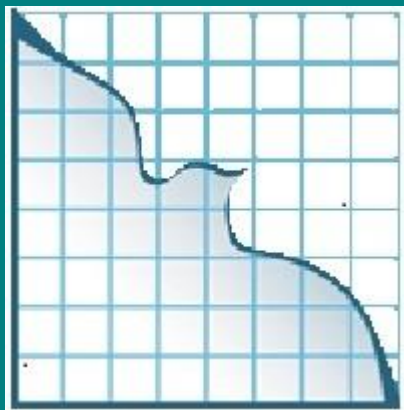


THE ECONOMICS OF PEACE AND SECURITY JOURNAL

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A journal of Economists for Peace and Security

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Six decades of consolidation in the European defense industry (1960-2022)

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Abstract

In the present security environment, the capabilities of the European defense industry and the impact of restructuring over the years have become issues of concern. Researchers have found considerable consolidation when looking at the overall industry, but have failed to consider that this might understate the loss of national capabilities in subsectors. This article investigates the effect that restructuring has had on twenty subsectors of the defense industry in thirty one European countries from 1960 to 2022. It finds that since the 1960s, the number of major European defense firms has contracted by between 29% and 80% across subsectors, implying the loss of a range of capabilities. It suggests that while Europeanization is inevitable, it is likely be accompanied by further diminishing capabilities at the national level.

In these times of heightened international tension, European institutions (notably the European Commission) and policymakers call for an intensification of Europe's defense-industrial integration efforts. The "Strategic Compass" is the latest expression of the aim to increase cross-border collaboration and consolidation to strengthen the industry and ensure the security of supply of armaments.¹ Consolidation² is a prominent feature in the evolution of defense industries, as many arms firms face high fixed costs, particularly R&D, and operate in decreasing-cost industries wherein larger production runs offer economic gains.³ In times of low demand, rising costs, growing competition, and other challenges, consolidation can reduce overcapacities and industrial fragmentation.⁴ Smith (2013) defines five strategies for defense firms facing demand downturns, three of which can lead to supply-side consolidation.^{5,6}

Based on the existing literature and available data, it is argued that taking an aggregate view on the European defense industry understates the historical restructuring within the individual countries and (sub-sectors). Following an assessment of 20 subsectors in 31 European countries⁷ over the period ranging from 1960 to

1 European External Action Service (2022).

2 In this article, 'consolidation' refers to supply-side consolidation, which we define as the concentration of defense production within fewer suppliers (e. g., due to mergers, acquisitions, or market exits).

3 Hartley (2017, 2013, 2011a); Hartley et al. (2008); Dunne et al. (2007).

4 Kleczka et al. (2020).

5 Commercial diversification, conversion toward civilian production, divestiture of defense divisions, cooperation among rivals, and concentration on core defense activities.

6 In several European countries, the decline in defense budgets following the end of the cold war has been slowed down, and sometimes even reversed, in recent years. Since we provide a historical assessment, our main findings are not affected by this development.

7 In this article, 'Europe' is defined as the EU27 plus Iceland, Norway, Switzerland, and the United Kingdom (U.K.).

2022, this article examines how the structure of Europe's defense industry evolved at both levels. First discussing how market structure and national production capabilities have changed since the 1960s before comparing the leading defense firms which have emerged from this restructuring process. The rising importance of the defense electronics sector is then briefly debated. The final section offers concluding discussions, highlights some limitations, and outlines opportunities for future research.

Our long-term disaggregated view on European defense industry consolidation makes three contributions to the existing literature. First, an outline of the heterogeneous impact of the restructuring processes since the 1960s on the number of defense firms for the most important subsectors of the aircraft, naval and land sectors. Second, a highlight of the different experiences with consolidation between Western Europe and East-Central Europe (i.e., the former Warsaw Pact countries). Third, a discussion of the industrial structure that has emerged from past restructuring and the implications for the individual countries' industrial capabilities. Taken together, the findings highlight facets of the restructuring process that are commonly overlooked—the existing literature being mostly confined to specific countries or sectors and to a more limited period.

Trends in the European defense industry

Europe's defense industry is the result of decades-long consolidation processes. All major European defense firms have emerged from mergers and acquisitions, with market exits of former competitors having further shaped industrial concentration. The end of the cold war with its budget cuts created over-capacities in most arms-producing countries and production became increasingly concentrated within fewer firms. Nevertheless, it is often argued that European restructuring did not go far enough. The United States (U.S.) with its much larger defense budget sustains significantly fewer defense firms and competing programs than Europe.⁸ European fragmentation reflected its collection of independent countries which are often reluctant to enter transnational ventures for reasons of national security and sovereignty⁹, export earnings, and the preservation of employment and industrial capabilities. As budgetary pressures increased, the further consolidation of Europe's defense industry was to be expected.¹⁰

A considerable body of research has been published on this topic. It can be separated into: company studies which analyze the evolution, strategy, or prospects of specific firms¹¹; country studies, which are by far the most numerous

In the present security environment, the capabilities of the European defense industry following years of restructuring is concerning. Researchers have found considerable consolidation when looking at the overall industry, but have failed to consider that this might understate the loss of national subsector capabilities. Disaggregate information highlights that the consolidation process experienced by Europe's defense industry is likely to be understated if only aggregate analyses are undertaken. For example, as of 2022, no single European country builds heavy transport aircraft independently.

8 On consolidation in the US, see Hensel (2015), Gansler (2011), Dunne et al. (2007), and Guay and Callum (2002). For a comparison of the number of major defense firms in Europe and the US, see Hartley (2017, 2011a) and Kleczka et al. (2020).

9 See Mölling (2015), Fiott (2015), Briani et al. (2013), and James (2002) on the link between national defense production and perceived sovereignty or security.

10 Bellais (2017), Bitzinger et al. (2017), Dunne and Smith (2016), Briani et al. (2013), and Hartley (2011b) are among those who discuss further consolidation as an option for Europe's defense industry.

11 For example, such publications exist for BAE Systems (Hartley, 2012; Bélanger and Hébert, 2001), Airbus (formerly EADS: Hartley, 2019; Engler, 2016; Fache, 2005; Thornton, 2003), Leonardo (formerly Finmeccanica: Caruso, 2019; Caruso and Locatelli, 2013; Felice, 2010) and Thales (Som, 2009). The consolidation processes which created BAE Systems, EADS, and Thales are summarized by Dunne and Surry (2006).

group comprising thousands of publications on sectoral developments within individual European nations¹²; and European level studies, which offer sectoral analyses without being limited to specific countries¹³. Reviewing these and other studies leads to two conclusions. First, that Europe's experience with defense industry consolidation has varied among individual countries and sectors, and second, that despite differences among countries, common sectoral trends have shaped the industries across Europe.

In the aircraft sector, successive mergers and acquisitions from the 1960s onwards established just one or two industrial leaders in most European countries. In parallel with these national consolidation processes, "*rapidly increasing R&D costs and shorter production runs made cross-border cooperation [...] a financial imperative*".¹⁴ Esposito (2004) separates this evolution of cooperation into distinct phases: An "*in-house production phase*" until the late 1950s, characterized by no cooperation across borders; a "*first collaboration phase*" in the 1960s, as technological advances spurred some joint projects; a "*European consortia phase*" in the 1970s, which established major trans-European ventures (e.g., Airbus and Tornado); and a "*worldwide co-operation phase*" in the 1980s, characterized by growing collaboration with non-European firms.¹⁵ When demand fell in the 1990s, European integration followed on the fundamentals of existing consortia and joint programs.¹⁶ As a result, Europe's aircraft production capabilities are now largely concentrated within a few system integrators (Airbus, BAE Systems, Dassault, Leonardo, and Saab).

In contrast, land weapons systems have lower R&D costs and sufficient domestic demand for consolidation to be more limited. Demand downturns and changing demand patterns¹⁷ did lead to several important cross-border projects (including ASCOD, Fennek, Boxer, and the Main Ground Combat System) and to transnational firms such as General Dynamics European Land Systems (GDELS), KNDS, and Rheinmetall BAE Systems Land.

The naval sector followed a different path. Until the 1960s, surface warships and submarines were commonly built by "mixed" shipyards which faced increasing competition, particularly from Japan and South Korea.¹⁸ Government responses saw action to consolidate shipyard groups and to stimulate specialization, and following the global decline in demand for commercial ships after the 1970s "oil crises", Europe's naval industry was significantly transformed

12 The evolution of Sweden's defense industry, for example, was assessed by Lundmark (2019), Eliasson (2017), Ikegami (2013), Andersson (2007) and Hagelin (1997). Consolidation in the U.K. has been for the aircraft analyzed industry (Nuttall et al., 2011; Hartley, 2010) and the naval sector (Johnman and Murphy, 2001). Similar studies are available on France (Belin et al. 2019; Serfati, 2001, 1997; Hébert and de Penanros, 1995; Hébert, 1995), Germany (Brzoska, 2019), Spain (Fonfría and Sempere, 2019; Casellas, 2003; Molas-Gallart, 1997, 1995, 1992a,b), and the naval industries of Italy (Sasco, 2017; Fragiaco, 2012) and the Netherlands (van der Velden, 2017; Lemmers, 2015; Smit, 2010). Kiss (2014, 1999, 1997) surveys the restructuring of East-Central Europe's major defense industries in much detail. Among the many other scholars covering individual countries in East-Central Europe are Markowski and Pieńkos (2019), Chovančík (2018), Bochniarz et al. (2016), Behr and Siwiecki (2004), Nelson (2003), Dimitrov (2002), Smith (1994) and Fučík (1991).

13 More recent examples include Esposito (2004), Braddon and Hartley (2013) and Droff (2017) on the aircraft sector, Andersson (2001), Fleurant et al. (2014), Caralp (2017) and Masson (2010) on the land sector, Bellais (2017) and Smit (2003) on the naval industry.

14 Andersson (2001). See also Guay and Callum (2002).

15 Besides Esposito (2004), see also Hartley (2019), Droff (2017) and Braddon and Hartley (2013) on collaborative programs in Europe's aircraft industry.

16 Esposito (2004). On pre-existing collaboration as a precursor for transnational integration, see also Sköns and Baumann (2003), Andersson (2001), and Schmitt (2000).

17 Kleczka et al. (2021). See also Guay (2007), Sköns and Baumann (2003), Guay and Callum (2002), James (2002), Andersson (2001), and Cornu (2001) on the limited scope of land sector consolidation until the early 2000s.

18 Cho and Porter (1986). See also Bruno and Tenold (2011), Poulsen and Sornn-Friese (2011), Lorenz (1991) and Lammers (1988) on Western Europe's diminishing market share.

in size and structure.¹⁹ Further consolidation after the end of the cold war was mostly national in scope.²⁰ Despite a few cross-border takeovers and some common designs (including Horizon, FREMM, Enforcer, Type 212A, Type 212CD), Europe's naval sector remains fragmented along national lines.

These broad trends naturally had different implications for individual countries. Notably, their impact varied between Western Europe and East-Central Europe, whose defense industries were largely unaffected by trans-European restructuring until the 1990s. In East-Central Europe, domestic production (often under Soviet license) prevailed until the 1990s, then collaborative production and European integration took place in the aircraft industry (which also experienced some transatlantic integration) and the naval sector. The land sector witnessed national consolidation, but relatively little European integration.²¹

While U.S. acquisitions in Western Europe were partly matched by European takeovers of U.S. defense firms (including important naval yards and armored vehicle producers), East-Central Europe's experience was rather "unidirectional". For example, Poland's leading aircraft producers were taken over by Leonardo, Lockheed Martin, and Airbus, and Romania's largest naval yards are now controlled by Damen and Fincantieri. However, some of these integration moves were recently scaled back. For example, Polska Grupa Zbrojeniowa (PGZ) are re-acquiring Poland's largest aircraft engine plant from Pratt & Whitney, and the Czechoslovak Group now controls a large share of the Czech and Slovak defense industries.

One common explanation for the different speed and scope of consolidations is that economic pressures varied across the industries. The aircraft industry was forced into cooperation in the 1960s, providing the foundation for later cross-border integration moves. Such pressures were less severe in the naval and land sectors in part due to lower R&D costs and longer production runs, thereby permitting national approaches to persist well into the 21st century.^{22,23} Further, Smit (2003) also identifies a weaker link between civilian and defense production, strong historical ties between naval forces and domestic shipyards, and small-batch supply in warship production. Bellais (2017) emphasizes higher degrees of state ownership, unwillingness to accept rationalizations after cross-border mergers, specific national requirements, perceived indispensability of naval yards and their in-service support for sovereignty reasons, and the strengthening of competitive positions of naval shipbuilders via vertical integration.

For the land weapons sector, Andersson (2001) identifies national prestige, varying national requirements, incompatible industrial incentives, limited experience with cross-border programs, persistent fragmentation within countries, lower pressure from commercial markets (due to higher defense dependency), and scant political support for trans-European consolidation. Other factors include the presence of highly specialized firms and the small size of

19 See Murphy and Tenold (2017) on the overall impact of the 'oil crises'. Concerning national naval restructuring, see Poulsen (2013) and Poulsen and Sornn-Friese (2011) on Denmark, Teräs (2017) on Finland, Lebailly and Bidaux (2017), Bourque (1996) and Domenichino (1991) on France, Strippoli *et al.* (2017), Fragiocomo (2012), Galisi (2011) and Melelli (1983) on Italy, van der Velden (2017), Lemmers (2015) and de Voogd (2007) on the Netherlands, Ågotnes and Heiret (2017) on Norway, Karlsson (2017) on Sweden, Wolf (2017) de Voogd (2007), Lammers (1988) and Fante (1983) on Germany, Murphy (2017), Johnman and Murphy (2001), Johnman (1996), Slaven (1992), Todd (1984) and Daniel (1980) on the U.K.

20 Bellais (2017), Guay (2007), Smit (2003), Guay and Callum (2002), James (2002).

21 'East-Central Europe': Bulgaria, the Czech Republic, Hungary, Poland, Romania, Slovakia, and the Baltic states. 'Western Europe': all other EU Member States (except Croatia and Slovenia) plus Iceland, Norway, Switzerland, and the U.K. Croatia and Slovenia are covered by our country studies in the Online Appendices A and B, but otherwise not included in the East/West country groups. For further information, we refer to the supplementary Online Appendices A and B, in which we chart the experience with consolidation for the individual countries and sectors. See Appendices section for URL.

22 Caralp (2017), Fleurant and Quéau (2014), Braddon and Hartley (2013), Briani (2013), Hartley (2011b), Esposito (2004), Guay and Callum (2002) and Andersson (2001).

23 'Cost escalation', as described by Augustine (1983), is notably severe for military aircraft. For further discussions and applications to Europe, see Hartley (2020, 2017), Bellais (2020), Hove and Lillekvelland (2016), Keating and Arena (2015) and Braddon and Hartley (2013).

most European land systems suppliers.²⁴ Success in export markets has also been argued to have eased the economic pressures on the naval and land sectors.²⁵

As a result of these trends, Europe's defense-industrial capabilities are now largely concentrated in a few countries. Briani *et al.* (2013) estimated that France, Germany, Italy, Poland, Spain, Sweden, and the U.K. together accounted for about "90% of the defense (industrial) turnover in Europe". In 2021, these countries accounted for 28 of the 30 largest European defense firms.²⁶ Other countries may have significant capabilities in selected areas (for example the Dutch naval sector), but otherwise mostly serve as suppliers to foreign defense firms and as providers of maintenance, repair and overhaul (MRO) services to national armed forces.²⁷ These seven leading countries accounted for almost 80% of Europe's total defense expenditure and equipment procurement spending in 2021. By the same year, Europe's defense R&D spending was even more concentrated, with 93% of it falling to France, the U.K., and Germany. The countries with the largest defense expenditure were also Europe's leading exporters during the last decade (except for Poland). On a sectoral level, the principal exporter of military aircraft was France, followed by the U.K., Spain, Italy, and Germany. Germany was the largest exporter of naval vessels (ahead of France, the Netherlands, Spain, Italy, and the U.K.) and, more noticeably, tops the list of land weapon systems exporters with 34% of all European exports.

Foreign sales are highly concentrated, with the seven leading countries accounting for 95% of aircraft, 98% of naval, and 85% of land systems for all European exports between 2012 and 2021—but care must be taken in interpreting the data as exports are cyclical, sectoral exports may not necessarily reflect capabilities at the sub-sectoral level,²⁸ and the inclusion of second-hand sales also distorts the ranking.²⁹ Trans-European firms must be considered when interpreting defense exports (for example, Spain's position as Europe's third largest aircraft exporter reflects the presence of Airbus).

This defense spending and exports are shown by country in Tables 1 and 2 below. Despite their limitations, the data do deliver a key conclusion—even among Europe's leading arms-producing countries, major differences in defense-industrial capabilities exist.

24 Cornu (2001).

25 This argument was delivered by Caralp (2017) and Fleurant and Quéau (2014) for the land sector and by Smit (2003) for the naval industry. See also Bellais (2017) on the importance of naval exports.

26 SIPRI (2022c), Defense News (2022) and own research based on Bureau van Dijk's (2022) ORBIS database.

27 Briani *et al.* (2013). Struys (2004) presents a similar distinction between 'large' and 'small and medium' defense industries.

28 For example, while Germany was the leading naval exporter in 2012–2021, its naval industry lacks capabilities possessed by other European countries (for example, the means to build nuclear-powered submarines, aircraft carriers and large amphibious ships).

29 The Netherlands, for example, decommissioned and sold its entire main battle tank fleet during the observed period and thus became the third largest European land systems exporter, far ahead of several countries with much larger land systems industries. For similar reasons, Poland and the Czech Republic (two countries with indigenous aircraft industries) reported lower aircraft exports than some countries which no longer produce military aircraft (for example, the Netherlands and Portugal).

Table 1: European countries' defense expenditure

	<i>Defense expenditure in EURm (2021)</i>		
	<i>Total</i>	<i>Equipment procurement</i>	<i>Defense R&D</i>
United Kingdom	57,059	10,328	2,523
Germany	52,431	7,355	1,995
France	47,900	6,800	6,500
Italy	27,365	5,907	62
Poland	12,765	4,326	79
Spain	12,546	2,766	116
Netherlands	12,300	3,300	148
Norway	7,130	2,000	82
Greece	6,578	2,519	23
Sweden	6,000	1,500	88
Belgium	5,358	903	17
Switzerland	5,253	n/a	n/a
Finland	5,124	1,983	47
Romania	4,477	973	58
Denmark	4,458	646	n/a
Czech Republic	3,331	651	16
Austria	3,299	391	8
Portugal	3,282	531	3
Hungary	2,591	963	5
Slovakia	1,731	564	2
Croatia	1,150	345	1
Lithuania	1,105	243	5
Bulgaria	1,078	218	5
Ireland	1,046	114	0
Latvia	696	199	5
Slovenia	648	96	3
Estonia	647	180	5
Cyprus	458	97	0
Luxembourg	341	135	1
Malta	61	4	0
Iceland	0	0	0
Total	288,208	56,037	11,797
CR ₃	55%	44%	93%
CR ₅	69%	62%	96%
CR ₇	77%	73%	97%

Notes: n/a=no data available; CR3/5/7=cumulative shares of the 3/5/7 major countries. Numbers are rounded to the nearest million. If reported in a different currency, expenditure was converted into EUR.

Sources: Own construction based on SIPRI (2022a), European Defense Agency (2022) and governmental publications.

Table 2: European countries' defense exports

<i>Defense exports (major systems only) in TIVm (2012–2021)</i>				
	<i>Total</i>	<i>Aircraft</i>	<i>Naval</i>	<i>Land</i>
France	23,457	11,415	4,509	871
Germany	13,789	1,911	5,726	2,081
United Kingdom	10,473	5,149	1,692	423
Italy	7,853	3,402	2,643	553
Spain	6,532	3,411	2,843	87
Netherlands	5,487	298	2,921	606
Sweden	2,714	874	366	141
Switzerland	2,389	1,283		329
Norway	1,278	15	26	
Czech Republic	620	278		253
Finland	461	22		340
Belgium	322	89		52
Portugal	316	313		
Poland	247	198		20
Bulgaria	243	56		159
Romania	216		216	
Denmark	160	4	44	
Austria	157	26		86
Ireland	125	14	10	101
Slovakia	72	19		41
Lithuania	62	2		
Hungary	41	41		
Greece	30		30	
Slovenia	9			
Malta	5	5		
Croatia	3	3		
Cyprus				
Estonia				
Iceland				
Latvia				
Luxembourg				
Total	77,071	28,828	21,026	6,143
CR3	62%	69%	63%	58%
CR5	81%	88%	89%	74%
CR7	91%	95%	98%	85%

Notes: Exports are reported based on a ten-year period due to their high year-on-year volatility. CR_{3/5/7}=cumulative shares of the 3/5/7 major countries; TIV=trend-indicator value. Numbers are rounded to the nearest million

Source: Own construction based on SIPRI (2022b).

Sectoral and sub-sectoral restructuring

To make a more detailed analysis feasible, we first focused on system integrators and suppliers of complete defense equipment—thereby largely omitting tier suppliers and providers of MRO or upgrading services. Second, we restricted the analysis to 20 subsectors related to “major” types of armaments. Of these, eight subsectors fall into the aircraft sector,³⁰ seven into the naval realm,³¹ and five into the land industry.³² For each of the 31 European countries covered, we first conducted country studies outlining consolidation in the 20 subsectors from 1960 to 2022, using information from the economic literature, corporate and governmental publications, research institutes and think tanks.³³

Market structure

As Figure 1 shows, Europe’s aircraft sector experienced large-scale consolidation since the 1960s and the impact of this process has varied among the subsectors. Concerning heavy military transport and tanker types, Airbus (created from the leading French, German and Spanish aircraft firms) is now the sole European supplier, while in the market for medium-sized transport and tanker aircraft, only Airbus and Leonardo remain active after the demise of Fokker (Netherlands) and the withdrawal of BAE Systems (U.K.) and Saab (Sweden). From nine major suppliers in the 1960s, Europe’s helicopter industry is now a duopoly of Airbus (heir to the German and French industries) and Leonardo (which has absorbed the helicopter manufacturers of Italy, the U.K., and Poland). The number of European producers of combat and jet trainer aircraft fell from 23 in the 1960s to six in 2022, of which five (Airbus, BAE Systems, Dassault, Leonardo, and Saab) supply advanced combat types.³⁴

As the development and production of combat, jet trainer, heavy and medium transport/tanker, and rotary-wing aircraft is becoming increasingly complex and costly, these markets no longer witness the emergence of new European competitors. Instead, they were characterized by consolidation among the established producers during the preceding decades. In contrast, European producers of less costly or complex types (light transport and piston/turboprop trainer aircraft) remain far more numerous, and market entries still occur.³⁵

In the naval sector, the number of suppliers fell from more than 30 to 10 for destroyers and frigates, and from 19 to 5 for conventionally powered submarines. In most countries with large naval industries, Germany being the exception, a sole “national champion” now dominates: BAE Systems (U.K.), Naval Group (France), Navantia (Spain), Damen (Netherlands), Saab Kockums (Sweden), and Fincantieri (Italy). The markets for less complex and costly vessels (including patrol ships and minehunters) remain characterized by many smaller competitors and by new market entrants.³⁶ Aside from nuclear-powered submarines, no monopolistic or duopolistic structures were established at a European level and only few major cross-border mergers took place. The 1999 takeover of Kockums

30 Strategic bomber aircraft, advanced combat aircraft, light combat and jet trainer aircraft, rotary-wing aircraft, heavy transport or tanker aircraft, medium transport or tanker aircraft, light transport aircraft, and piston/turboprop trainer aircraft. Specialized variants are included (such as electronic warfare or maritime patrol types), but ultralight aircraft are not.

31 Nuclear-powered submarines, conventionally powered submarines, aircraft carriers and large amphibious ships, destroyers, frigates, corvettes and offshore-patrol ships, and mine-countermeasure vessels (offshore or coastal). Producers of smaller types (such as inshore minesweepers, landing craft, patrol boats) or auxiliary ships are excluded.

32 Main battle tanks and assault guns, other tracked armored fighting vehicles, other wheeled armored fighting vehicles, guns and howitzers (self-propelled or towed), and turrets or weapon stations (major suppliers only). Other segments (such as ammunition or non-armored logistics vehicles) are not assessed.

33 While the scope of this article does not permit presenting the country studies in full, they are provided in the supplementary Online Appendices A and B. See Appendices section for URL.

34 The sixth firm, Aero Vodochody, is much smaller and produces light rather than advanced combat aircraft.

35 Additional European aircraft producers with moderate capabilities are listed in Online Appendix C. See Appendices section for URL.

36 Additional European naval shipbuilders with moderate capabilities are listed in Online Appendix C. See Appendices section for URL.

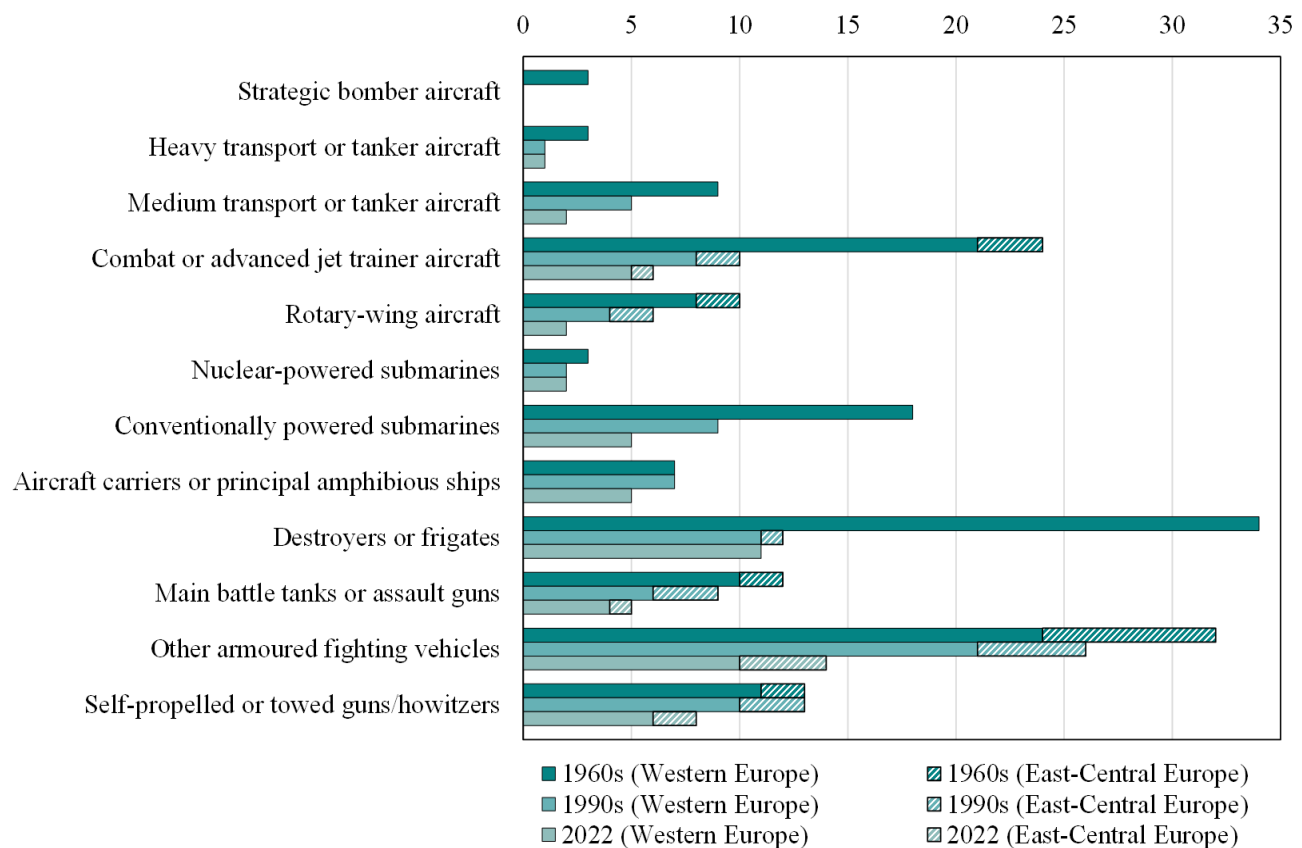


Figure 1: Change in the number of major European suppliers.

Notes: Only selected categories. Companies are reported at the highest level of consolidation and restricted to major established producers (for some categories, notably for armored vehicles, the number of suppliers would otherwise be higher). The former Yugoslavian countries (Croatia, Slovenia) are not included.

Source: Own construction based on data collected from the economic literature, and corporate and governmental publications (see online Appendices A and B for further information—the link is found in the Appendices section of this document)

by HDW was revoked in 2014,³⁷ and Fincantieri's intended acquisition of Chantiers de l'Atlantique fell through in 2021. New competitors do still enter the markets however—an example being Damen which now builds amphibious ships and aims to revive the Dutch submarine industry together with Saab Kockums (which has regained its independence from ThyssenKrupp). German Naval Yards and Lürssen now engage in the supply of destroyers and frigates. Babcock (U.K.) and Rauma Marine Constructions (Finland) have won contracts to supply frigates.

Decades of restructuring have integrated most armored vehicle and artillery systems industries into a single “national champion” or into a maximum of two major firms per country. However, even when small suppliers and licensed producers are not counted,³⁸ this still leaves about five (potential) European producers of main battle tanks, at least fourteen major suppliers of other armored fighting vehicles, and eight producers of artillery systems.

³⁷ Bellais (2017).

³⁸ Additional European land systems producers with moderate capabilities are listed in Online Appendix C. See Appendices section for URL.

		Prevalent type of production	
		Entirely or predominantly domestic (including licensed production of foreign designs)	Transnational programmes with major (but not predominant) domestic participation
Ownership of leading domestic company	Domestic	A	B
	Foreign	C	D

Figure 2: A categorization of domestic production modes.
Source: Own construction.

Examples of multiple national suppliers are Rheinmetall and Krauss–Maffei Wegmann (Germany), Nexter and Arqus (France), Leonardo and Iveco Defense Vehicles (Italy), and General Dynamics UK and BAE Systems (U.K.).

National production capabilities

Figure 2 provides a classification system based on production activities and the ownership of the leading firm. It distinguishes type A, domestic production under domestic ownership; type B, partial domestic production under a transnational project with major participation of a domestically owned company; type C, domestic production under foreign ownership; and type D, partial domestic production under a transnational project with major participation of a foreign-owned domestic company. “Production” distinguishes whether a specific equipment type is mainly produced on a domestic basis (local production of a national design or of a foreign design under license) or under a transnational program (such as Eurofighter, Tiger, and the A400M).³⁹ “Ownership” specifies whether the leading domestic firm is either domestically owned or controlled by a foreign company (including trans-European corporations such as Airbus).⁴⁰

For the aircraft sector, Figure 3 shows that most national industries have withdrawn from some segments since the 1960s. Six countries no longer produce advanced combat aircraft, while a similar number discontinued the domestic supply of jet trainer or light combat aircraft. The production of strategic bomber aircraft in Europe has ceased entirely. Furthermore, most remaining producers of advanced combat, rotary-wing, heavy or medium transport/tanker aircraft now conduct these activities within transnational consortia or as an integral part of a foreign or trans-European firm. Only France and Sweden still build advanced combat aircraft independently, though Italy produces medium-sized military transport aircraft. Light transport and piston/turboprop trainer aircraft remain in production in a much larger number of countries.

Figure 4 shows that Europe maintains a national approach toward naval construction, with the U.K., France, Germany, Italy, the Netherlands, and Spain still possessing the capabilities to produce most surface craft; apart from the Netherlands, all these countries also sustain indigenous submarine industries, as does Sweden. Submarine construction has ceased in the Netherlands, Denmark, and Croatia, and five countries no longer build frigates or

39 In Figures 3–5, ‘production’ refers to entire systems (including licensed production) or to a major participation in transnational consortia, but not to the tier supply of subsystems and components or the final assembly of foreign-made systems.

40 Based on corporate publications, defense industry associations, news releases, and specialized literature.

	Prevalent production mode in the 1960s								Prevalent production mode in 2022							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
United Kingdom	A	A	A	A	A	A	A	A		B	A	C	D	D	A	
France	A	A	A	A	B	A	A	A		A		C	D	D	A	A
Italy		A	A	A		A	A	A		B	A	A		A	A	A
Germany		A	A	A	B	A	A	A		D		C	D	D	D	A
Sweden		A	A					A		A	B					
Spain		A	A			A	A	A		D			D	D	D	
Poland		A	A	A			A	A				C			A	A
Czechoslovakia		A	A				A	A								
Czech Republic											A				C	A
Switzerland		A					A	A							A	A
Romania		B	B	A			A	A			A	D				
Belgium		B	B													A
Netherlands		B	B			A	A									
Finland			A					A								

Figure 3: Change in prevalent aircraft production modes.

Notes: Only selected countries and categories. ‘Production’ refers to entire systems (including licensed production) or to a major participation in transnational consortia, but not to the tier supply of subsystems and components or the final assembly of foreign-made systems. ‘Germany’ in the 1960s refers to the Federal Republic of Germany. Information on Romania’s historical production refers to the 1970s since its industry had not been fully established in the 1960s. Categories: (1) strategic bomber aircraft; (2) advanced combat aircraft; (3) jet trainer or light combat aircraft; (4) rotary-wing aircraft; (5) heavy transport or tanker aircraft; (6) medium transport or tanker aircraft; (7) light transport aircraft; (8) piston or turboprop trainer aircraft. See figure 2 for lettered categorization.

Source: Own construction based on data collected from the economic literature, and corporate and governmental publications (see online Appendices A and B for further information—the link is found in the Appendices section of this article).

destroyers. So again, European level developments can conceal the true impact of consolidation at the national level.

In the land sector, Figure 5 shows that more than a dozen European states still maintain production capabilities for armored fighting vehicles other than main battle tanks. This is roughly comparable to the 1960s (although the magnitude of the production capabilities may have been reduced). On the other hand, the number of countries with main battle tank industries has halved. Overall, the restructuring of the land sector was largely national, although some important cross-border mergers and acquisitions have taken place. These were mostly takeovers by much larger foreign competitors,⁴¹ with some mergers between competitors of more comparable size also happening. In 2003, the leading armored vehicle producers of Austria (Steyr–Daimler–Puch Spezialfahrzeug), Spain (Santa Bárbara Sistemas) and Switzerland (Mowag) were consolidated into GDELS.⁴² In 2015, the Franco–German KNDS alliance of Nexter and Krauss–Maffei Wegmann was formed, followed in 2019 by the establishment of Rheinmetall BAE Systems Land.

41 Such as the consolidation of the Dutch armored vehicle industry into Rheinmetall and Krauss–Maffei Wegmann (Caralp, 2017), Rheinmetall’s acquisition of Oerlikon–Contraves Defense (Switzerland), the integration of Hägglunds and Bofors (Sweden) into BAE Systems, and the transfer of Slovakia’s MSM Group to the Czechoslovak Group.

42 Followed by further acquisitions and partnerships in Germany, the Czech Republic, Denmark, Portugal, and Romania.

	Prevalent production mode in the 1960s							Prevalent production mode in 2022						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(1)	(2)	(3)	(4)	(5)	(6)	(7)
United Kingdom	A	A	A	A	A	A	A	A		A	A	A	A	A
France	A	A	A	A	A	A	A	A	A	C	A	A	A	A
Germany		A		A	A	A	A		A		A	A	A	A
Italy		A		A	A	A	A		A	A	A	A	A	A
Spain		A		A	A	A	A		A	A	A	A	A	A
Netherlands		A		A	A	A	A			A	A	A	A	A
Sweden		A		A	A	A	A	A					A	A
Denmark		A			A	A							A	
Norway					A	A	A						C	A
Portugal					A		A						A	
Finland						A						A		
Poland							A						A	A
Croatia		A					A							A
Belgium					A	A	A							D

Figure 4: Change in prevalent naval shipbuilding modes.

Notes: Only selected countries and categories. ‘Production’ refers to entire systems (including licensed production) or to a major participation in transnational consortia, but not to the tier supply of subsystems and components or the final assembly of foreign-made systems. Information on Germany and Croatia in the 1960s refers to the Federal Republic of Germany and the Socialist Republic of Croatia (within Yugoslavia). Categories: (1) nuclear-powered submarines; (2) conventionally powered submarines; (3) aircraft carriers or large amphibious ships; (4) destroyers; (5) frigates; (6) corvettes or offshore-patrol ships; (7) mine-countermeasure vessels (offshore or coastal). See figure 2 for lettered categorization.

Source: Own construction based on data collected from the economic literature, and corporate and governmental publications (see online Appendices A and B for further information—the link is found in the Appendices section of this article).

Taken together, these assessments show that national capabilities have often disappeared even though the supply of almost the entire range of aircraft, naval, and land systems is maintained on a European level. Production is now concentrated in fewer countries as compared to earlier decades, and national programs have often been replaced by collaboration.

	Prevalent production mode in the 1960s					Prevalent production mode in 2022				
	(1)	(2a)	(2b)	(3)	(4)	(1)	(2a)	(2b)	(3)	(4)
Germany	A	A	A	A	A	A	A	A	A	A
France	A	A	A	A	A	A		A	A	A
United Kingdom	A	A	A	A	A	A	C	A	A	A
Italy	A	A		A	A	A	A	A	A	A
Poland	A	B	B	A	A	A	A	A	A	A
Spain	A		A	A	A	C	C	C	C	B
Sweden	A	A		A	A		C	C	C	C
Switzerland	A	A	A	A	A			C		A
Romania	A		A	A	A			A		A
Czechoslovakia	A	A	B	A	A					
Czech Republic								A		B
Slovakia								C	A	A
Finland				A				A	A	A
Austria		A			A			C		C
Belgium			A	A	A					A
Norway				A						A
Netherlands			A							B
Portugal			A		A					

Figure 5: Change in prevalent land systems production modes.

Notes: Only selected countries and categories. ‘Production’ refers to entire systems (including licensed production) or to a major participation in transnational consortia, but not to the tier supply of subsystems and components or the final assembly of foreign-made systems. ‘Germany’ in the 1960s refers to the Federal Republic of Germany. Information on Romania’s and Spain’s historical production refers to the 1970s as their industries had not been fully established in the 1960s. Categories: (1) main battle tanks or assault guns; (2) other types of armoured fighting vehicles (a: tracked; b: wheeled); (3) self-propelled or towed guns/howitzers; (4) armoured vehicle turrets or weapon stations. See figure 2 for lettered categorization.

Source: Own construction based on data collected from the economic literature, and corporate and governmental publications (see online Appendices A and B for further information—the link is found in the Appendices section of this article).

Leading defense firms resulting from consolidation

Companies with high defense dependency are potentially at higher risk if domestic budgets fall or foreign defense market competition increases.⁴³ On the other hand, diversified firms with low defense dependency may be less committed to promoting their defense business⁴⁴ and experience larger commercial consolidation pressure.⁴⁵ State-ownership can inhibit necessary corporate restructuring and cross-border consolidation,⁴⁶ but as Hartley (2019) points out, cross-border mergers may require governmental support even if the participating defense firms are not state-owned.

⁴³ Mölling (2015).

⁴⁴ Fleurant and Quéau (2014).

⁴⁵ Andersson (2001).

⁴⁶ Belin et al. (2019); Balis (2013); Briani et al. (2013).

Table 3: Leading European aircraft manufacturers (2021)

<i>Company</i>	<i>Country</i>	<i>Defense sales (aircraft segment, in USD million)</i>	<i>Defense dependency in %</i>	<i>State ownership in %</i>	<i>Capabilities</i>
Airbus	Trans-European	9,872	18	25.9	2/3/4/5/6/7/8
BAE Systems	United Kingdom	8,380–8,860	97	0	2/3
Leonardo	Italy	6,840–7,610	83	30.2	2/3/4/6/7
Dassault Aviation	France	6,250	73	0	2/7
Saab	Sweden	1,340–1,380	90	0	2/3
Pilatus Aircraft	Switzerland	484	33	0	7/8

Notes: Sales are approximate. Since the definition of “aircraft” or “aerospace” operations varies among the firms, column 3 states maximum values. Where possible, revenues unrelated to military aircraft have been excluded. The British Government holds a “special share” in BAE Systems. Capabilities: (2) advanced combat aircraft; (3) jet trainer or light combat aircraft; (4) rotary-wing aircraft; (5) heavy transport or tanker aircraft; (6) medium transport or tanker aircraft; (7) light transport aircraft; (8) piston or turboprop trainer aircraft. Includes licensed production and major participations in national or transnational consortia. *Source:* Own compilation based on SIPRI (2022c), Defense News (2022), corporate and governmental sources.

Table 4: Leading European naval shipbuilders (2021)

<i>Company</i>	<i>Country</i>	<i>Defense sales (naval segment, in USD million)</i>	<i>Defense dependency in %</i>	<i>State ownership in %</i>	<i>Capabilities</i>
BAE Systems	United Kingdom	5,160–6,440	97	0	1/3/4/5/6/7
Naval Group	France	4,740	99	62.3	1/2/3/4/5/6/7
Fincantieri	Italy	2,980	36	71.3	2/3/4/5/6
ThyssenKrupp	Germany	1,800–2,390	6	0	2/4/5/6
BIG	United Kingdom	1,280	55	0	3/5/6
Navantia	Spain	1,080	70	100	2/3/4/5/6/7
Lürssen	Germany	600–700	40–50	0	4/5/6/7
DSG	Netherlands	400–700	15–25	0	3/4/5/6/7
Saab	Sweden	390–400	90	0	2/6/7
CdA	France	200–300	10–15	84.3	3/5/6
Prininvest	Trans-European	130–200	n/a	0	4/5/6

Notes: Sales are approximate. Since the definition of “naval” operations varies among the firms, column 3 states maximum values. Where possible, revenues unrelated to military vessels have been excluded. Defense sales of Prininvest include German Naval Yards and Lindenau in Germany, CMN in France, and Isherwoods in the U.K. The British Government holds a “special share” in BAE Systems. Capabilities: (1) nuclear-powered submarines; (2) conventionally powered submarines; (3) aircraft carriers or large amphibious ships; (4) destroyers; (5) frigates; (6) corvettes or offshore-patrol ships; (7) mine-countermeasure vessels (offshore or coastal). n/a=no data available; BIG=Babcock International Group; CdA=Chantiers de l’Atlantique; DSG=Damen Shipyards Group.

Source: Own compilation based on SIPRI (2022c), Defense News (2022), corporate and governmental sources.

As Table 3 shows, Europe’s capabilities in military aircraft are concentrated in just five leading firms (Airbus, BAE Systems, Leonardo, Dassault, and Saab). BAE Systems is by far the largest European defense firm in total defense sales, but ranks below Airbus if only the aircraft-related turnover is considered. Indeed, Airbus’ defense-related aircraft sales exceeded those of Dassault by almost 60 percent, and those of Saab and Pilatus Aircraft by a factor of 7 and 20, respectively. Governmental ownership was reduced to a minority stake in Airbus and Leonardo,

and to a “golden share” in BAE Systems. The companies also vary in their defense dependency, ranging from 18% (Airbus) to 97% (BAE Systems), and in their diversification (with Airbus and Leonardo having broader aircraft portfolios). If the proposed EADS/BAE Systems merger had happened, it might have marginalized Dassault and Leonardo.

Europe’s naval sector is likewise very unevenly distributed, as relatively few shipbuilders account for most naval-related defense sales. While there are some limitations to the available information, Table 4 suggests that BAE Systems was the largest European naval supplier in 2021, followed by Naval Group, Fincantieri, ThyssenKrupp, Navantia, Lürssen, Damen Shipyards Group., and Saab. Babcock’s position is difficult to assess due to the particularly large share of maintenance and service activities in its naval revenues. In contrast to Europe’s largest aircraft firms, three leading naval shipbuilders (Naval Group, Fincantieri, Navantia) still operate under governmental control.

Table 5 shows that Rheinmetall, KNDS (comprising of Nexter and Krauss–Maffei Wegmann), BAE Systems, and General Dynamics’ major European subsidiaries (GDELS and General Dynamics U.K.) are the largest European producers. Most of BAE Systems’ land-based revenues, however, are generated by its U.S.-based subsidiaries. In 2019, Rheinmetall acquired a majority in BAE Systems’ U.K.-based military vehicle business. The size differential vis-à-vis Europe’s next-largest armored vehicle suppliers (Arquus, Iveco Defense Vehicles, PGZ, Leonardo, Czechoslovak Group, and Patria) is substantial. The data also shows that firms with higher land sales usually have more diversified portfolios (although there are some exceptions).

Table 5: Leading European land systems manufacturers (2021)

<i>Company</i>	<i>Country</i>	<i>Defense sales (land segment, in USD million)</i>	<i>Defense dependency in %</i>	<i>State ownership in %</i>	<i>Capabilities</i>
Rheinmetall	Germany	2,860–3,570	67	0	1/2a/2b/3/4
KNDS	Trans-European	3,030	95	50	1/2a/2b/3/4
BAE Systems	United Kingdom	2,750–3,180	97	0	1/2a/2b/3/4
GDELS & GDUK	Trans-European	730–1,270	69	0	2a/2b/3/4
Arquus	France	620	1	0	2b/4
IDV	Italy	560–730	2	0	1/2a/2b/3
PGZ	Poland	500–700	90	100	1/2a/2b/3/4
Thales Group	France	n/a	51	25.7	2b/4
Leonardo	Italy	250–580	83	30.2	1/2a/2b/3/4
John Cockerill	Belgium	370–420	35–40	0	4
Kongsberg	Norway	210–280	37	50.001	4
CSG	Czech Republic	140–210	60–75	0	2b/4
Patria Group	Finland	140–200	93	50.1	2b/3/4
RUAG MRO	Switzerland	120–210	86	100	3/4

Notes: Sales are approximate. Since the definition of “land” operations varies among the firms, column 3 states maximum values. Where possible, revenues unrelated to armored vehicles and artillery systems have been excluded. Leonardo only supplies armored vehicles via CIO (a joint venture with Iveco Defense Vehicles). Defense dependency rates for GDUK, GDELS, Arquus and Iveco Defense Vehicles refer to the parent firms (General Dynamics, Volvo Group, CNH Industrial). The British Government holds a “special share” in BAE Systems. The French Government holds a “golden share” in Nexter (which makes up 50% of KNDS) and Thales. Capabilities: (1) main battle tanks or assault guns; (2) other types of armored fighting vehicles (a: tracked; b: wheeled); (3) self-propelled or towed guns/howitzers; (4) armored vehicle turrets or weapon stations. n/a=no data available; CSG=Czechoslovak Group; GDELS=General Dynamics European Land Systems; GDUK=General Dynamics UK; IDV=Iveco Defense Vehicles; KNDS=Krauss–Maffei Wegmann + Nexter Defense Systems; PGZ=Polska Grupa Zbrojeniowa.

Source: Own compilation based on SIPRI (2022c), Defense News (2022), corporate and governmental sources.

Defense electronics warrants a brief reflection as it now accounts for a large share of European defense production.⁴⁷ As Table 6 shows, the combined sales of the five largest suppliers (about USD 22.2–25.5bn) significantly exceed those of the leading firms from the naval (USD 16.0–17.8bn) and land systems sectors (USD 10.0–11.8bn). Only the aircraft sector offers higher combined revenues (USD 32.7–34.0bn), although we cannot rule out that these sales might also include an electronics component. In contrast to the land and naval sectors, no leading defense electronics company still operates under majority public ownership.

This does not necessarily imply that the “older” industries are on the way out, as 23 of Europe’s 30 largest defense firms generate most of their revenues in segments other than defense electronics.⁴⁸ More importantly, defense electronics solutions form an integral part of equipment delivered by the “traditional” sectors, and we may expect this

Table 6: Leading European defense electronics manufacturers (2021)

<i>Company</i>	<i>Country</i>	<i>Defense sales (electronics segment, in USD million)</i>	<i>Defense dependency in %</i>	<i>State ownership in %</i>
Thales Group	France	7,800–9,300	51	25.7
Leonardo	Italy	5,500–6,700	83	30.2
BAE Systems	United Kingdom	5,960–6,480	97	0
Hensoldt	Germany	1,610	92	25.1
Safran	France	1,100–1,400	28	11.2
Saab	Sweden	1,300–1,330	90	0
Rheinmetall	Germany	1,102	67	0
QinetiQ	United Kingdom	1,000–1,300	83	0
Airbus	Trans-European	700–980	18	25.9
Ultra Electronics	United Kingdom	920	79	0
Indra Sistemas	Spain	752	19	18.7
Thales Group	France	7,800–9,300	51	25.7

Notes: Sales are approximate. Since the definition of “defense electronics” and associated operations varies among the firms, column 3 states maximum values. The British Government holds a “special share” in BAE Systems and QinetiQ, respectively. The French Government holds a “golden share” in Thales.

Source: Own compilation based on SIPRI (2022c), Defense News (2022), corporate and governmental sources.

integration to increase further in the future.⁴⁹ The rise of the defense electronics sector may therefore (at least in part) also be considered a by-product of Europe’s strong position in the more “traditional” defense-industrial sectors.

47 “Defense electronics” is defined as all military command, control, communications, computers, intelligence, surveillance, target acquisition and reconnaissance (C4ISTAR) activities, plus related electronic components and certain space systems.

48 SIPRI (2022c), Defense News (2022) and own research based on Bureau van Dijk’s (2022) ORBIS database.

49 Dowdall et al. (2004) illustrate the rising importance of avionics in combat aircraft.

Conclusion

While the end of the cold war spurred consolidation in the defense industrial sector, a complex interplay of national and trans-European restructuring processes had, in fact, started much earlier. This reflected long run pressures of rising R&D cost, rising production costs, and technological change—all driven by industrial and political factors. To see this clearly requires the disaggregated analysis undertaken here. Subsectors had varying experiences with the number of important European suppliers contracting since the 1960s by between 29% and 80%. In some subsectors, the reduction was larger from the 1960s to the 1990s than that between the 1990s and 2022. The overall reduction was somewhat larger for the aircraft sector than for the naval and land segments, but sub-sectoral developments often differed from this broad trend.

Some segments of the aircraft sector are now characterized by European duopolies and monopolies, but five European firms maintain advanced combat aircraft production. Further, although the total number of remaining land systems manufacturers and naval shipbuilders far exceeds the number of aircraft producers, there are as many European combat aircraft manufacturers as there are suppliers of main battle tanks and conventional submarines. For East-Central European countries, the reductions were even higher, as their defense industries experienced larger economic shocks with the end of the Cold War.

A degree of national autonomy has often been relinquished to preserve industrial capabilities, particularly in the aircraft sector. As of 2022, no single European country builds heavy transport aircraft independently. Only Italy produces medium transport aircraft on its own, and all national helicopter industries are controlled by Leonardo and Airbus. Besides transnational integration, consolidation has also advanced via unilateral withdrawals from specific subsectors—with the loss of individual capabilities becoming much greater if the 1960s are used as a baseline. Using disaggregate information highlights that the consolidation process experienced by Europe's defense industry is likely to be understated if only aggregate analyses are undertaken.

Further attributes of consolidation trends deserve mention. Public interest may suppress market forces that would otherwise initiate consolidation, but at other times, governments have spearheaded rapid sectoral consolidation of nationalized firms. Consolidation is often preceded by collaborative programs, which can strengthen industrial ties and provide a foundation for later mergers. However, competitors with weak industrial ties may also merge and only later align their portfolios. Finally, we can sometimes attribute disappearing capabilities to changing requirements stemming from technological progress (rather than to industrial consolidation).

It has been suggested that advances in manufacturing due to the ongoing “Fourth Industrial Revolution” could establish new modes of defense-industrial cooperation, lessen the need for centralized production, and permit shorter production runs.⁵⁰ This may result in the deceleration of the identified six-decade trend of concentrating complex defense systems production into fewer European countries and firms.

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Appendix

The online appendix can be found at: <https://www.epsjournal.org.uk/index.php/EPSJ/rt/suppFiles/371/0>

The effect of crude oil price changes on civil conflict intensity in rentier states

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Abstract

While existing literature has considered the relationship between oil and conflict, most of the studies have failed to consider mechanisms that might mediate the effect of the fluctuating market price of oil on conflict. We theorize that the military capacity of the state is a key mediating mechanism for understanding the relationship between shifting oil market prices and conflict intensity. We argue that states which rely upon oil sales to fund a large portion of government spending will have a more difficult time maintaining conflict-reducing state capacity during times in which oil prices are below previously prevailing averages for extended lengths of time. Using country-year data in 67 conflict states from 1989–2019, we find that low average oil prices are associated with lower military spending which in turn is associated with higher rates of battle fatalities in existing civil conflicts.

The relationship between oil and conflict is one which has given rise to broad scholarly interest. One identified component of this relationship is an increased risk of intrastate conflict in oil rich nations, a “curse” which can lead to instability in regions important to the global energy market.¹ Research on the impact of oil on intrastate conflict however tends to treat oil as a constant, contrasting with a reality in which oil prices are continuously in flux. Indeed, there has been significant variation in crude oil prices since 1980, with prices often settling at multi-year averages that are significantly higher or lower than previously. This leads to a lingering question in the literature, what impact does variation in the price of oil have on intrastate conflicts?

This paper addresses this gap in the literature, theorizing that fluctuating oil prices affect the intensity of civil conflict through an intervening variable, military expenditures. While we theorize that the impact of higher oil prices is higher military expenditures and lower combat fatalities, we also recognize that the link between higher military expenditures and civil conflict intensity may be non-linear.

Drawing on crude oil prices, military expenditures, and conflict severity data we examine 67 conflict states from the period of 1989–2019, demonstrating that low average oil prices are correlated with higher battle fatalities in existing civil conflicts. We also demonstrate the role of our proposed causal mechanism, showing that low average oil prices are associated with lower military expenditures, which are in turn associated with higher battle fatalities in low-intensity conflict states.

The remainder of this article starts with a review of relevant literature on oil prices, conflict, and state capacity—to provide context for our analyses. This is followed by defining the theoretical approach and establishing the primary hypotheses. Next is a description of the data used to test the hypotheses and, subsequently, the results of the empirical evaluation are given. The article then closes with some conclusions.

¹ Ross (2012).

Literature on oil prices and civil conflict

Many examinations of oil and civil conflict focus on rebel incentives. The notion that natural resources would provide a valuable “prize”² or an opportunity to make conflict more viable by offsetting the costs of rebellion³ is well founded in the literature. Scholars have likewise examined the potential linkage between other lootable natural resources and conflict onset, with mixed results.⁴ For instance, work has found that loss of income (in this case from labor-intensive agriculture) can serve as a catalyst for conflict when it impacts a politically marginalized ethnic group.⁵ There has been a specific interest on the role that oil plays in conflict. The “oil curse” is a theory that has received considerable attention in the literature, focusing primarily on intrastate conflict onset.⁶ Some leading scholars such as Ross argue that the presence of onshore oil production provides a financial incentive for would-be rebels and opposition forces to resort to armed conflict.⁷

We hypothesize that the price of oil does not meaningfully affect the incentive of potential separatist rebels. Those with very poor economic opportunities (i.e., a lack of alternatives) will be similarly enticed by potential spoils from oil revenue regardless of prices.⁸ Rebels would still get a larger share of the revenue if they alone controlled the oil reserves instead of the existing central government. This mechanism occurs regardless of prices.⁹ Thus we consider rebels to be insensitive to oil price shocks.

In contrast to the incentive approach described above, some find that oil revenue can increase a state’s ability to “pay off” opposition and thus lower the probability of civil conflict.¹⁰ This suggests there are multiple potential mechanisms to understand oil’s effect on conflict, particularly relating to the resources at the disposal of the state and how that impacts on whether it can stave off rebellions.

Oil, like other commodities, varies in pricing, which begs the question as to whether its value to rebels and states also varies. While other researchers have examined the linkages between oil prices and conflict, they have often exclusively focused on interstate conflicts.¹¹ Increases in the price of oil can in fact lead to an increase in state capacity, in the form of military capacity used in interstate conflict.¹² Positive resource shocks, however, could also allow the state to strengthen its security measures and control and suppress or buy off internal rebellion.¹³

There are indeed some studies that have examined commodity prices and civil conflict. Several analysts have focused on agricultural commodity prices and their relationship with conflict, with important trends emerging. However, these studies tend to focus on either the opportunity cost of insurrection or the state prize model.¹⁴ Under the opportunity cost model, falling agricultural yields make rebellion more appealing as an alternative to agricultural

For states which rely upon oil sales to fund a large portion of government spending, low average oil prices are associated with lower military spending which in turn is associated with higher rates of battle fatalities in existing civil conflicts.

Further to this, the changing energy economy towards less oil-reliance will hold serious consequences for states that derive significant government revenue from the sale of oil. One of these effects is likely to be the reduced capacity for oil reliant states to prosecute ongoing civil conflicts.

2 Fearon (2005).

3 Collier and Hoeffler (2004).

4 Collier and Hoeffler (2004); Ross (2008); Ali and Abdellatif (2015); Le Billon (2012).

5 Buhaug *et al.* (2021).

6 Collier and Hoeffler (2004); Ross (2008); Watts (2007); Fjelde (2009); Gunter (2015).

7 Ross (2012).

8 Demuynck and Schollaert (2008).

9 Ross (2012).

10 Fjelde (2009).

11 Duffield and Klare (2005); Hendrix (2017).

12 Hendrix (2017).

13 Snyder (2006); Ross (2012); Bazzi and Blattman (2014).

14 Ray and Esteban (2017).

production.¹⁵ The state prize model assumes that rising prices increase rebel incentives to capture lootable resources. Others argue that sub-Saharan African states, which rely on tropical agricultural commodities and mineral wealth, are less likely to see conflict when high agricultural prices provide laborers an alternative to mining and competition over its spoils.¹⁶ Low agricultural prices, however, increase the attractiveness of the mineral sector and thereby fuel conflict onset. A meta-analysis mirrors this line of reasoning, showing that rises in agricultural prices decreases conflict likelihood, while rises in oil prices increases it.¹⁷

However, other recent work has suggested that lootable, capital-intensive resources like oil are less likely to affect rebel conflict incentives than labor-intensive resources.¹⁸ Price shocks to labor-intensive resources are more likely to provoke conflict given the greater returns and employment opportunities, rather than capital intensive resources like oil and gas. Despite this, commodity price shocks (including oil price shocks) have been shown to effect conflict intensity—measured in battle deaths, conflict onset and duration, and coups. Notably, rising oil and mineral prices have been associated with shorter, less intense conflicts in recent studies, including in a key 2014 study by Bazzi & Blattman.¹⁹ While this study focused primarily on agricultural price shocks, and bundled oil and gas price shocks with mineral price shocks, it provides an important addition to the literature and some basis for our approach. Notably, this study did not provide an empirical treatment of the mechanism, which was loosely explained as military spending and state capacity. However, the authors argue that “the evidence tips...toward a ‘state capacity’ effect”. Other approaches have reached competing conclusions such as income shocks, due to rising oil prices in the 1990s, increasing violence in Colombia during a notoriously long-lasting civil conflict in that state.²⁰

In sum, oil price fluctuations ought to have important implications for civil conflict. However, the literature does not clearly link oil price fluctuations with civil conflict in the way described in this article, which is through the transmission mechanism of state military capacity (although some studies suggest this). When oil prices are high and the state can both produce and generate revenues from oil, then conflicts will subside as the state is better able to fund counter-insurgency measures against rebels. The next two subsections briefly discuss the literature around both sides of this mechanism to provide a basis for our theoretical approach.

State capacity, military expenditures, and conflict

The ability for the state to project power and engage with belligerents is a long-standing explanatory factor for conflict. States must be able to reach and control far and difficult to reach corners of its territory.²¹ Large militaries can help with favorable outcomes for the government (assuming that they can win quickly) and have been linked to primary commodity exports.²² Recent work has also linked military capacity to the prevention of civil conflict onset.²³ Others have reached similar findings about the effect of military capacity on conflict duration and intensity by examining *military expenditures* specifically as a measure of military capacity.²⁴

The literature’s debate on state capacity measures and its relationship to conflict onset is long-standing. Relative to conflict onset, there is a smaller literature on how military state capacity affects conflict *severity*.²⁵ Most literature

15 Collier and Hoeffler (1998); Miguel, Satyanath, and Sergenti (2004); Dal Bó and Dal Bó (2011).

16 Demuyne and Schollaert (2008).

17 Blair, Christensen, and Rudkin’s (2021).

18 Blair *et al.* (2021).

19 Bazzi and Blattman (2014).

20 Dube and Vargas (2013).

21 Tilly (2017); Herbst (2000); Buhaug *et al.* (2009); Roessler (2016).

22 DeRouen and Sobek (2004).

23 Müller-Crepon *et al.* (2021).

24 Hendrix (2010).

25 In general, the literature focuses on the determinants of conflict onset compared to how wars are fought. See Lu and Thies (2011); Balcells and Kalyvas (2014).

focuses on the relationship between state capacity and conflict onset using static measures such as the size of the army or gross domestic product. These studies do not provide much information about how state capacity affects ongoing conflict. Moreover, the determinants of conflict onset differ from severity.²⁶ Recent work has shown how various state level factors can explain conflict intensity and duration such as state economic conditions²⁷ and regime and cultural characteristics.²⁸ Military capacity is likely to affect the severity of conflict as the government works to defeat insurgents. National militaries with combined arms capabilities, or mechanized infantry, armor, and air units working in tandem, are correlated with shorter civil conflict duration.²⁹ Such capabilities, not only in the form of equipment, but in the necessary training in tandem, require significant investments. Building on existing work, we focus here on military state capacity and factors related to conflict intensity, conceptualized as conflict-related battle deaths.³⁰ We depart from this work by arguing that impacts on state capacity overwhelm impacts on rebel capabilities or incentives, as oil rents enable more military spending and leave governments better equipped to fight rebels.

In sum, there is reason to suspect that military capacity is an important variable in determining the intensity of ongoing civil conflict, and that military expenditure is a reasonable means by which to estimate this capacity.

Oil and military expenditures

As discussed, military strength and the state's capacity for coercion is an important variable for examining conflict intensity. However, how fluctuating oil prices impact oil-dependent states' coercive capacity is still an open question. Revenue reflects the ability of the state to fund operations, namely conflict relevant operations, that are important to the course of conflict. Scholarship on the link between decreasing oil prices and shrinking military expenditures has been mixed, but generally favors a positive correlation. Military expenditures were found to be inelastic relative to variations in oil revenues in one study of five major oil producing states between 1997–2007.³¹ Likewise, a similar analysis of Gulf Cooperation Council (GCC) states found limited correlation between oil price volatility and increases in military expenditures.³² However, a positive effect was found in non-GCC Middle East and North African (MENA) states in a similar study.³³ The study argued that corruption plays a mediating role between oil rents and military spending, with oil having a larger, more positive impact on military spending in polities which are more corrupt. This finding is also reinforced by work linking higher oil rents with greater military expenditures in MENA states.³⁴ Other studies posit a positive relationship between oil rents and military spending in GCC states as well.³⁵

These findings of a positive relationship have been substantiated by several case studies including Chad³⁶, Algeria³⁷, and Iran.³⁸ Scholars have generally supported a positive correlation between oil wealth and military spending in non-democratic countries.³⁹ Various causal mechanisms linking oil revenue to military spending have been proposed in prior literature such as corruption⁴⁰, buying the loyalty of the military⁴¹, or a combination of these

26 Lacina (2006).

27 Lu and Thies (2011); Chaudoin *et al.* (2017).

28 Lacina (2006).

29 Caverley and Sechser (2017).

30 Lacina (2006); Hendrix (2010); Balcells and Kalyvas (2014).

31 Chun (2010).

32 Erdoğan, Çevik, Gedikli (2020).

33 Farzanagen (2018).

34 Ali and Abdellatif (2015); Dizaji (2019); Dizaji (2022).

35 Al-Mawali (2015).

36 Frank and Guesnet (2009).

37 Perlo-Freeman and Brauner (2012).

38 Farzanegan (2011).

39 Cotet and Tsui (2013).

40 Farzanagen (2018).

41 Bellin (2004).

variables.⁴²

In sum, it seems clear that positive resource shocks, such as those created in oil-reliant states by a significant and lasting increase in the price of oil, ought to often result in greater military expenditures. However, the literature contains gaps in our understanding of oil resources and conflict intensity, as well as unclear mechanisms surrounding how price fluctuations may impact this relationship. With this article, we seek to clarify one mechanism by which this relationship is governed. Specifically, we suspect that oil revenues support military spending, and that greater military spending increases state capacity to suppress rebellion. Next, we present a theory, focused on state military capacity, that seeks to address these concepts directly.

A theory of oil price shocks and conflict in rentier states

In conflict states in which the central government budget is heavily reliant on oil revenues, we predict that significant negative changes in price will impact on the ability of the government to finance security measures in areas vulnerable to rebellion. States are best suited to prevail in intrastate, and particularly counter-insurgency, conflicts when their forces are well equipped and properly trained, both of which are resource-intensive endeavors. Positive resource shocks allow the state to strengthen its security measures and control and suppress or buy off rebellion.⁴³ Rising oil and mineral prices are therefore associated with shorter, less intense conflicts.⁴⁴ Below, we introduce three hypotheses to support this position.

If our core hypothesis proves correct, then we will have shown that an increase in oil prices leads to more effective security and less battlefield fatalities. We would then expect that greater oil prices correlate to lower battlefield fatalities in oil reliant states:

Hypothesis 1 (H1): An increase in oil prices will be correlated with a decrease in combat fatalities, i.e., “battle deaths,” in conflict states reliant on oil, relative to those not reliant on oil, all else being equal.

In states dependent on the sale of oil, higher prices lead to more revenue. These higher revenues lead to more military and security spending, allowing states to fund additional soldiers, police, and other security personnel. This increase in security capacity leads to a reduction in rebels’ ability to operate, and so ought to reduce the number of battle deaths—as in the medium term rebels scale back operations or lay down their arms.

To test the mediating variable in this hypothesis, we also examine whether oil prices impact oil-dependent states’ military expenditures. In line with the conclusions of previous scholars who demonstrated a correlation between oil rents/revenue and military spending⁴⁵, we theorize a correlation exists between oil prices and military expenditures among states more reliant on oil rents. As the price of oil rises, rentier states highly dependent on oil will see a growth in revenue. As their revenue increases, these states will be inclined to dedicate more resources to the military. In contrast, when oil prices drop along with rents, states will respond with cuts to military spending:

Hypothesis 2 (H2): When oil prices are at high average levels, oil dependent conflict states will have higher levels of military expenditures relative to periods of low oil prices, all else being equal.

States can derive oil rents from a variety of sources, such as through taxation or the capture of profits through state-owned enterprises. Depending on the time of year and how the state budgeting process works, the impacts from a

⁴² Fjelde (2009).

⁴³ Snyder (2006); Ross (2012); Bazzi and Blattman (2014).

⁴⁴ Bazzi and Blattman (2014).

⁴⁵ Frank and Guesnet (2009); Perlo-Freeman and Brauner (2012); Al-Mawali (2015); Dizaji (2019).

positive or negative shock to revenue could happen in the same or following year. We examine both scenarios by testing lag variables for both H1 and H2.

Lastly, we propose to link this measure of state capacity; military expenditures, with the primary dependent variable from H1, i.e., “battle deaths”. When state military expenditures are higher, this ought to reduce the number of battle deaths from civil conflict as the security environment improves. However, the relationship between these variables is complex and may be nonlinear. For example, increases in military capacity may lead to “crackdowns” that temporarily lead to *higher* battle deaths. However, for most states in civil conflict, we predict that this relationship will be negative:

Hypothesis 3 (H3): When oil dependent conflict states have higher military expenditures, this will be correlated with a decrease in combat fatalities, i.e., “battle deaths”, relative to when military expenditures are lower, all else being equal.

One way we choose to examine this possibility of a nonlinear effect is by splitting the sample along the lines of conflict intensity.

Data

67 conflict states with varying degrees of oil dependence from 1989–2019 were considered. Since government budgets do not fluctuate daily like oil prices, an average over a longer term is the most appropriate measure, thus our unit of analysis is measured at the country-year. We employ several methods to estimate the effect of the primary independent variable, *oil prices*. Government spending decisions are typically made in advance, so a lagged measure which captures the dynamic shifts in oil prices from year to year is prudent. We tested a one-year average of crude oil prices for our primary measures. This data was obtained from the Federal Reserve Bank of St. Louis FRED dataset, a widely accepted benchmark for crude oil prices.⁴⁶ We opted to use the West Texas Intermediary (WTI) price of oil instead of Brent. These two measures are highly correlated, and the results using Brent were substantively indistinguishable from using WTI.

Second, we expect the effect of oil prices to appear primarily in states that are heavily dependent on oil for government revenue. Therefore, we employ a measurement of relative oil rents. Oil rents are a continuous variable which indicates the percentage of total GDP which was derived from the sale of oil each year. This data can be obtained from the World Bank Open Data online database.⁴⁷ Ross (2012) uses oil income per capita as his primary measure of a petro-state. However, there are some concerns about this measure. The measure does not estimate the relative importance of oil to the overall economy, the degree to which the government derives state revenue from it, or independent effects from changes to GDP—leading researchers to consider other measures in more recent work.⁴⁸ For this reason, we opt to use oil rents as a percentage of GDP, which provides a better estimate of how important oil is to the overall economy.

Oil reliant states ought to have greater capacity to deal with rebels when oil prices are high. To test this hypothesis, we examine the impact of oil prices on military expenditures, and the impact of military expenditures on conflict intensity. When military spending is high, governments ought to have additional military resources to devote to suppressing armed rebellions and providing security. When these resources are scarcer, governments may need to scale back military and security operations, potentially allowing groups more opportunity to sustain and intensify an armed

⁴⁶ U.S. Energy Information Administration (2020).

⁴⁷ The World Bank (2020).

⁴⁸ Wright *et al.* (2015).

rebellion. For example, Nigerian military spending was at an all-time high in 2011, which coincided with a peak in the two-year average price of oil during the same year. Oil prices hit a two-year low in 2014, and Nigerian military expenditure that year was less than half the value than in 2011.⁴⁹ Our data on military expenditures was obtained from a dataset on military expenditures developed by the Stockholm International Peace Research Institute, which is integrated into the World Bank Open Data online database. We use military expenditure in constant U.S. dollars (USD) as our primary measure.

Rebel-incentive based theories are limited to describing the behavior of rebels located in regions with onshore oil reserves and little economic opportunity cost for rebellion.⁵⁰ However, our theoretical mechanism ought to work in any conflict-prone oil state, regardless of the type of rebel (secessionist or non-secessionist) or location of reserves. However, key conflict-related independent variables identified in prior studies, such as overall GDP, still need to be included.

We expect that states with higher military expenditures will have less intense civil conflicts. There are multiple series that allow for the creation of a variable measuring conflict intensity—this article uses battle-related deaths. Another possible measure is found by aggregating battle-related deaths and deaths from one-sided violence (i.e., civilian deaths), but we view these measures of violence and conflict intensity as separate, with the latter not capturing conflict between government forces and rebels, but rather crimes against civilians, which is a theoretically distinct phenomenon. Therefore battle-related deaths are used here as the measure of conflict intensity—obtained from the UCDP Battle-Related Deaths Dataset.⁵¹

The Uppsala Conflict Data Program (UCDP) defines an armed conflict as a contested incompatibility that concerns government and/or territory over which the use of armed force between two parties, of which at least one is the government of a state, has resulted in at least 25 battle-related deaths in one calendar year. Battle-related deaths refer to those deaths caused by the warring parties that can be directly related to combat.

Our dataset includes approximately 1,200 country-year cases of states in which civil conflict was occurring and for which we have both a measurement of battle related deaths and a measurement of the share of oil sales in the state's GDP. Among the universe of civil conflict states in the dataset, that average level of military spending was USD 7.1bn. The average level of oil rents as a share of GDP was 4.75%. The mean level of yearly battle deaths was 703, ranging from 25 to 30,000—however, most civil conflict state cases saw fewer than 500 fatalities per year. The mean level of military expenditure as a percentage of GDP and as a percentage of total government spending was 3.2% and 11.9%, respectively.

The conflict models used here incorporate several controls for confounding variables. The first of these is population size—a larger population size ought to be predictive of a higher number of battle deaths in a civil conflict.⁵² Among other control measures used were a security effectiveness score taken from the Center for Systemic Peace (which also produces the well-known Polity series).⁵³ A higher score on this index indicates a less secure state, making it a good indicator of state capacity. Lastly, GDP was also introduced as a control variable, another measure of relative state capacity and size.⁵⁴ The models also include fixed effects which are described in detail in the results section.

The model examining military expenditures and conflict carries some concern about endogenous variables. States in more severe conflicts will tend to spend more on the military. The presence of this effect serves to work against

49 Stockholm International Peace Research Institute Data (2018).

50 Ross (2012).

51 Davies *et al.* (2023); UCDP(2023)

52 Bruckner (2010).

53 Center for Systemic Peace (2022)

54 d'Agostino *et al.* (2011).

our hypothesis, and we control for it by incorporating previous period conflict intensity as a control, as well as fixed effects.⁵⁵

The spending models include controls for GDP, total currency reserves (excluding gold), and government debt—all taken from the World Bank data. Each of these measures ought to be expected to be positively related to military spending, as they are measures of government resources and state capacity.⁵⁶ The spending models also include controls for fixed effects.

An initial examination of this aggregated data indicates support for H1. A full move across the range of observed price values for WTI Crude Oil in the dataset (from the lowest observed price to the highest) is predictive of over 50 fewer monthly deaths in ongoing civil conflicts on average among the most oil-reliant conflict states observed (where oil rents were greater than 20 percent of GDP). A figure illustrating this association can be found in the appendix. In the next section we rigorously examine the data to determine the strength and characteristics of this relationship.

Results

To examine our hypotheses using this data, we first subdivided the full set of conflict states into a smaller subset of “oil states”. States that saw the sale of oil comprise a mean value of 10% or more of GDP over the observation period were designated as “oil states”. These oil states ought to be most sensitive to the impact of oil price fluctuations on state capacity. We also designated a smaller subset of “extreme oil states”—states in which the sale of oil was over 20% of GDP. Among the sample, there were 8 “oil states” and 5 “extreme oil states”, comprising about 197 and 104 total cases respectively.

The first set of models were designed to test the impact of oil price changes on battle deaths in these oil reliant states. We employed four measures for oil prices. First, a simple measure of the mean price for WTI in the current year. Second, a measure of the prior year’s mean price. The reason for testing a lagged variable here was because increases or decreases in the price of oil may not impact state revenues until a later period in states where budgets are set the year prior. The next two measures evaluate the change in WTI prices in percentage terms from the prior year’s mean. We include a measure of the change relative to the prior period mean (i.e., the change for the current year), and a measure of the change between the prior period and the period preceding that (i.e., the change for the prior year). These measures provide a variety of ways to evaluate the degree to which oil prices changes may impact conflict-reducing state capacity.

Our standard specification approach for the first set of models was to use ordinary-least-squares (OLS) regression models with fixed effects for state errors. State fixed effects are particularly important as states have wide endogenous variation in the number of battle deaths.⁵⁷ In this first test of Hypothesis 1, we specify the following four basic models of yearly conflict battle deaths:

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI Price}_{it} + B_2 \log(\text{population})_{it} + B_3 \text{SecScore}_{it} + B_4 \log(\text{GDP})_{it} + C_i + e$$

$$\text{Battle Death}_{sit} = B_0 + B_1 \text{WTI Price}_{i(t-1)} + B_2 \log(\text{population})_{it} + B_3 \text{SecScore}_{it} + B_4 \log(\text{GDP})_{it} + C_i + e$$

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI PriceChange}_{it} + B_2 \log(\text{population})_{it} + B_3 \text{SecScore}_{it} + B_4 \log(\text{GDP})_{it} + C_i + e$$

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI PriceChange}_{i(t-1)} + B_2 \log(\text{population})_{it} + B_3 \text{SecScore}_{it} + B_4 \log(\text{GDP})_{it} + C_i + e$$

⁵⁵ d’Agostino *et al.* (2011).

⁵⁶ Ali and Bhuiyan (2022).

⁵⁷ Fixed effects for time were not included in this model due to poor model fit. Fixed effects for time are used in the interactive effects regressions presented later in this section and tested for all subsequent regressions.

As Table 1 illustrates, we find that three out of four measures of oil price levels were significantly and negatively associated with the number of battle deaths in the state. An increase in the price of oil by USD 50 was associated with roughly 15 fewer battle deaths per year. While this figure appears rather small at first, it is more significant when we consider that roughly half of the conflicts in the dataset saw 100 or fewer battle deaths per year. We also tested measures of the percentage change in oil prices. Positive changes in both the current and prior period were associated with fewer battle deaths. A 10% increase in price in the current or prior period was associated with a decrease in yearly battle deaths of over 100.

Table 1: Oil prices and conflict intensity in oil reliant conflict states

	Dependent variable: Battle deaths (yearly)			
	Model			
	1	2	3	4
WTI P(t)	−28.875*** (10.693)			
WTI P(t-1)		−2.888 (9.602)		
WTI % chng(t)			−1,190.311** (600.541)	
WTI % chng(t-1)				−1,617.526** (673.981)
log(Population)	2,244.934 (2,038.138)	4,279.730** (1,977.919)	4,161.462** (1,901.066)	3,452.998* (1,925.875)
Sec score	1,152.992** (510.982)	875.673* (526.654)	773.926 (504.849)	976.206* (503.646)
log(GDP)	841.387 (626.393)	−281.843 (580.287)	−403.644 (432.539)	−212.523 (436.278)
Observations	139	139	139	139
R ²	0.113	0.062	0.090	0.103
Adjusted R ²	0.036	−0.019	0.011	0.025
F Statistic (df = 4; 127)	4.034***	2.116*	3.138**	3.626***

Notes: Models are panel linear regressions with country fixed effects. Price coefficients show the result of a 100 dollar increase in oil prices. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01

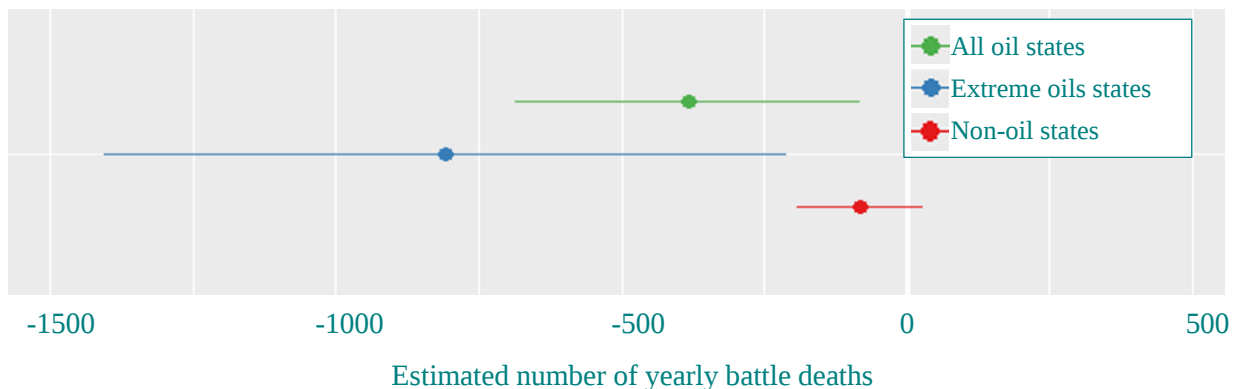


Figure 1: Marginal effect of oil price moves on battle deaths.

Notes: The figures represent the marginal effect of 1 standard deviation increase in the West Texas Intermediary (WTI) price of oil (from the prior year in percentage terms).

Among the control variables, performance was largely in line with expectations based on similar models. Overall model fit was within an acceptable range. However, the number of observations was limited to fewer than 200, as most states in the dataset were not “oil states”. In response to this, to examine the robustness of these findings, and to determine the effect that oil dependency has on the size of the marginal effect, we tested two additional subsets of Model 4 in Table 1. The first additional subset was tested using only extreme oil states and the second was tested using all states in the set.

As Figure 1 illustrates, the effect of oil prices increases was most pronounced for the most oil-reliant states. By contrast, among non-oil states, there was no statistically significant effect. This all indicates that oil price increases have conflict-reducing impacts to state capacity in these oil-reliant states. To provide an additional examination of the robustness of this observation, we also examined the entire set of cases using an interactive term between oil price and the level of oil rents.

To undertake a test using all the data, we employed the variable measuring oil rents as a percentage of GDP directly into the model. The term was multiplied with the variable measuring the price of oil to form an interactive term. As before, our standard specification approach for all models was to use ordinary-least-squares (OLS) regression models with two-way fixed effects for time (by year) and state errors. The formal specifications for these models can be found in the appendix.

Observing the results of these four interactive models in Table 2, we see that both the current and prior year percentage change in oil price is negatively associated with the number of battle deaths in ongoing conflicts. In both cases, a 100% increase in the price of oil during the current or prior year is associated with roughly 60 fewer fatalities per year. Substantively speaking, the effect from oil shocks is modest. However, it represents the average across the entire dataset. The marginal effect increases significantly as the level of oil dependence increases (discussed below).

Among the control variables, the prior year battle deaths variable was most statistically significant, as might be expected. The independent effect of oil prices was dropped in these models due to the inclusion of time fixed effects, meaning that price was invariant within states in many cases. This is also the reason that time fixed effects were not included in Table 1. When time fixed effects were dropped for these regressions, the independent effect of oil price was not statistically significant. This is expected, as we ought to expect a significant effect from oil prices only when oil rents as a percentage of GDP are also high.

Table 2: Oil prices and conflict intensity in all conflict states

	Dependent variable: Battle deaths (yearly)			
	Model			
	1	2	3	4
WTI P(t)	−0.148 (0.231)			
WTI P(t-1)		0.229 (0.201)		
WTI % chng(t)			−60.175** (25.878)	
WTI % chng(t-1)				−62.031*** (25.889)
OilRents	7.823 (20.850)	−26.362 (18.116)	17.942 (15.166)	10.998 (15.655)
Battle deaths(t-1)	0.347*** (0.029)	0.348*** (0.029)	0.342*** (0.029)	0.340*** (0.029)
log(Population)	558.401 (1,061.429)	545.259 (1,062.073)	405.422 (1,060.751)	446.246 (1,058.723)
log(GDP)	213.170 (242.903)	144.129 (240.011)	183.295 (232.703)	197.094 (232.683)
Observations	1,040	1,020	1,040	1,020
R ²	0.132	0.131	0.136	0.137
Adjusted R ²	0.053	0.053	0.058	0.060
F Statistic (df =5; 953)	28.881***	28.833***	30.031***	30.375***

Notes: Models are panel linear regressions with country fixed effects. Price coefficients show the result of a 100 dollar increase in oil prices. The OilRents variable in models 2 and 4 is lagged. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01

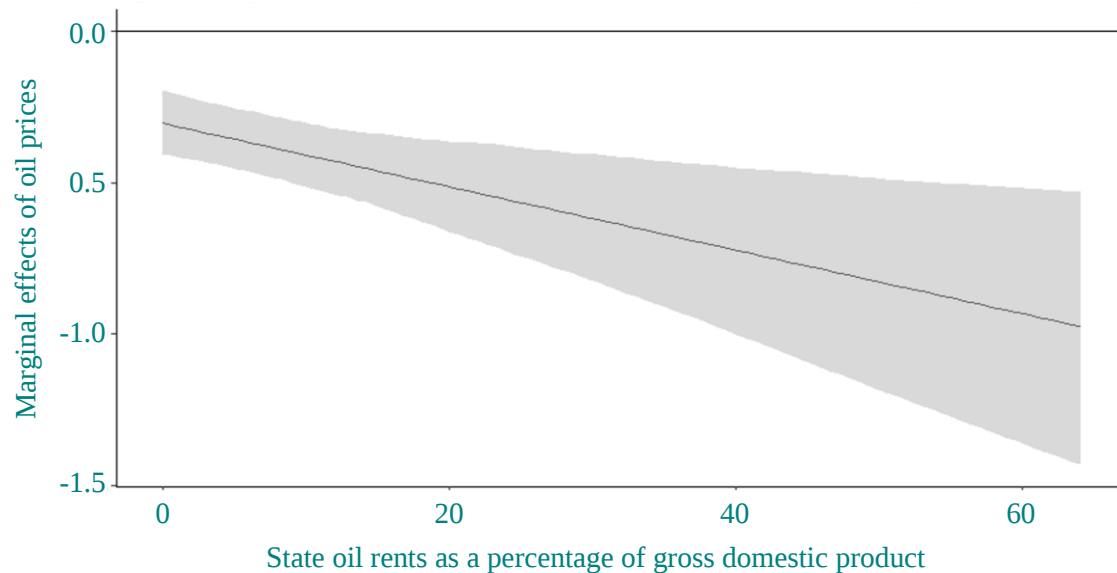


Figure 2: Marginal effect of oil prices on conflict deaths at various levels of oil dependence

Notes: The effect illustrated here is modeled in Model 1 of Table 2 (using monthly data in place of yearly).

Figure 2 provides an illustration of the effect modeled in Model 1 of Table 2 (using monthly data in place of yearly).⁵⁸ As shown in Figure 2, the marginal effect of the oil price coefficient increases as the level of rentierism increases. Across the range of the sample, the marginal effect increases by nearly 3 times. This indicates that, on average, states without dependence on oil revenue experience a substantively insignificant effect on the level of conflict intensity even during large shocks. However, for states in which oil represents over 20 percent of gross domestic product, the negative marginal effect of price increases on conflict intensity are more significant. Around the median point, where oil rents represent approximately 30 percent of GDP, a one dollar increase in oil prices is expected to result in approximately 0.6 fewer monthly battle deaths. This is equivalent to roughly 72 fewer battle deaths on average in a year where prices increased by USD 10. This illustration mirrors the results from the three non-interactive models illustrated in Figure 1, where the effect was observed most strongly for the most oil reliant states.

It is possible that the effects shown in Tables 1 and 2 are weakened in part because the effect of military spending on battle deaths may in some cases work in the opposite direction that we hypothesize. For example, if increased military spending/greater military capacity leads to military “crackdowns” on rebels, we may expect a short-term uptick in battle deaths because of increased military activity. This is examined in greater detail below.

For all the models using an interactive term between oil rents and oil price, it is also important to note a feature of the interactive model which likely causes an underestimation of the true effect. As oil prices decline, the proportion of a state’s GDP that is normally generated by the sale of oil declines, causing the state to appear as less of an “oil state”. However, it is in precisely these states that we are trying to observe an effect. This causes an underestimation of the effect—which makes the results more conservative.

As previously theorized, the reason for these observed effects is the impact that declines in oil prices have on

⁵⁸ This is done for illustrative purposes to provide more observations. We chose models using yearly oil price data in the tables because our conflict and spending data is yearly. The model using monthly data used for this illustration can be found in the appendix.

government revenue in rentier states. When oil dependent states face large declines in oil prices, they have a few limited options to make up the shortfall. Borrowing on capital markets is an option, but for most of these states, creditworthiness is inherently tied to the value of oil exports, so this option also becomes constrained. Some states have “rainy day funds” in the form of sovereign wealth funds, and others may receive foreign military aid. However, these alternatives are present for only a select number of states. For most states, significant declines in real government revenue means significant declines in actual government spending, which includes the military.

We specify four models to test Hypothesis 2. The first two models estimate the effect of the measures of oil price in the current and prior period on military expenditures in oil reliant states only (using the same set of cases used for the models in Table 1). The second two models use all states and employ the interactive effect between oil rents and oil prices (similar to the method used for the models in Table 2). Once again, the models are OLS linear regressions with fixed effects included. The formal model specifications can be viewed in the appendix.

Table 3 demonstrates the effect of oil price shocks on gross military expenditures in constant 2017 USD. For the linear models using oil reliant states only (the first two models), a USD 100 increase in the price of oil in the prior period was associated with an increase in military expenditures of USD 36mn.

In the first interactive model (the third model), the marginal effect of an increase in the price of oil during the current year, when multiplied by an increase in oil rents, is associated with a more positive marginal effect on military expenditures by the magnitude of roughly USD 14mn. For the price of oil during the prior year, this figure was a USD 5mn increase in the marginal effect on military expenditures. For context, the standard deviation for military expenditure in the data was roughly USD 12bn. Using the figure in model 3, an increase in oil rents by five percent is associated with an increase in the positive marginal effect of oil prices by USD 700mn dollars, and a USD 10 increase in the price of oil at this level would entail a USD 7bn dollar increase in spending.

States that use the revenue from oil sales to fund government expenditures often have alternative sources of funding such as sovereign wealth funds or access to international credit markets. Thus, control variables for these features were added to the models here and in the appendix. The appendix models also provide alternative specifications, taking the log of the dependent variable and additional fixed effects. The results of these models were similar to those shown here. While the second two models in the table used the full dataset of 1200 cases, the number of observations was more severely limited by the inclusion of the control variables for which there were fewer observations. Models without control variables saw similar performance of the primary independent variables of oil price and oil rents, but these models without controls had a much weaker fit.

Based on these results, it seems plausible to suspect that significant price shocks can be expected to have an impact on both the intensity of civil conflict (H1), as well as the level of military spending, which mediates this outcome (H2).

Table 3: Oil prices and military spending in conflict states

<i>Dependent variable: Oil prices and military spending in conflict states</i>				
	<i>Models</i>			
	<i>1</i> <i>Oil Reliant States</i>	<i>2</i> <i>Oil Reliant States</i>	<i>3</i> <i>All States</i>	<i>4</i> <i>All States</i>
WTI P(t)*OilRents			14,087,750*** (3,689,224)	
WTI P(t-1)*OilRents(t-1)				3,216,664*** (1,905,151)
WTI P(t)	5,314,081 (9,607,049)		-28,047,722** (13,037,850)	
WTI P(t-1)		36,188,156*** (8,552,945)		-18,518,084 (12,181,288)
OilRents			-264,725,160 (261,892,763)	28,324,14 (228,550,421)
log(GDP)	966,952,011*** (322,459,424)	287,898,859 (308,713,578)	-159,851,212 (624,665,693)	-45,925,586 (617,583,728)
Total reserves	369,389,520*** (130,978,480)	283,032,140** (122,189,741)	11,039,391*** (364,678)	11,038,959*** (368,679)
Central government debt			-3,802,557 (10,384,174)	2,979,000 (10,232,084)
Observations	154	154	384	373
R ²	0.431	0.494	0.863	0.860
Adjusted R ²	0.392	0.458	0.852	0.849
F Statistic (df =5; 953)	36.171*** (df = 3; 143)	46.465*** (df = 3; 143)	371.400*** (df = 6; 354)	363.277*** (df = 6; 354)

Notes: Models are panel linear regressions with country fixed effects. Total reserves are logged for models using only oil reliant states. Oil rents variable is lagged for Model 4. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01

The final hypothesis (H3) examines the relationship between military spending and the number of battle deaths in oil reliant conflict states. Analysis here is made more challenging by the fact that, without control variables, military spending can be expected to have a strong positive association with conflict intensity—since states experiencing more conflict will tend to spend more on the military. The inclusion of a measure for the number of battle deaths in the previous period helps to mitigate this effect and improve model fit, as do fixed effects.

Table 4: Military spending and conflict intensity in oil reliant conflict states

<i>Dependent variable: Battle deaths (yearly)</i>			
	<i>Models</i>		
	<i>1</i>	<i>2</i>	<i>3</i>
	<i>All Oil States</i>	<i>Low Intensity Conflict</i>	<i>High Intensity Conflict</i>
log(milex)	552.724 (430.128)	-106.947* (56.211)	1,584.703 (1,522.129)
Battle deaths(t-1)	0.472*** (0.092)	0.049 (0.030)	0.046 (0.246)
log(Population)	6,438.542* (3,508.574)	91.047 (363.617)	73,134.420 (48,482.200)
Sec score	144.797 (529.507)	-54.749 (62.593)	-8,809.556** (3,302.620)
log(GDP)	-307.582 (743.779)	-112.682 (96.471)	-8,491.844** (3,180.431)
Observations	128	83	45
R ²	0.431	0.494	0.863
Adjusted R ²	0.146	-0.446	-0.518
F Statistic (df =5; 953)	11.348*** (df = 5; 92)	1.938 (df = 5; 47)	3.597** (df = 5; 11)

Notes: Models are panel linear regressions with time and country fixed effects. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01

As previously discussed, we can expect the effect of military spending on the number of battle deaths in a conflict to be nonlinear. States during higher intensity conflicts may see the number of associated battle deaths rise with increased military spending, as additional military spending is used to crack down on rebels. However, in states where ongoing conflict is less intense, we can expect that opportunity-minded or less-numerous rebels may have less appetite for conflict as the security environment improves. For this reason, we ought to primarily observe additional military spending reducing the number of battle deaths in states where conflict is already relatively mild and rebels can more easily disengage.

Based on these intuitions, we split the sample of oil reliant conflict states into high intensity conflict states (those where yearly battle deaths exceeded 500), and low intensity conflict states (where battle deaths were less than 500). The formal specifications for these models can be found in the appendix. Table 4 illustrates the results of these tests. The first model illustrates the effect using all oil reliant states. The second model includes the low intensity conflict states, and the third model uses the high intensity conflict states. As before, we employed OLS panel regressions with

fixed effects for time and country.

As Table 4 shows, the logged value of military expenditures was negatively associated with the number of battle deaths in oil reliant states in which low-level conflict was occurring. A 25 percent increase in military expenditures was associated with roughly 25 fewer yearly battle deaths. This result supports the general hypothesis that military expenditures reduce conflict by increasing state capacity and dissuading rebel attacks. It also helps to explain why higher oil prices are negatively associated with the number of battle deaths in oil reliant states that are in conflict—because it links the results from H2 relating to military expenditures and oil prices with an estimation of how military expenditures in turn impact battle deaths.

Conclusion

The research described in this article helps define important aspects of the relationship between oil prices and civil conflict in oil-reliant states. When oil prices are high, rentier states can better fund conflict-reducing state capacity, such as expenditures on military force. Rebels seeking to capture oil-rich regions can be expected to contend with the central government seeking to end their rebellion. Additionally, this research helps to expand an already existing literature on the impact of oil prices and conflict, which thus far has mainly focused on rebel incentives, or on the propensity for interstate conflict. By understanding the associations between these variables more closely, both researchers and policy makers will have additional insight into what conditions can be expected to generate conflict in oil dependent states.

The article's study could be improved by developing and testing alternative measures of state capacity and conflict intensity. As seen in the data analysis, high state capacity may not always lead to less battle deaths, and likewise lower military expenditure may not always indicate a weaker security sector. Improved measures of these variables will allow analysts to develop more flexible models than the ones presented here. The newness of many state capacity measures limits their usage in quantitative studies, and addressing this limitation ought to be a priority for peace researchers.

Regardless of the true size of the effects estimated here, it seems clear that the changing energy economy will hold serious consequences for states that derive significant government revenue from the sale of oil. As oil demand continues to decline in the face of economic greening and technological improvement, states oriented around the sale of these commodities will be faced with fewer options. Although some may find alternative sources of revenue, it seems plausible to expect that this shift in the global economy could result in significant political instability in vulnerable states.

As we have attempted to demonstrate in this article, one of these effects is likely to be the reduced capacity for oil reliant states to prosecute ongoing civil conflicts. In most cases, we can expect this to lead to increased conflict intensity. Policy makers and political scientists are well advised to continue to examine these relationships, and, if possible, develop solutions to reduce these unintended consequences of both oil price fluctuations and the ultimate move away from fossil fuels.

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Appendix

A visual model of our primary hypothesis yields a clear negative relationship between the prevailing market price for oil (measured in monthly mean intervals) and the average monthly battle deaths in ongoing conflicts—provided those conflicts are occurring in states heavily reliant upon the sale of crude oil for government revenue. Shown in Figure A1, a full move across the range of observed price values for WTI Crude Oil in the dataset (from the lowest observed price to the highest) is predictive of over 50 fewer monthly deaths in ongoing civil conflicts on average among the states observed.

To re-test Hypothesis 1 with an interactive term, we specify the following four basic models of yearly conflict battle deaths to include oil rents as a share of the state's total GDP interacted with various measures of oil prices:

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI Price}_{it} * \text{Oil Rents}_{it} + B_2 \text{WTI Price}_{it} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{population})_{it} + B_5 \log(\text{GDP})_{it} + B_6 \text{BattleDeaths}_{it-1} + C_i + e$$

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI Price}_{i(t-1)} * \text{Oil Rents}_{it} + B_2 \text{WTI Price}_{i(t-1)} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{population})_{it} + B_5 \log(\text{GDP})_{it} + B_6 \text{BattleDeaths}_{it-1} + C_i + e$$

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI Price Change}_{it} * \text{Oil Rents}_{it} + B_2 \text{WTI Price Change}_{it} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{population})_{it} + B_5 \log(\text{GDP})_{it} + B_6 \text{BattleDeaths}_{it-1} + C_i + e$$

$$\text{Battle Deaths}_{it} = B_0 + B_1 \text{WTI Price Change}_{i(t-1)} * \text{Oil Rents}_{it} + B_2 \text{WTI Price Change}_{i(t-1)} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{population})_{it} + B_5 \log(\text{GDP})_{it} + B_6 \text{BattleDeaths}_{it-1} + C_i + e$$

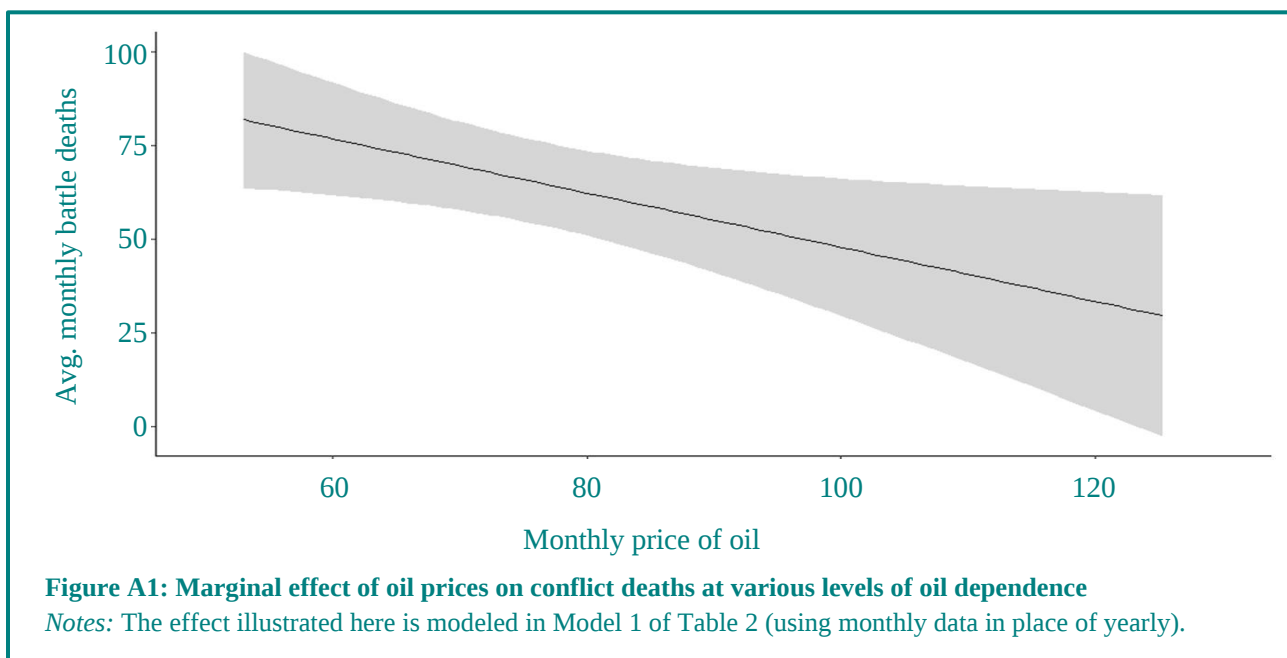


Table A1 presents the results of the formal model used for the illustration in Figure 2, which uses monthly data instead of yearly data.

Table A1: Oil prices and conflict intensity in all conflict states

Dependent variable: Battle deaths (monthly avg.)

	(1)	(2)
WTI P(t)*Oil rents	-1.1*** (0.004)	
WTI P(t-1)*Oil rents		-0.8** (0.004)
WTI P(t)	-0.302*** (0.055)	
WTI P(t-1)		-0.295*** (0.055)
Oil rents	-3.456*** (0.378)	-3.696*** (0.377)
log(Population)	122.718*** (9.557)	121.018*** (9.588)
Sec score	7.061* (3.770)	7.239* (3.772)
Observations	10,224	10,224
R ²	0.043	0.042
Adjusted R ²	0.037	0.036
F Statistic (df =5; 10161)	91.804***	89.749***

Notes: Models are panel linear regressions with country fixed effects. Price coefficients show the result of a 100 dollar increase in oil prices. Robust standard errors in parentheses. *p<0.1; **p<0.05; ***p<0.01

Below are the formal model specifications used for H2. The models using only oil reliant states were not able to employ the debt variable due to the limited number of observations:

$$\text{Military Expenditures}_{it} = B_0 + B_1 \text{WTI Price}_{it} * \text{Oil Rents}_{it} + B_2 \text{WTI Price}_{it} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{GDP})_{it} + B_5 \text{FX Reserves}_{it} + B_6 \text{Gov Debt}_{it} + C_i + e$$

$$\text{Military Expenditures}_{it} = B_0 + B_1 \text{WTI Price}_{i(t-1)} * \text{Oil Rents}_{it} + B_2 \text{WTI Price}_{i(t-1)} + B_3 \text{Oil Rents}_{it} + B_4 \log(\text{GDP})_{it} + B_5 \text{FX Reserves}_{it} + B_6 \text{Gov Debt}_{it} + C_i + e$$

$$\text{Military Expenditures}_{it} = B_0 + B_1 \text{WTI Price}_{it} + B_2 \log(\text{GDP})_{it} + B_3 \text{FX Reserves}_{it} + C_i + e$$

$$\text{Military Expenditures}_{it} = B_0 + B_1 \text{WTI Price}_{i(t-1)} + B_2 \log(\text{GDP})_{it} + B_3 \text{FX Reserves}_{it} + C_i + e$$

To test the robustness of these models, we employed additional specifications shown in Table A2. The first two models add the use of fixed effects for time. The second two models include this and log the dependent variable. In each specification, the results remained consistent.

Table A2: Robustness checks for spending models

	Dependent variable:			
	<i>milex (2017 constant USD)</i>	<i>milex (2017 constant USD)</i>	<i>log(milex (2017 constant USD))</i>	<i>log(milex (2017 constant USD))</i>
	(1)	(2)	(3)	(4)
Oilrents	-384,447,114 (246,662,205)	-160,865,293 (223,333,541)	-0.026 (0.024)	-0.021 (0.022)
log(GDP)	3,283,270,833*** (1,094,388,524)	3,666,134,906*** (1,088,693,981)	1.170*** (0.107)	1.184*** (0.105)
Total reserves	10,815,253*** (356,339)	10,759,540*** (357,815)	0.0001*** (0.00003)	0.0001*** (0.00003)
Central government debt	11,786,521 (10,796,978)	19,292,384* (10,398,843)	0.004*** (0.001)	0.004*** (0.001)
WTIprice(t)*Oilrents	11,922,098*** (3,576,031)		0.001* (0.0003)	
WTIprice(t-1)*Oilrents		5,342,796*** (2,010,420)		0.0004** (0.0002)
Observations	384	384	384	384
R ²	0.783	0.781	0.366	0.368
Adjusted R ²	0.748	0.745	0.261	0.264
F Statistic (df =5; 953)	237.792***	234.174***	37.911***	38.277***

Notes: *p<0.1; **p<0.05; ***p<0.01

Below is the formal model specification used for H3:

$$\text{Battle Deaths}_{it} = B_0 + B_1 \log(\text{milex})_{it} + B_2 \log(\text{population})_{it} + B_3 \text{SecScore}_{it} + B_4 \log(\text{GDP})_{it} + B_5 \text{Battledeaths}_{it-1} + C_i + e$$

Military spending and economic growth: A post-Keynesian model

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Abstract

One important criticism of models of military spending and growth is that they focus on the direct impact, ignoring critical indirect impacts through, for example, income distribution. This article introduces a post-Keynesian model incorporating military spending that allows workers and capitalists to have different marginal propensities to consume. The model suggests first that civilian spending is more likely to increase the productive capacity of the economy due to higher human capital and, second, that military spending and civilian spending will have different effects on the profit share and the wage share.

While the economic *effects of military spending* can be explained by various theoretical approaches such as the Neoclassical, Keynesian, Institutional, and Marxist (Dunne and Coulomb, 2008; Elveren, 2019), empirical works on the *effect on growth* mainly use the neoclassical growth models (Dunne et al., 2005). The models on the nexus of military spending and economic growth include the Feder-Ram model¹; the Deger-type model²; the endogenous growth model³; the augmented Solow growth model⁴; the new macroeconomic model⁵; and a small open economy stochastic growth model⁶. Some major criticism noted in Dunne et al. (2005) and Alexander (2015), include taking either supply-side or demand-side of the economy into account, the arbitrary inclusion of variables into the estimated equation, the unsound interpretation of coefficients of the estimated variables, and ignoring major features of the economies.

One important feature that is often ignored is inequality. There are several channels through which military spending affects income (or pay) inequality.⁷ First, military spending can lead to higher aggregate demand and employment in the economy, which benefits the poor relatively more in peaks thereby reducing income inequality. Second, depending on its composition, military spending may increase or decrease income inequality. Since pay is higher in defense and defense-related industries (e.g., R&D) that employ skilled labor, increasing military spending is likely to increase the wage gap. However, an increase in less well paid military personnel may be associated with lower income inequality. Finally, increasing military spending is likely to be at the expense of social spending and so increase inequality.

There have been some studies on the nexus of military spending and income inequality. Abell (1994) was an early attempt to investigate the interaction between military spending and income inequality for the U.S., but the first

1 Feder (1983); Biswas and Ram (1986).

2 Smith (1980); Deger and Smith (1983); Deger (1986).

3 d'Agostino et al. (2020).

4 Knight et al. (1996).

5 Atesoglu (2002).

6 Shin-Chyang et al. (2016).

7 Ali (2007); Elveren (2012).

comprehensive work is Ali (2007). Using a dataset provided by the University of Texas Inequality Project, that calculates inequality in the manufacturing sector using the Theil index as a basic indicator of income inequality, Ali (2007) showed a significant association between military spending and income inequality for global panel data for the years 1987 to 1997. His results were confirmed by researchers for different time periods,

country groups, and model specifications.⁸ These studies examined the impact of military spending on income (or pay) inequality, not the impact of military spending on economic growth in the context of income inequality, which was the focus of Töngür and Elveren (2016). They used an augmented Solow growth model with effective human capital stock, a function of education level, and income inequality. However, their model did not specify a connection between military spending and income inequality—treating them as two independent variables.

This article develops a post-Keynesian model to examine the nexus of military spending, inequality, and economic growth. It considers the different impacts of civilian government spending and military spending, as workers and capitalists are assumed to have different marginal propensities to consume. The key aspect of post-Keynesian approaches is that the production of goods adjusts itself to the demand for goods. In other words, the economy (i.e., growth) is demand-determined and not constrained by supply. Investment is not determined by savings, but causes it. It does not require prior savings nor prior deposits because the causality runs from loans to deposits.⁹ Entrepreneurs and firms make their investment decisions independently from the level of savings in the economy. Since the future is unknown and unpredictable, firms invest based on their confidence in the economy (e.g., their sentiment about demand and profitability, “animal spirits” as Keynes put it) as well as on financial factors.¹⁰ Investment, private or public, affects aggregate demand through multiplier effects.

Another important aspect of post-Keynesian approach is the central role of capitalists’ and workers’ propensity to consume and save. Investment is a function of capacity utilization and profit and the propensity to save differs across different income classes.¹¹ That is, in contrast to the mainstream approach, where the demand side of the economy is ignored, the distribution of income between capital and labor plays a key role in the post-Keynesian framework.

Kalecki independently developed a macroeconomic framework that is similar to Keynes’s income-expenditure model and established the fundamentals of the effect of income distribution on economic growth.¹² Accordingly, the relative shares of wage and profit in the economy are determined by markup pricing of oligopolistic firms. In turn, these relative shares would have different effects on economic growth as they affect aggregate demand to different degrees. While in Kaleckian economics markup pricing is a given, determined by bargaining power issues, neo-Kaleckian models make income distribution a function of capacity utilization, which is determined by investment and savings. Income distribution plays a central role in determining aggregate demand, and thereby, economic growth.¹³ In the same tradition, Joan Robinson (1956; 1962) developed a growth model that differed from Kalecki by assuming full capacity utilization in the long run rather than assuming capacity utilization was endogenous. In this

One important criticism of models of military spending and growth is that they focus on the direct impact, ignoring critical indirect impacts through, for example, income distribution. The model suggests that functional income distribution is a key channel by which military spending affects economic growth—workers and capitalists have differing marginal propensities to consume.

8 Inter alia: Vadlamannati (2008); Lin and Ali (2009); Ali (2012); Elveren (2012); Meng et al. (2015); Wolde-Rufael (2016a and b); Michael and Stelios (2020); Biscione and Caruso (2021).

9 Lavoie (2006: 58).

10 Stockhammer and Onaran (2022).

11 We acknowledge that post-Keynesian is a general concept that covers various approaches. For example, one may contest that Kalecki was more wage-led and that the notion of an independent investment function is strictly Robinsonian. However, for the purpose of this article we think it is acceptable to use the general concept of post-Keynesian.

12 Kalecki (1954).

13 Bhaduri and Marglin (1990; Blecker (1989).

Robinsonian growth model, the rate of profit is the key variable for investment, which determines the rate of accumulation and growth.¹⁴

Following this approach, the next section develops a growth model that emphasizes the demand effect of military spending on growth via the impact of the profit rate in investment decisions, where military investment is autonomous. This provides an appropriate framework to incorporate a military sector and examine the nexus of military spending, inequality, and economic growth. The next section presents the model and then the concluding section discusses the main insights that can be drawn from this model.

A post-Keynesian model for the nexus of military spending and economic growth

Elveren (2023) adapted the growth model of Onaran *et al.* (2022) to incorporate the military sector and examine the effect of military spending on economic growth through gender inequality. This model focuses on how civilian expenditures and military spending would have different impact on economic growth. Starting from aggregate output (Y_t), which is the sum of total wage bill WB_t and profits (R_t).

$$(1) Y_t = WB_t + R_t$$

The total wage bill (WB_t) is a function of wages in the civilian sector (w_t^C), employment in the civilian sector (E_t^C), wages in the military sector (w_t^M), employment in the military sector (E_t^M), where superscripts C and M refers to the civilian and the military, respectively. For simplicity, we assume that the military sector is a totally public sector and government military spending refers to arms production and payment to military personnel.

$$(2) WB_t = w_t^C E_t^C + w_t^M E_t^M$$

In line with Onaran *et al.* (2022) we define all wage rates in terms of hourly real wages and employment in terms of total hours worked by persons. We assume that the average wage in arms production, which is high-tech production, is higher than that of military personnel and of workers in the civilian sector¹⁵. The wage gap (α_t) for the C and M sectors is then defined as:

$$(3) \alpha_t = \frac{w_t^M}{w_t^C} > 1$$

Aggregate output (Y_t) is

$$(4) Y_t = C_t^C + I_t + G_t^C + G_t^M + X_t - M_t,$$

where C_t^C is household consumption in the civilian sector, I_t is private investment expenditures, G_t^C is government spending in the civilian sector, G_t^M is government spending in the military sector, X_t is exports of goods and services, and M_t is imports of goods and services. We assume that share of private military companies in private investment is negligible, so that all military spending in the economy is covered by government spending in the military sector, and there is no investment in the military sector.¹⁶

Government spending in the military sector is determined by fiscal policy decisions, targeted as a share of aggregate output κ_t^M , and constitutes the military component of public sector output in the previous year Y_{t-1}^M .

¹⁴ Stockhammer (1999).

¹⁵ The wages of military personnel may be lower than the average wage in civilian sector in some countries. However, our model focuses on the military production and since military production is a very high-tech production it is plausible to assume that wages in arms production are higher. For example, Vaze *et al.* (2017) show that there is a wage premium in defense industry in the U.K. This, however, does not necessarily imply that profits are lower in the defense industry. In fact, some show that profit rates in the defense industry in the U.S. are inherently higher due to the market power (Peltier, 2021).

¹⁶ We make this simplifying assumption here and leave it to future studies to investigate the effect of relaxing it.

Therefore:

$$(5) Y_t^M = G_t^M = \kappa_t^M Y_{t-1}$$

$$(6) Y_t^C = Y_t - G_t^M = Y_{t-1}(1 - \kappa_t^M)$$

Hours of employment in both the civilian and the military sector are determined by output and labor productivity in the relevant sectors. The structuralist characteristics of the model suggest that employment is demand-constrained, which results in excess capacity and involuntary unemployment in the economy, and that supply is determined by the capital stock.

The employment in the civilian sector C is output over labor productivity sector C (T_t^C),

$$(7) E_t^C = \frac{Y_t^C}{T_t^C} = \frac{(1 - \kappa_t^M)Y_t}{T_t^C}$$

We assume that productivity in the military sector is constant¹⁷ but that productivity in the civilian sector (T_t^C) changes over time and is a function of government spending in the civilian sector (e.g., education and health spending), as follows¹⁸:

$$(8) \log T_t^C = t_0 + t_1 \log(w_{t-1}^C E_{t-1}^C)$$

Government spending on the military G_t^M can be written as follows:

$$(9) G_t^M = \kappa_t^M Y_t = w_t^M E_t^M + G_t^A,$$

where G_t^A is an autonomous component, referring to spending on arms rather than personnel.

The profit income (R_t^M) in the military sector is the surplus after wage payments,

$$(10) R_t^M = Y_t^M - w_t^M E_t^M - G_t^A$$

and the military profit share (π_t^M) is the share of profit in total output and depends on productivity in the sector:

$$(11) \pi_t^M = \frac{Y_t^M - w_t^M E_t^M - G_t^A}{Y_t^M}$$

Similarly, the profit income (R_t^C) in the civilian sector is the surplus after wage payments,

$$(12) R_t^C = Y_t(1 - \kappa_t^M) - w_t^C E_t^C$$

and the profit share (π_t^C) is:

$$(13) \pi_t^C = \frac{Y_t(1 - \kappa_t^M) - w_t^C E_t^C}{Y_t(1 - \kappa_t^M)}$$

On the demand-side household consumption is a function of wage and profits. In the civilian sector it depends on the differences in the marginal propensities to consume (MPC) out of wage and profits¹⁹:

¹⁷ We acknowledge that productivity in the military sector changes over time. However, given that productivity growth is likely to be smaller in the military sector than the civilian sector, we assume for simplicity that productivity in the military sector is constant.

¹⁸ Equation 8 is defined in logs since the impact of government spending in the civilian sector on productivity might be non-linear.

¹⁹ We specify equations 14 and 15 in logs since the effects of the variables in question might be non-linear (i.e., between consumption and its determinants, and between private investment and its determinants, respectively).

$$(14) \log C_t^C = c_0 + c_R \log [R_t^C (1 - t_t^R)] + c_W \log [(w_t^C E_t^C)(1 - t_t^W)] ,$$

where t_t^R is the implicit tax rate for profits and t_t^W is the implicit tax rate for wages.

Private investment I_t is a function of the after-tax π_t^M and π_t^C , GDP, and public debt/GDP $(\frac{D}{Y})_t$:

$$(15) \log I_t = i_0 + i_1 \log Y_t + i_2 \log [\pi_t^M (1 - t_t^R)] + i_3 \log [\pi_t^C (1 - t_t^R)] + i_4 \log (\frac{D}{Y})_t$$

The public debt (D_t) is determined by the public debt in the previous period (D_{t-1}) , the interest rate (r_{t-1}), plus the total government expenditures in t , minus the taxes collected on profits, wages, and consumption:

$$(16) D_t = (1 + r_{t-1})D_{t-1} + G_t^C + G_t^M - t_t^W W B_t - t_t^R (R_t^C + R_t^M) - t_t^C C_t^C ,$$

where t_t^C is the implicit tax rate on consumption.²⁰ The public debt to GDP ratio refers to possible effects of public debt on investment. Higher public debt may crowd-out private investment, or it may increase private investment (i.e., crowding-in) if public spending leads to higher productivity.²¹

Exports are a function of prices of exports relative to foreign prices and foreign income (Y_{world}) and the exchange rate (ε), imports are a function of Y^C and domestic prices relative to import prices. For simplicity, we assume that the country has a military industry and does not need to import, so the marginal propensity to import is zero.

The wage share is considered as the real unit labor cost, so when the profit share decreases (wage share increases), exports decrease and imports increase. The magnitude of the effect is determined by the pass through from the wage share to nominal unit labor costs and prices, and the price elasticity of exports and imports. For simplicity, exports and imports are defined as reduced form functions of π :

$$(17) \log X_t = x_0 + x_1 \log Y_t^{world} + x_2 \log \pi_t^C + x_3 \log \pi_t^M + x_4 \log \varepsilon_t$$

$$(18) \log M_t = n_0 + n_1 \log Y_t^C + n_2 \log \pi_t^C + n_3 \log \pi_t^M + n_4 \log \varepsilon_t$$

The effect of κ_t^M on output can be shown as follows (explicit forms of the derivations are provided in the Appendix):

$$(19) \frac{dY_t}{dk_t^M} = \frac{\frac{\partial C_t^C}{\partial k_t^M} + \frac{\partial I_t}{\partial k_t^M} + \frac{\partial G_t^C}{\partial k_t^M} + \frac{\partial G_t^M}{\partial k_t^M} + \frac{\partial X_t}{\partial k_t^M} - \frac{\partial M_t}{\partial k_t^M} - \frac{\partial Y_t}{\partial k_t^M}}{1 - \Phi}$$

$$(20) \Phi = \frac{\partial C_t^C}{\partial Y_t} + \frac{\partial I_t}{\partial Y_t} + \frac{\partial G_t^C}{\partial Y_t} + \frac{\partial G_t^M}{\partial Y_t} + \frac{\partial X_t}{\partial Y_t} - \frac{\partial M_t}{\partial Y_t}$$

20 It is worth noting that military spending directly affects public debt. Pempetzoglou (2021) reviews the literature on the military spending and external debt, which is the sum of private sector debt and public debt. Increasing military spending can lead to higher debt for three ways: It may increase domestic or foreign borrowing; it may expand external debt if arms are imported; and it may increase debt even if the country produces its own arms, but it is dependent on some imported intermediate goods. Most of the studies suggest that higher military spending is associated with higher debt, and causality is running from military spending to debt (inter alia Dunne et al., 2019; Caruso and Di Domizio, 2017).

21 Our model considers debt, not the deficit per se. Running budget deficit increases debt, which can be considered as accumulated deficits. Also, according to Ricardian equivalence theorem, an increase in debt leads to a decline in consumption as people adjust their consumption by anticipating an increase in tax in future, keeping aggregate demand the same. However, empirical evidence is not supportive of the theorem (see for example Stanley (1998) and Hayo and Nuemeier (2017)).

The model suggests two main reasons why the effect of military spending and civilian spending on output might be different. First, civilian spending in terms of education and health spendings increase productivity, which in turn increases the productive capacity of the economy due to higher human capital in the long run. Second, military spending and civilian spending can have different effects through the profit share and wage share. An increase in the wage share can boost economic growth because workers' propensity to consume is higher than that of capitalists, but can also have negative effects. First, a higher wage share and so a lower profit share can reduce capitalists' incentive to invest and, second, it can reduce the firms' competitiveness in international markets, thereby decreasing exports.

Based on the benchmark model of Bhaduri and Marglin (1990), a number of empirical studies have investigated whether the positive effects of wage-led growth or the negative effects dominate.²² In a comprehensive analysis, Oyvatt *et al.* (2020) found that countries that are more open to trade, that have higher wage inequality, higher private credit-to-GDP ratios, and greater household debt/GDP ratios are more likely to see profit-led growth.²³ In this context, the size and decomposition of military spending on growth can be important. A recent study by Becker and Dunne (2021) is critical because, instead of using general military spending data that covers expenditures on arms, infrastructure, military personnel, etc., the authors decompose military spending data to show that, for 34 major countries for 1970–2019, it is the negative correlation between military personnel expenditures and growth that drives the overall negative effect on growth. Moreover, it has been shown with a circuit of capital model that the military sector, compared to the civilian sector, is inherently associated with higher profit rates due to shorter realization lags.²⁴ Therefore, the ultimate effect on output depends on whether growth regime is wage-led or profit-led. That is, on the one hand, rising wage share can increase economic growth since workers have a larger marginal propensity to consume compared to capitalists; on the other hand, it creates disincentives for private investment and reduces the international competitiveness of domestic firms. If the positive impact of wage share through higher consumption is larger than its negative impact through private investment then the regime is called wage-led, otherwise it is profit-led. Therefore, our model suggests that functional income distribution is a key channel by which military spending affects economic growth.

Conclusion

The goal of this article was to develop a post-Keynesian model to examine the impact of military spending on economic growth that allows for the fact that military spending may have a different impact on economic growth than civilian expenditure—as they affect income distribution differently. The model shows that civilian expenditure is likely to have a higher positive impact on growth because it increases aggregate demand more—as most of this spending goes to workers whose higher marginal propensity to consume is higher than that of capitalists.

While introducing the income distribution channel is a valuable contribution, we acknowledge that our model is, of necessity, based on simplistic assumptions on productivity and investment in the military sector. It could be improved by relaxing them, but at the cost of increasing complexity. Future work will aim to address this.

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22 Blecker (2016); Stockhammer (2017); Oyvatt *et al.* (2020).

23 It is worth noting that the controversy between profit-led versus wage-led models is not of concern here as the goal is to emphasize the relationship between military spending and potential output.

24 Realization lags refer to the number of periods required on average to turn value as finished products into sales flow (Elveren, 2022).

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Appendix: Explicit forms of the derivations

$$(19) \quad \frac{dY_t}{dk_t^M} = \frac{\frac{\partial C_t^C}{\partial k_t^M} + \frac{\partial I_t}{\partial k_t^M} + \frac{\partial G_t^C}{\partial k_t^M} + \frac{\partial G_t^M}{\partial k_t^M} + \frac{\partial X_t}{\partial k_t^M} - \frac{\partial M_t}{\partial k_t^M} - \frac{\partial Y_t}{\partial k_t^M}}{1 - \Phi}$$

$$(20) \quad \Phi = \frac{\partial C_t^C}{\partial Y_t} + \frac{\partial I_t}{\partial Y_t} + \frac{\partial G_t^C}{\partial Y_t} + \frac{\partial G_t^M}{\partial Y_t} + \frac{\partial X_t}{\partial Y_t} - \frac{\partial M_t}{\partial Y_t}$$

For equation (19), the derivations are as follows (for simplicity we ignore subscript t in derivation):

$$(21) \quad \frac{\partial C^C}{\partial k^M} = \frac{\partial C^C}{\partial E^C} \cdot \frac{dE^C}{dk^M} + \frac{\partial C^C}{\partial R^C} \cdot \frac{dR^C}{dk^M}$$

$$(22) \quad \frac{\partial C^C}{\partial E^C} = -c_W w^C e^{c_0} (-R^C (t^R - 1))^{c_R} (t^W - 1) (-E^C w^C (t^W - 1))^{c_W - 1}$$

$$(23) \quad \frac{\partial C^C}{\partial R^C} = -c_R e^{c_0} (-R^C (t^R - 1))^{c_R - 1} (t^R - 1) (-E^C w^C (t^W - 1))^{c_W}$$

$$(24) \quad \frac{dC^C}{dk^M} = c_R e^{c_0} (-R^C (t^R - 1))^{c_R-1} \left(Y - \frac{Y w^C}{T^C} \right) (t^R - 1) (-E^C w^C (t^W - 1))^{c_W} \\ + \frac{Y c_W w^C e^{c_0} (-R^C (t^R - 1))^{c_R} (t^W - 1) (-E^C w^C (t^W - 1))^{c_W-1}}{T^C}$$

$$(25) \quad G^M = Y_{t1} \cdot k^M$$

$$(26) \quad \frac{\partial G^M}{\partial k^M} = Y$$

$$(27) \quad G^C = -Y_{t1} \cdot (k^M - 1)$$

$$(28) \quad \frac{\partial G^C}{\partial k^M} = -Y$$

$$(29) \quad I = Y^{i_1} e^{i_0} \left(\frac{D}{Y} \right)^{i_4} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2}$$

$$(30) \quad \frac{\partial I}{\partial k^M} = \frac{\partial I}{\partial D} \cdot \frac{dD}{dk^M} + \frac{\partial I}{\partial \pi^C} \cdot \frac{d\pi^C}{dk^M} + \frac{\partial I}{\partial \pi^M} \cdot \frac{d\pi^M}{dk^M}$$

$$(31) \quad \frac{\partial I}{\partial D} = \frac{Y^{i_1} i_4 e^{i_0} \left(\frac{D}{Y} \right)^{i_4-1} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2}}{Y}$$

$$(32) \quad \frac{\partial I}{\partial \pi^C} = -Y^{i_1} i_3 e^{i_0} \left(\frac{D}{Y} \right)^{i_4} (-\pi^C (t^R - 1))^{i_3-1} (-\pi^M (t^R - 1))^{i_2} (t^R - 1)$$

$$(33) \quad \frac{\partial I}{\partial \pi^M} = -Y^{i_1} i_2 e^{i_0} \left(\frac{D}{Y} \right)^{i_4} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2-1} (t^R - 1)$$

$$(34) \quad \frac{dI}{dk^M} = \frac{Y^{i_1} i_4 e^{i_0} \left(\frac{D}{Y} \right)^{i_4-1} \sigma_5^{i_3} \sigma_4^{i_2} \left(Y - Y_{t1} - Y t^R + t^R \sigma_1 - t^C \left(c_R e^{c_0} \sigma_6^{c_R-1} \sigma_1 (t^R - 1) \sigma_2^{c_W} + \frac{Y c_W w^C e^{c_0} \sigma_6^{c_R} (t^W - 1) \sigma_2^{c_W-1}}{T^C} \right) + \frac{Y t^W}{T^C} \right)}{Y} \\ - Y^{i_1} i_2 e^{i_0} \sigma_3 \left(\frac{Y}{Y^M} - \frac{R^M Y}{Y^M{}^2} \right) \sigma_5^{i_3} \sigma_4^{i_2-1} (t^R - 1) \\ - Y^{i_1} i_3 e^{i_0} \sigma_3 \sigma_5^{i_3-1} \sigma_4^{i_2} \left(\frac{R^C}{Y (k^M - 1)^2} + \frac{\sigma_1}{Y (k^M - 1)} \right) (t^R - 1)$$

where

$$(35) \quad \sigma_1 = Y - \frac{Y w^C}{T^C}$$

$$(36) \quad \sigma_2 = -E^C w^C (t^W - 1)$$

$$(37) \quad \sigma_3 = \left(\frac{D}{Y}\right)^{i_4}$$

$$(38) \quad \sigma_4 = -\pi^M (t^R - 1)$$

$$(39) \quad \sigma_5 = -\pi^C (t^R - 1)$$

$$(40) \quad \sigma_6 = -R^C (t^R - 1)$$

$$(41) \quad \frac{dX}{dk^M} = \frac{\partial X}{\partial \pi^C} \cdot \frac{d\pi^C}{dk^M} + \frac{\partial X}{\partial \pi^M} \cdot \frac{d\pi^M}{dk^M}$$

$$(42) \quad \frac{\partial X}{\partial \pi^C} = Y^{world^{x_1}} \varepsilon^{x_4} \pi^{C^{x_2-1}} \pi^{M^{x_3}} x_2 e^{x_0}$$

$$(43) \quad \frac{\partial X}{\partial \pi^M} = Y^{world^{x_1}} \varepsilon^{x_4} \pi^{C^{x_2}} \pi^{M^{x_3-1}} x_3 e^{x_0}$$

$$(44) \quad \frac{dX}{dk^M} = Y^{world^{x_1}} \varepsilon^{x_4} \pi^{C^{x_2}} \pi^{M^{x_3-1}} x_3 e^{x_0} \left(\frac{Y}{Y^M} - \frac{R^M Y}{Y^{M^2}} \right) \\ + Y^{world^{x_1}} \varepsilon^{x_4} \pi^{C^{x_2-1}} \pi^{M^{x_3}} x_2 e^{x_0} \left(\frac{R^C}{Y (k^M - 1)^2} + \frac{Y - \frac{Y w^C}{T^C}}{Y (k^M - 1)} \right)$$

$$(45) \quad \frac{dM}{dk^M} = \frac{\partial M}{\partial Y^C} \cdot \frac{dY^C}{dk^M} + \frac{\partial M}{\partial \pi^C} \cdot \frac{d\pi^C}{dk^M} + \frac{\partial M}{\partial \pi^M} \cdot \frac{d\pi^M}{dk^M}$$

$$(46) \quad \frac{\partial M}{\partial G^C} = Y^{C^{n_1-1}} \varepsilon^{n_4} n_1 \pi^{C^{n_2}} \pi^{M^{n_3}} e^{n_0}$$

$$(47) \quad \frac{\partial M}{\partial \pi^C} = Y^{C^{n_1}} \varepsilon^{n_4} n_2 \pi^{C^{n_2-1}} \pi^{M^{n_3}} e^{n_0}$$

$$(48) \quad \frac{\partial M}{\partial \pi^M} = Y^{C^{n_1}} \varepsilon^{n_4} n_3 \pi^{C^{n_2}} \pi^{M^{n_3-1}} e^{n_0}$$

$$(49) \quad \frac{dM}{dk^M} = Y^{C^{n_1}} \varepsilon^{n_4} n_3 \pi^{C^{n_2}} \pi^{M^{n_3-1}} e^{n_0} \left(\frac{Y}{Y^M} - \frac{R^M Y}{Y^{M^2}} \right) - Y^{C^{n_1-1}} Y_{t1} \varepsilon^{n_4} n_1 \pi^{C^{n_2}} \pi^{M^{n_3}} e^{n_0} \\ + Y^{C^{n_1}} \varepsilon^{n_4} n_2 \pi^{C^{n_2-1}} \pi^{M^{n_3}} e^{n_0} \left(\frac{R^C}{Y (k^M - 1)^2} + \frac{Y - \frac{Y w^C}{T^C}}{Y (k^M - 1)} \right)$$

$$(50) \quad \frac{\partial E^C}{\partial k^M} = -\frac{Y}{T^C}$$

$$(51) \quad \frac{\partial R^C}{\partial E^C} = -w^C$$

$$(52) \quad \frac{\partial R^C}{\partial k^M} = -Y$$

$$(53) \quad \frac{dR^C}{dk^M} = \frac{Y w^C}{T^C} - Y$$

$$(54) \quad \frac{dG^M}{dk^M} = Y$$

$$(55) \quad \frac{dG^C}{dk^M} = -Y_{t1}$$

$$(56) \quad E^C = -\frac{Y(k^M - 1)}{T^C}$$

$$(57) \quad R^C = \frac{Y w^C (k^M - 1)}{T^C} - Y(k^M - 1)$$

$$(58) \quad \frac{\partial R^M}{\partial G^M} = 1$$

$$(59) \quad \frac{dR^M}{dk^M} = Y$$

$$(60) \quad \frac{\partial \pi^M}{\partial R^M} = \frac{1}{Y^M}$$

$$(61) \quad \frac{\partial \pi^M}{\partial G^M} = -\frac{R^M}{Y^{M2}}$$

$$(62) \quad \frac{d\pi^M}{dk^M} = \frac{Y}{Y^M} - \frac{R^M Y}{Y^{M2}}$$

$$(63) \quad \frac{\partial \pi^C}{\partial k^M} = \frac{R^C}{Y(k^M - 1)^2}$$

$$(64) \quad \frac{\partial \pi^C}{\partial R^C} = -\frac{1}{Y(k^M - 1)}$$

$$(65) \quad \frac{d\pi^C}{dk^M} = \frac{R^C}{Y(k^M - 1)^2} + \frac{Y - \frac{Y w^C}{T^C}}{Y(k^M - 1)}$$

$$(66) \quad \frac{\partial D}{\partial G^C} = 1$$

$$(67) \quad \frac{\partial D}{\partial G^M} = 1$$

$$(68) \quad \frac{\partial D}{\partial WB} = -t^W$$

$$(69) \quad \frac{\partial D}{\partial R^C} = -t^R$$

$$(70) \quad \frac{\partial D}{\partial R^M} = -t^R$$

$$(71) \quad \frac{\partial D}{\partial C^C} = -t^C$$

$$(72) \quad \frac{dWB}{dk^M} = -\frac{Y}{T^C}$$

$$(73) \quad \frac{dD}{dk^M} = Y - Y_{t1} - Y t^R + t^R \sigma_1 - t^C \left(c_R e^{c_0} (-R^C (t^R - 1))^{c_R - 1} \sigma_1 (t^R - 1) \sigma_2^{c_W} + \frac{Y c_W w^C e^{c_0} (-R^C (t^R - 1))^{c_R} (t^W - 1) \sigma_2^{c_W - 1}}{T^C} + \frac{Y t^W}{T^C} \right)$$

where

$$(74) \quad \sigma_1 = Y - \frac{Y w^C}{T^C}$$

$$(75) \quad \sigma_2 = -E^C w^C (t^W - 1)$$

For equation (20), the derivations are as follows:

$$(76) \quad \frac{dG^M}{dY} = 0$$

$$(77) \quad \frac{dG^C}{dY} = 0$$

$$(78) \quad \frac{dC^C}{dY} = c_R e^{c_0} (-R^C (t^R - 1))^{c_R - 1} (k^M - 1) (t^R - 1) (-E^C w^C (t^W - 1))^{c_W}$$

$$(79) \quad \frac{dC^C}{dY} = \frac{\partial C^C}{\partial E^C} \cdot \frac{dE^C}{dY} + \frac{\partial C^C}{\partial R^C} \cdot \frac{dR^C}{dY}$$

$$(80) \quad \frac{dX}{dY} = Y^{world x_1} \varepsilon^{x_4} \pi^{C x_2 - 1} \pi^{M x_3} x_2 e^{x_0} \left(\frac{1}{Y} + \frac{R^C}{Y^2 (k^M - 1)} \right)$$

$$(81) \quad \frac{dX}{dY} = \frac{\partial X}{\partial \pi^C} \cdot \frac{d\pi^C}{dY} + \frac{\partial X}{\partial \pi^M} \cdot \frac{d\pi^M}{dY}$$

$$(82) \quad \frac{dM}{dY} = Y^{C n_1} \varepsilon^{n_4} n_2 \pi^{C n_2 - 1} \pi^{M n_3} e^{n_0} \left(\frac{1}{Y} + \frac{R^C}{Y^2 (k^M - 1)} \right)$$

$$(83) \quad \frac{dM}{dY} = \frac{\partial M}{\partial G^C} \cdot \frac{dG^C}{dY} + \frac{\partial M}{\partial \pi^C} \cdot \frac{d\pi^C}{dY} + \frac{\partial M}{\partial \pi^M} \cdot \frac{d\pi^M}{dY}$$

$$(84) \quad \frac{dI}{dY} = Y^{i_1 - 1} i_1 e^{i_0} \sigma_3 \sigma_4^{i_3} \sigma_1 - \frac{D Y^{i_1} i_4 e^{i_0} \sigma_2 \sigma_4^{i_3} \sigma_1}{Y^2} - Y^{i_1} i_3 e^{i_0} \sigma_3 \sigma_4^{i_3 - 1} \sigma_1 \left(\frac{1}{Y} + \frac{R^C}{Y^2 (k^M - 1)} \right) (t^R - 1) + \frac{Y^{i_1} i_4 e^{i_0} \sigma_2 \sigma_4^{i_3} \sigma_1 (t^R (k^M - 1) - c_R t^C e^{c_0} (-R^C (t^R - 1))^{c_R - 1} (k^M - 1) (t^R - 1) (-E^C w^C (t^W - 1))^{c_W})}{Y}$$

where

$$(85) \quad \sigma_1 = (-\pi^M (t^R - 1))^{i_2}$$

$$(86) \quad \sigma_2 = \left(\frac{D}{Y} \right)^{i_4 - 1}$$

$$(87) \quad \sigma_3 = \left(\frac{D}{Y} \right)^{i_4}$$

$$(88) \quad \sigma_4 = -\pi^C (t^R - 1)$$

$$(89) \quad \frac{dI}{dY} = \frac{\partial I}{\partial Y} + \frac{\partial I}{\partial D} \cdot \frac{dD}{dY} + \frac{\partial I}{\partial \pi^C} \cdot \frac{d\pi^C}{dY} + \frac{\partial I}{\partial \pi^M} \cdot \frac{d\pi^M}{dY}$$

$$(90) \quad \frac{dE^C}{dY} = 0$$

$$(91) \quad \frac{dR^C}{dY} = 1 - k^M$$

$$(92) \quad \frac{\partial \pi^C}{\partial Y} = \frac{R^C}{Y^2(k^M - 1)}$$

$$(93) \quad \frac{d\pi^C}{dY} = \frac{1}{Y} + \frac{R^C}{Y^2(k^M - 1)}$$

$$(94) \quad \frac{d\pi^M}{dY} = 0$$

$$(95) \quad \frac{\partial I}{\partial Y} = Y^{i_1-1} i_1 e^{i_0} \left(\frac{D}{Y}\right)^{i_4} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2} \\ - \frac{D Y^{i_1} i_4 e^{i_0} \left(\frac{D}{Y}\right)^{i_4-1} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2}}{Y^2}$$

$$(96) \quad \frac{\partial I}{\partial Y} = Y^{i_1-1} i_1 e^{i_0} \left(\frac{D}{Y}\right)^{i_4} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2} \\ - \frac{D Y^{i_1} i_4 e^{i_0} \left(\frac{D}{Y}\right)^{i_4-1} (-\pi^C (t^R - 1))^{i_3} (-\pi^M (t^R - 1))^{i_2}}{Y^2}$$

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