Krause, 1995). The demand for arms imports aligns with national strategic defense objectives, such as South Korea's goal to expand its participation in the arms production market and India's need for arms imports with technology transfer requirements (Jurgen Brauer and Paul Dunne, 2005). While South Korea and India remain significant importers, they are gradually developing large-scale, technologically advanced defense companies and establishing diversified military production (Tulyakova et al., 2021).

The key difference between configurations 2 and 4 lies in the degree of trade globalization and the occurrence of international and domestic warfare. In configuration 2, Indian arms-producing companies have a trade globalization index of 42.95, ranking 15th out of 16 countries, and South Korea’s index in configuration 4 is 62.15, ranking 10th. Additionally, the average value for domestic and foreign warfare in India is 5, whereas that for South Korea is 0. This suggests that for companies with a high specialization in arms production, the domestic demand for arms production is higher in contexts of political violence. Arms imports and domestic production complement each other, reflecting the significant domestic demand for arms. Conversely, for countries with high trade globalization, a substitution effect emerges between trade and the presence of warfare. In these cases, high arms production depends on the level of specialization in a company’s arms production and domestic demand for imports.

Configuration 3: R&D oriented

The R&D-oriented configuration has the highest initial coverage among the four configurations, explaining 30% of high arms production cases. Its core conditions include a large economic scale and high specialization in arms production, with high trade globalization as a secondary condition. Two arms-producing companies, Saab and BAE Systems, are included in this configuration. When focusing only on the core conditions in the parsimonious solution—large economic size and high specialization—this configuration also includes 14 U.S. arms-producing companies with high specialization in weapons production, such as Raytheon Technologies, L3Harris Technologies, Vectrus, Huntington Ingalls, and The Aerospace Corp.

Sweden and the UK, which have larger economies than the U.S., feature Saab and BAE Systems, with 84.5% and 92% specialization in arms production, respectively. However, Sweden and the UK have higher trade globalization indexes—79.75 and 73.42—while the U.S. has a trade globalization index of 55.35. This suggests that in countries with higher trade globalization, high arms production depends on the degree of specialization and the size of the domestic economy. The economic size condition in the R&D-oriented configuration is more conducive to autonomous R&D than the import-oriented configuration, replacing the domestic import demand as a sufficient condition for high arms production.

For instance, Saab held 156 military patents and 47 dual-use patents between 2002 and 2011 (Acosta et al., 2017). BAE Systems, with 57 military patents and 36 dual-use patents, ranks among the top defense companies in terms of military patents. Saab's CEO, Ake Svensson, emphasized that "We're not going to be a big systems integrator like Lockheed Martin, Northrop Grumman, or EADS … [but] Saab could provide the U.S. with some of its advanced niche products, including those for the radar or aircraft training markets" (Neuman, 2010).

Combining the three groups of companies engaged in high arms production, we find that arms exports are neither necessary nor sufficient condition for high arms production. Arms production is primarily dependent on domestic demand, defense spending on weapons, and domestic arms imports. Additionally, for companies with a high degree of specialization in arms production, high national arms imports, warfare, and the degree of trade globalization can contribute to high domestic arms production. Conversely, when the national arms trade is not highly globalized, and defense spending is insufficient, the size of the national economy and a high degree of trade globalization support arms companies in pursuing independent R&D to boost arms production.

Robustness test

In fsQCA, robustness tests are essential to verify the research results. One way to test robustness is by adjusting the consistency threshold. In this study, the consistency threshold is adjusted to 0.82, which results in the intermediate solution presenting the first three configurations. The overall consistency level improves to 0.8, while the overall coverage decreases, as shown in Table 6.

Table 6 Changing the consistency threshold

Condition	Outcome variables: arm sales		
	1	2	3
Export	⊗	⊗	⊗
Import	●	⬤	⊗

Miles	●	⊗	⊗
KOFTrGI	⨂	⨂	•
lnGDP	⊗	⊗	●
Specialization	⊗	●	●
MEPV	⊗	•	⊗
Raw coverage	0.25114	0.15627	0.296621
Unique coverage	0.11208	0.02306	0.152671
Consistency	0.92686	0.83218	0.820306
Solution coverage		0.438272	
Solution consistency		0.805373	

The second robustness test involves adjusting the calibration method of the original data. In this case, the 90th, 50th, and 10th percentiles are selected as the anchor points to transform the original data into a fuzzy set. A consistency threshold of 0.75 is used, resulting in four intermediate solution configurations consistent with the study's results before adjustment. Overall consistency level is 0.75, and the overall coverage is 0.38. Both tests indicate that the results are robust.

Table 7 Changing the calibration method

Condition	Outcome variables: arm sales			
	1	2	3	4
Export	⊗	⊗	⊗	⊗
Import	•	●	⊗	●
Miles	●	⊗	⊗	⊗
KOFTrGI	⨂	⨂	•	•

lnGDP	⊗	⊗	●	⊗
Specialization	⊗	●	●	●
MEPV	⊗	•	⊗	⊗
Raw coverage	0.22327	0.137107	0.246541	0.18648
Unique coverage	0.10692	0.02075	0.068553	0.002201
Consistency	0.93176	0.79562	0.821803	0.769131
Solution coverage	0.385535			
Solution consistency	0.749389			

Research Conclusions and Recommendations

This study applies the fsQCA method, which integrates qualitative and quantitative analysis. This method addresses data limitations while providing researchers with a framework for understanding how combinations of conditions influence the complexity of outcomes. Using three primary SIPRI databases—arms transfers, defense spending, and the arms industry—the study investigates the arms production of 77 major arms-producing and military service companies that consistently rank among the top 100 in the SIPRI Arms Industry Database from 2015 to 2020. The findings indicate that arms exports and imports, defense spending, firm specialization in arms production, national economic size, trade globalization, and warfare are not necessary for increased arms production. Instead, a combination of multiple conditions drives arms production for these companies.

While our results confirm some established patterns (e.g., the importance of defense budgets and technological capacity (Richard Bitzinger, 2015)), they also reveal new insights, such as the role of arms imports in sustaining domestic production in countries with concentrated industries. Specifically, three combinations of conditions contribute to high arms production: domestic procurement-oriented, weapons import-oriented, and R&D-oriented configurations. The domestic procurement-oriented configuration highlights enhanced arms production resulting from high defense spending, low trade globalization, and high arms imports. The weapons import-oriented combination emphasizes high arms imports, high arms production specialization, and a high level of trade globalization. The R&D-oriented

configuration emphasizes the effects of large economic scale, high arms production specialization, and high trade globalization on increased arms production. All three configurations indicate that external export demand does not drive arms production; domestic demand—through domestic procurement, arms imports, and independent R&D—plays a central role.

The differences in the driving forces behind weapons production reflect the variations in the arms industries of different countries, particularly in terms of security and economic priorities. These results offer insights into a country's defense industry policy and arms industry structure, helping to better position the development of the arms industry under varying conditions. For instance, countries focused on domestic procurement should prioritize high-tech weapon performance over cost to ensure technological independence and weapon supply security. An import-led model can address the imperfect competitive structure of the equipment market and find a balance between domestic weapon types and production scale. For R&D-oriented countries, maintaining favorable military-technical conditions and developing civil and dual-use technologies are key to increasing economic scale and fostering a positive cycle of R&D.

While fsQCA provides a powerful tool for analyzing the complex interplay between defense expenditure, arms transfers, and other key variables, we acknowledge certain limitations. The mixing of national and company-specific characteristics may introduce biases, particularly due to the varying number of arms-producing companies across countries. For instance, the dispersion of production among numerous firms in the United States may dilute their impact, while concentration in fewer firms in countries like France or Russia could overemphasize their influence. Additionally, our analysis is limited to countries with companies in the SIPRI Top 100 list, potentially overlooking dynamics in smaller or less industrialized nations, and the findings may not be fully generalizable to countries with unique industrial structures or defense policies. These limitations highlight the need for future research to incorporate weighted analyses, expand data coverage, and develop new methodological approaches to better capture the diversity of national arms production landscapes.

Declaration of Interest Statement

We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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