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Against the odds: The evolution of the European naval shipbuilding industry

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Abstract

Despite a low volume of production at national levels, the European naval industry remains quite fragmented 25 years after the end of the cold war. Contrary to what might be expected from an industrial or budgetary perspective, neither cross-border consolidation nor cooperative programs have resulted in European restructuring. The sovereign nature of shipyards has led to the promotion of a domestically-centered industry transformation. Again, contrary to what might be expected, this appears to be a potentially sustainable approach due to the long-term relationship between navies and their domestic industrial partners. Even so, one can question the sustainability of the current economic model, reliant as it is on export contracts and insufficient margins to manoeuver.

While other arms production sectors have engaged in a consolidation process, even if on a limited scale, the setup of the European military naval industry is quite similar today to what it was at the end of the cold war. Of all arms sectors, it is certainly the one for which the emergence of a European-wide defense technological and industrial base appears as a distant future option. The lack of consolidation appears paradoxical, however, as shipyards have faced decreasing military spending (as have many other defense industries). Shipbuilding requires the investment of large sunk costs—both in development and production. With production series of very limited numbers, this drives up unit costs.

Moreover, connections between military and commercial shipyards have been increasingly limited since the beginning of the 1990s, making development of dual-use platforms less likely. Defense-related companies tend to specialize in military naval systems as strong competitors, first from Japan in the 1970s, and since then from South Korea and China, have destroyed most commercial ship production in Europe. This is the primary reason why, sooner or later, a shipyard consolidation process was expected to adjust Europe's industrial capabilities to a lower scale of production.[1]

Increasing the effectiveness of Europe's naval industry is a requirement to preserve technological and industrial assets that remain important to achieve defense and security goals. Naval systems were not favored after the end of the cold war, especially since most military operations did not take place in high seas, but they remain essential to project forces, implement security missions, and support operations away from the homeland. And new threats have emerged that require naval capabilities, ranging from piracy to terrorism, illegal migration, and tensions in the South China Sea.

Even as the idea of a "Naval Airbus" has been proposed from time to time, the consolidation of the industry has been quite limited over the past three decades. The questions nonetheless stand: Is consolidation truly an issue, let alone a necessity, for the European naval industry? And can European naval consolidation be achieved with regard to states' specific interests, e.g., their strategic autonomy, and companies' own industrial stakes and long-term survival?[2]

Focusing on producers of large naval platforms—aircraft carriers, frigates, and submarines produced by the six largest of Europe's shipyards (BAE Systems, DCNS, ThyssenKrupp, Fincantieri, Navantia, and Saab)—this article first examines the historical evolution and industrial heterogeneity of the industry, detailing reasons why no trans-European leader has emerged over the past few decades. Another section analyses the extent to which the model of nation-centric naval industries addresses expectations of domestic customers and thus maintains this non-consolidation. Industry options and risks are discussed.

A nation-centric industry

In October 2016, the Chief Executive of the European Defense Agency (EDA), Jorge Domecq, called for more naval program cooperation in Europe, notably for next generation platforms. Indeed, despite limited production, each major arms-producing country keeps its own naval shipyard. Which factors explain this lack of Europeanization? Does this *status quo* jeopardize preservation of Europe's naval competencies?

Features of the European naval industry

The global market for naval systems is estimated at around US$40 billion. American companies dominate the market with a total turnover reaching USD12 billion but are completely

Table 1: Main actors in the European naval industry (2015)

Company	*Country*	*Naval turnover (EUR millions)*	*Naval employees*
BAE Systems	U.K.	6,900	14,000
DCNS	France	3,040	12,950
TKMS	Germany	1,700	3,200
Fincantieri	Italy	1,060	~5,000
Navantia	Spain	705	5,500
Saab Kockums	Sweden	460	850

Source: Annual company reports and websites. *Note*: EUR are at average European Central Bank exchange rates for 2015.

This article examines the evolution and current state of affairs in the European military shipbuilding industry. It finds that while the "national champions"-based approach of the major European naval powers works reasonably well in the current environment, financial dangers loom on the horizon that could yet force substantial pan-European consolidation of the industry.

centered on the needs of the United States. The U.S. market is sheltered from international competition and, simultaneously, American companies work almost exclusively for the Pentagon. Naval shipyards in China and Russia claim between USD3 to 4 billion, and they, too, work mainly for their domestic customers, sheltered from external competition.[3]

The European markets are worth around USD10 billion. In addition, European companies derive a large share of their turnover from export markets. (They generally make up about half of their sales but the ratio of domestic to international revenues varies widely from year to year.) While there are tens of industrial actors, the European naval industry is dominated by six big companies (see Table 1). The sector constitutes about 25 percent of Europe's defense industrial base and features very complex, sophisticated, high-tech products. The industry has developed all competencies required to design, integrate, and produce the whole range of naval ships and almost the totality of its core systems and components. The major companies are system integrators, and the old image of shipbuilders as mere assemblers of steel blocks is outdated.

However, the European naval sector is characterized by overcapacity, fragmentation, and redundant structures. Each arms-producing country with naval ambitions has its own national champion, the main reason why there exist a large number of ongoing programs for quite similar platforms. In 2009, then- EDA Chief Executive Alexander Weis stated: "For each U.S. naval system, Europe has 7.2 systems. Europe is still able to afford 11 different frigates, and 7 different diesel submarines. There are currently 25 naval prime contractors across Europe, many of them encompassing more than one shipyard." His successor, Jorge Domecq, made a similar observation in 2016: "European navies operate 20 different types of frigate, four different types of aircraft carrier, and multiple types of support ships and MCM Vessels." Despite a limited market, arms-producing countries reserve major naval procurement contracts for their domestic shipyards. This lack of industrial consolidation beyond national borders puts the survival of the industry at risk due to the very limited and irregular workload schedule.[4]

As will be shown, this does not mean that consolidation never occurred. With the end of the cold war, national consolidation was widely seen as a precondition for eventual transnational restructuring. But the domestic consolidation phase was not followed by a Europe-wide one.

Limited, and reversible, consolidation at the European scale

One writer noted in 2004, that "despite the encouraging noises made at the Euronaval show here this week about the consolidation of Europe's naval shipbuilding industry, the fact remains that the prospect of a pan-European naval group is still a long way off, and may in fact never materialize." This still appears to be the case today. In the years following the end of the cold war, one could perceive a wish to consolidate strategic industrial assets to overcome the fall of military spending. However, except for one example—later reversed—a Europe-wide transformation of the naval industry was not achieved.[5]

The idea of creating a "Naval Airbus" has been promoted for several decades. Airbus, in the aeronautics industry, was an answer to a deep crisis of the civilian aeronautical industry in the late 1960s. France, Germany, and the United Kingdom each had domestic aircraft industries that were too fragmented and small to face American competition. The only solution was to consolidate industrial assets and create a European company, able to invest and innovate to regain international leadership. To a large extent, the European naval industry faced the same challenges in the early 1990s. Yet no major consolidation happened. Conflicting interests prevented companies from consolidating at the European level. For one thing, consolidation would mean that each company would lose essential assets for future production and national programs.

Additionally, a significant part of the European naval industry was composed of state-owned companies (until recently). This was not deemed compatible with private companies' interests. For instance, a merger between DCNS and ThyssenKrupp was often seen as a major possible move to restructure naval assets at the relevant scale to secure the future of Europe's naval industrial base. But ThyssenKrupp has always considered the state ownership of DCNS as a "no go" situation because of a fear of political interference with its own strategic decisions. Indeed history shows that all too often state ownership has resulted in political rather than industrial decisions, like the preservation of inefficient sites to meet local political concerns unaligned with, or even contradictory to, sound business strategy.[6]

Moreover, the only significant cross-border merger ended as a failure. In 1999, the German shipyard HDW bought its Swedish counterpart Kockums, one of its main competitors in the submarine market. It also bought Hellenic Shipyards in 2002. In 2005, ThyssenKrupp took over HDW, adding its own naval assets in surface vessels. Unexpectedly, these moves in the direction of the long-awaited industry-wide restructuring did not result in lasting consolidation. Not only did these mergers not result in cross-border specialization, but ThyssenKrupp and Kockums demerged in 2014. The reason was that first HDW's, and then ThyssenKrupp's, strategy was not compatible with the preservation of Swedish submarine capabilities. German decisionmakers would not support the A26 submarine project sponsored by the Swedish Ministry of Defense. In addition, on export markets, ThyssenKrupp promoted German-designed submarines while pushing Kockums to discontinue construction of its large submarines in favor of focusing on the development of small submarines. Perceiving ThyssenKrupp's business strategy as a threat to its strategic autonomy, Sweden decided to grant its next-generation submarine program to Saab (even though Saab had no shipyard). Losing its sole source of Swedish revenue, ThyssenKrupp had no choice but to sell its Swedish assets to Saab (which is how Saab acquired a shipyard). The demerger recreated a purely domestic Swedish naval champion, reversing the hoped-for consolidation at the European level.[7]

Unhappy cooperative programs

If mergers and acquisitions are an obvious and rapid way for industry consolidation, cooperative programs are a second-best solution. Following the examples of the aeronautics and space sectors, cross-country cooperation might help rationalize the industry. However, naval cooperative programs appear quite unsuccessful in delivering expected homogenous platforms and in pushing ahead with production specialization in Europe.

Confronted with decreasing or low military orders, naval shipyards and states certainly looked for opportunities to cooperate. As mentioned, despite high sunk costs (including R&D), the naval sector is characterized by short production series so that unit costs are high. This is why ships and submarines should be natural candidates for cross-country cooperation. Despite this, there are few such programs, and the ones that have taken place have delivered few savings and almost no true cross-border integration. Indeed, recent history is filled with project failures. The most emblematic example is the NFR-90 frigate. Launched in 1979, this ambitious NATO project aimed at developing a unique air-defense frigate for the United States, the United Kingdom, France, Germany, Italy, Spain, and the Netherlands. Aborted in 1989, the project was replaced with the German-Spanish-Dutch Trilateral Frigate program. It resulted in the delivery of three quite different ships: the German F124, the Spanish F100, and the Dutch LCF frigates. France and the United Kingdom ended up in a similar situation when they tried to jointly develop their aircraft carriers, the PA2 and CVF, respectively. Since each country was expected to produce only one or two carriers, it would seem obvious that by joining efforts cost savings could be realized. In 2005, France agreed to pay one-third of the costs of the British CVF design. But it quickly emerged that the British and French Navies were unable to converge on military specifications and, in time, they chose to end their cooperation.

Even when cooperative programs go on, they do not necessarily result in true cross-border industrial consolidation. Beyond the formal appearance of a unique platform, most of the time the resulting ships are quite different from country to country as each requires specific features and promotes domestic technical solutions to guarantee work shares for its own defense industry. The French-Italian FREMM frigate illustrates this outcome. While sharing the same name, the ships' commonalities are so limited that DCNS and Fincantieri compete with each other on export markets.

These unsatisfactory results also reveal one reason why the naval shipbuilding industry remains on a national setup. Such vessels appear extremely customized in response to the specific requests of each Navy. This customization imperative induces huge transaction costs not only with the integrator but also its suppliers (even more than in other cooperative programs such as fighters or military aircraft). Indeed each Navy expects to keep control over key military systems that secure its strategic autonomy, which are developed and produced by domestic companies. Transaction costs thus explode when acquisitions rely on cooperative programs. Although huge, transaction costs can be minimized when the Navy can work with a domestic industrial partner with whom it has established a decades-long relation and who perfectly understands its needs, implicit requirements, and specifications. Thus, large transaction costs associated with naval acquisitions favor a reputation-based relationship on a domestic basis.[8]

Consolidation maybe, but only domestically

In large part because of booming export markets, European manufacturers of military vessels and submarines actually have been doing well in recent years. According to the European defense industry association, known as ASD, European naval turnover has increased from EUR10.2 billion in 2005 to EUR18.7 billion in 2009 and to EUR22.5 billion in 2014. Is Europe-wide consolidation then necessary, especially when considering domestic strategic and nonindustrial criteria? Even if industrial restructuring was required, does the cross-border approach fit this sector well?[9]

Shipyards as a core sovereign capability

Lack of Europeanization in the naval industry is intrinsically linked to certain features of its industrial assets and naval platforms. Geography, in particular, matters in naval systems, even more so than it does for other defense capabilities.

Apart from production, to provide in-service support (ISS) for their vessels' decades-long life-cycle (vessels can remain in service from 20 years for a surface ship to 50 years for an aircraft carrier, going through regular maintenance, retrofits, and upgrades), navies need access to domestic capacities. Accepting cross-country consolidation would mean the loss of industrial resources to support, retrofit, and modify its platforms. (This need to preserve domestic industrial bases also arises when some capabilities cannot be shared for reasons of sovereignty. The best example is the production and support of deterrence submarines in France and the United Kingdom.) States therefore are reluctant to lose domestic industrial capabilities without which their navies can no longer preserve full autonomy. ISS opens the way for a different industrial model. The naval sector can achieve balance not by leveraging scale economies, as in military aircraft or land systems, but due to a through-life business model that equilibrates production and ISS. BAE Systems and DCNS already prove the feasibility of such a model and its ability to preserve essential competencies on a purely domestic basis.[10]

Arms-producing countries support their domestic naval industry thanks to long-term acquisition plans. For instance, in 2016, the Italian Navy committed to a EUR5.4 billion funding package that secured several programs for Fincantieri, securing long-term production for the shipyard by relying on domestic orders and boosting its export competitiveness. In France, DCNS was awarded a new program for five Belh@rra intermediary frigates in 2016, to be delivered as from 2023, with a global contract value of EUR3.8 billion. Beyond domestic needs, the French Ministry of Defense expects that DCNS will be able to replicate the export success of the La Fayette-class frigate of the 1990s, which was acquired by Taiwan, Singapore, and Saudi Arabia. In its 2015 Strategic Defence and Security Review, the U.K. also secured the viability of its naval industry on a domestic basis through the Type 26 frigate program, the future "workhorse of the Royal Navy." Pouring billions of pounds' worth of investment into British shipbuilding, this commitment guarantees hundreds of skilled jobs through 2035.

These acquisition plans are complemented by long-term ISS workloads and constitute a large part of companies' expected revenues. Because of the size of ISS revenues, the share of ISS outsourced by navies, and the exceptional visibility provided to naval shipyards (even compared to other defense industries that provide ISS services), ISS amounts to an original feature of this industry. For instance, in 2008 BAE Systems signed a 15-year partnering agreement with the British Ministry of Defense, which also provided its subsidiary BVT Surface Fleet with leadership of defined future programs.

Consolidation yes, but on domestic grounds

Saying that the naval sector has not engaged in any restructuring at all would be unfair. The sector did experience successive waves of restructuring in the 1940s, 1960s, and 1970s, notably because of the crisis of merchant shipyards facing tougher competition from East Asia. At the national level, most European countries experienced horizontal consolidation, even well before the 1990s.

In the United Kingdom, there were 42 companies in 1945 (44 shipyards). This reduced to 14 companies (17 shipyards) in 1960, and then 2 companies (4 shipyards) in 2000. In 2008, BAE Systems and VT Group merged to form a joint venture company, BVT Surface Fleet. In Spain, Astilleros Españoles had been created in 1967 by merging the Basque shipyards of Euskalduna, La Naval de Sestao, and Astilleros de Cádiz. When this entity was merged in 2000 with the public naval shipyards, Empresa Nacional Bazán, to form IZAR (rebranded Navantia in 2005), domestic consolidation was achieved. Similar moves were implemented in other European countries. In Italy, from the 1950s to the 1990s, Fincantieri consolidated all naval shipyards. In Germany, ThyssenKrupp's merge with HDW in 2005 already has been mentioned. In France, while most naval shipyards were state-owned, DCNS rationalized its assets since the 1970s to reduce shipyard numbers and to specialize the remaining ones. And in the Netherlands, Damen Shipyards acquired Royal Schelde in 2001.[11]

Shipyard mergers might not be the most relevant option to support the naval industry, however. In fact, European naval shipyards are more likely to cooperate on subsystems, the technological "bricks". This is notably the case for submarine anaerobic propulsion systems between Italian and German companies. Spanish and Norwegian shipyards have cooperated to develop their respective frigates. And in 2015, it was revealed that "DCNS and Fincantieri of Italy [had] agreed on a 'road map' to discuss potential cooperation on further work on the multimission frigate, developing technology and equipment while seeking common benefits."[12]

Beyond horizontal consolidation, some degree of vertical integration has occurred among the largest naval countries in Europe. This is a recent trend and reflects the displacement of the center of gravity of naval platforms from shipbuilding (hulls) to system integration and embedded systems. To an extent, electronics and weapon systems matter more today than the hull that carries them. It is not surprising that the core of mergers and acquisitions lies in the shipyards and electronics companies of the largest arms-producing countries. Vertical integration took place mostly at the national level, again with the objective to better address the expectations of domestic customers.

In Germany, EADS (now Airbus) and ThyssenKrupp acquired the German naval and electronics specialist Atlas Electronik in 2007 from BAE Systems. This takeover helped create a vertically-integrated naval leader, ThyssenKrupp Marine Systems. In France, the French government tied up DCNS and Thales as the most relevant consolidation for a viable and competitive naval sector. The previously mentioned acquisition of Kockums' shipyard by electronics company Saab led to a similar arrangement under the auspices of the Swedish state. And in the United Kingdom, even if the merger between British Aerospace and Marconi in 1999 was not primarily motivated by naval considerations, in the end it did gather the worlds of defense electronics and naval shipyards within the new company, BAE Systems, through a truly vertical integration.

These examples of vertical integration improved the effectiveness of the naval industry by reducing transaction costs and by nurturing innovation in line with the changes in navies' capability expectations. They strengthened the sector's viability while maintaining a domestically-centered approach that is compatible with the requirements of national strategic autonomy. But this sort of consolidation can be a problem in the longer term as the various national champions in Europe are now quite similar to each other and may seriously hamper future cross-border horizontal consolidation at the European level. Today, any cross-border consolidation would provide few synergies and complementarities and would require that participating companies (and countries) sacrifice part of their domestic assets and competencies.

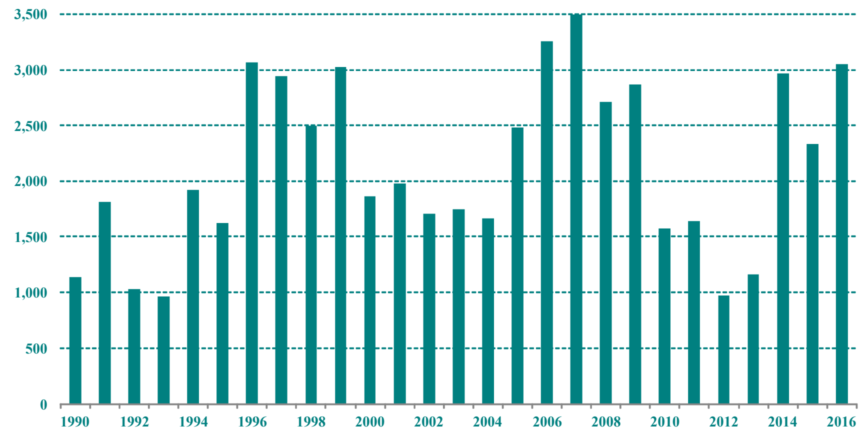

Figure 1: Naval exports of main producing European countries, 1990-2016. *Notes*: France, Germany, Italy, the Netherlands, Spain, Sweden, and the United Kingdom. Figures are SIPRI Trend Indicator Values (TIVs) expressed in USD millions at constant (1990) prices. *Source*: www.sipri.org/databases/armstransfers [accessed 12 March 2017].

Exports as a condition for viability?

Partnership between navies and their domestic suppliers as well as horizontal and vertical integration have contributed to the domestic viability of Europe's naval industries. Yet these developments are insufficient. Domestic orders alone are not enough, in part because of the cyclical nature of domestic orders and production, in part because of declining European naval budgets. Therefore, the industry's reliance on export orders has not only increased but become essential. European naval industries are very strong in the international markets such as the Middle East, Africa, Asia, and Latin America. The defense budgets of these regions are steadily rising and they do not possess a comprehensive naval industry. Export markets nowadays account for 42 percent of the European naval order book value. Indeed, as underlined in Figure 1, exports of the European naval shipbuilding industry have fluctuated widely since the end of the cold war. The European industry cannot rely on exports to sustainably balance domestic orders.[13]

Due to innovative platforms and the relative weakness of non-European competitors, the European industry has been able to obtain a large share of open international tenders and one would expect this to be true for at least the near future as well. According to *PRNewswire*, a consultancy, the global submarine market will grow to USD36.3 billion in 2026 from USD22.8 billion in 2016, with large markets in Asia Pacific (32 percent), Europe (24 percent), and the Middle East, Latin America, and Africa (7 percent, respectively). Similarly, according to *Business Wire*, the global naval surface vessels market is valued at USD50.3 billion by 2026 as compared to USD6.3 billion in 2016.[14]

Nevertheless, reliance on exports could be dangerous. The long-term importance of international markets is not guaranteed and export dependence can create biases in the development of new platforms when their specifications are overly determined by export requirements. For instance, France launched the Belh@rra intermediary frigate program, which aims at conquering international sales thanks to its modularity and flexibility. Many recent projects are structured on the same idea, and one has to wonder whether such export-driven naval programs will continue to satisfy the domestic needs for strategic autonomy.[15]

Even if an export strategy is successful for the time being, many importing countries expect to develop their own naval industry. As intra-European competition is fierce on the export markets, companies (and countries) may be forced to accept large transfers of technological and production know-how. Therefore, the facilitator of today's viability contains seeds of potential doom once importing countries achieve some degree of self-sufficiency.

Conclusion

Despite relatively low levels of activity, Europe's main naval shipyards have survived since the 1990s. They did this without entering into true Europe-wide consolidation even as sectoral redundancies have been clear for decades. Even if national naval shipyards benefit today from the reinvestment cycle of their domestic customers, the future of the industry does not necessarily look rosy. For now, the companies can survive with low production levels and the in-service support of fleets. However, low turnover and profitability do not provide enough resources to invest in tomorrow's technologies and systems.

Neither companies nor states can be satisfied by today's organization of Europe's naval sector, sensitive as it is to budgetary and export "bumps". Yet Europe-wide consolidation is unlikely, especially if one looks for the same sort of merger and acquisition process that the aeronautics and space sectors achieved in the 1990s or the more recent consolidation in land systems. The European naval sector needs to invest in both R&D and industrial capacities in critical technologies to maintain its competitive and technological lead and also to ensure the required level of operational superiority. It seems unlikely that European countries each can realize such investment alone. As cooperative programs appear difficult to launch and as there is a limited sharing of technologies and production, the European Defense Action Plan could constitute a means to develop top-down cooperation among stakeholders in the naval industry.[16]

In November 2016, the European Commission proposed a European Defence Action Plan (EDAP) to support its member states' more efficient spending on joint defense capabilities. EDAP aims to set up a European Defence Fund to support joint investment in research and development of defense equipment and technologies. After a three-year Preparatory Action, the Commission intends to propose "a research window" through a defense research program, funded at EUR500 million per year as from 2020. Additionally, a "capability window" would act as a financial tool allowing participating member states to jointly purchase certain assets to reduce their costs, which should be able to mobilize about EUR5 billion per year. Both mechanisms are ideal tools to promote deeper cooperation among European naval shipbuilders on future capabilities and, one hopes, to the consolidation of this defense sector at the European level.[17]

The overview provided in this article of the transformations experienced by Europe's naval industry shows that a European consolidation was not the only solution approach to sustain fragmented production. A domestically-centered approach does constitute an alternative way but it appears insufficient to guarantee the industry's long-term survival. As European consolidation seems unlikely, one wonders what possible alternative moves could maintain a balance between domestic dynamics and true strategic autonomy. Here convergence with civilian shipyards could be revisited. While an initial round of diversification appeared unsuccessful, some naval companies focused on specialized ships like cruise ships or yachts. Fincantieri, of Italy, is a successful example of this strategy. It may appear surprising, but these civilian market segments share many features with military naval systems, and naval shipyards can leverage competencies to design and produce complex, customized products.

Diversification in the high-end segments of merchant shipbuilding (e.g., cruise ships and mega-yachts) and in related maritime activities (e.g., offshore and marine renewable energy) appears quite successful. According to a 2015-2016 study conducted on behalf of the European Defense Agency, "this diversification strategy has created a favourable cross-fertilization between civil and military technologies (dual-use technologies), both at the Prime Contractors and at the Supply-Chain levels, leading to cost-effective designs and solutions." One wonders if one possible future for Europe's naval industry may lie in convergence with sectors beyond shipbuilding or even beyond the defense industrial base.[18]

Notes

1. Strong competitors: ECORYS (2009).

2. In Europe, the aeronautics and space sectors went through successive consolidation waves that resulted in one overly dominant producer of missile systems (MBDA), two major producers of satellites (Airbus and Thales Alenia Space) and two of helicopters (Airbus and Leonardo). To a lesser extent, the land systems sector experienced cross-border consolidation, too. U.S.-based General Dynamics and BAE Systems took over several small players throughout Europe in the early 2000s, and Nexter (France) and KMW (Germany) merged in 2015, followed by Patria (Finland) and Kongsberg (Norway) in 2016.

3. Global market size: Tran (2016).

4. Weis quote: Weis (2009, p. 3). Domecq quote: http://eda.europa.eu/info-hub/press-centre/latest-news/2016/10/18/jorge-domecq-at-euronaval-more-cooperation-needed-to-develop-the-next-generation-naval-platforms.

5. One writer: de Briganti (2004).

6. See Bellais, Foucault, and Oudot (2014, pp. 28-31).

7. On ThyssenKrupp and Kockums, see Lundmark (2014).

8. Transaction costs and reputation: Williamson (1967).

9. Booming export markets: EDA (2016, p. 20).

10. Life-cycle issues in the naval shipbuilding industry: See de Penanros and Sellin (2003).

11. Competition from East Asia: Smit (2003, p. 48). U.K. shipyards: Goudie (2003). Italy: Brunelli (2003).

12. Tran (2015).

13. Book value: EDA (2016, p. 20).

14. Submarine market: http://www.prnewswire.com/news-releases/the-global-submarine-market-2016-2026-300338425.html. Surface vessels market: http://www.businesswire.com/news/home/20161104005930/en/Global-Naval-Vessels-Surface-Combatants-Related-MRO.

15. Belh@rra: Cabirol (2016).

16. On aeronautics, land, and space systems, see the other symposium articles in his issue.

17. European Commission: Press release 30 November 2016. http://europa.eu/rapid/press-release_IP-16-4088_en.htm.

18. Quote: EDA (2016, p. 20).

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The restructuring of the European land armaments industry: Between political incentives and economic pressures

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Abstract

Within the context of the restructuring of the European defense industry since the end of the cold war, this article addresses the land armaments sector in general, and armored vehicles in particular. The industry is generally divided into the aerospace, naval, land, and electronics sectors, of which aerospace and electronic are highly internationalized while the land and naval ones remain fragmented and nationally based. Economic characteristics of the land armaments industry—lower R&D costs and longer production runs—still permit the predominance of a nationally-focused production model, yet post-cold war market changes toward lighter platforms, and resulting synergies with the civilian truck industry, imply a comparative weakening of state sovereignty and, consequently, stronger market contestability as compared to the other defense industry sectors.

This article is about the restructuring of the European land armaments industry, with an emphasis on the armored vehicle sector. While the European defense electronic and aerospace industries generally are viewed as consolidated and internationalized, the land armaments and naval industries are seen as fragmented, even on a national basis. Fragmentation is often seen as a weakness, even a threat from a market-driven perspective, but can also be seen as a logical and potentially positive consequence of the primacy of political factors in military equipment choices. In a context of ever-tougher budget pressures and rising international competition, however, the current industrial organization at work in Europe is once again in question.

Apart from fragmentation, the research question addressed in this article concerns the specifics of the land armaments as compared to the other European military industries. Why do political incentives seem to be stronger in the land armaments industry, which is not of any more strategic importance than the others? I address this question in the context of theoretical debates on the scale of globalization, denationalization, and liberalization processes at work in the defense sector, and I use a regulation framework to question the way the European land armaments industry is regulated in the current environment: should it be national, pan-European, or even multinational beyond Europe?

The following sections discuss the current situation and the restructuring of the European land armaments industry. The article describes the sector's main features and general trends and focuses on the main developments aimed at creating a more integrated industry. The final section concludes the article.

Literature review and theoretical framework

While only a few studies are devoted to the European land armaments industry, four documents in particular allow us to characterize the state of knowledge and to identify the main issues and debates.

State of knowledge

A decade after the end of the cold war, a Swedish researcher (Andersson, 2001) suggested that due to a particular mix of political and economic reasons, the European land armaments industry has followed a path that differentiates it from those of other armament sectors. These include the modest increase in R&D costs, when compared to military aeronautics, together with the comparatively longer production runs for the land systems. This situation "made it financially possible to maintain nationally focused land armaments programs and production facilities throughout the Cold War. Without very strong economic pressure, it has proved politically difficult for governments to overcome the vested interests of groups that benefit more from local production than from European cooperation" (p. 24). Governments played a crucial role since, unlike the commercial pressures that apply to aerospace, the European land armaments sector was less diversified. But the end of the cold war and the resulting upheaval in European armies altered market conditions. The focus shifted to smaller and lighter forces, and growing competition from new entrants, and the impact of the revolution in military affairs on R&D costs implied that "Europe's land armaments industry is presently struggling with problems similar to those that aerospace companies have learnt to live with since the mid-1960s" (p. 25). Andersson thus believes that a deep restructuring process will necessarily happen: "There are simply too many companies chasing too few contracts" (p. 26).

In a 2009 report, the Western European Union took a different view. Despite overcapacity and fragmentation inherited from the cold war, it believes that the relatively large number of companies in the land armaments sector is a sign of dynamism, competition, the lure of profit, and that cooperation goes together with competition. The emphasis is put on a specific military vehicle segment: "There is one category in this range that is of particular interest to us: the 6x6 or 8x8 wheeled vehicles. They are the most in demand, attract the lion's share of investment and are the main focus of technological research and development" (p. 2). The authors note the then-existence of some 23 national armored vehicles programs within the EU, of which only one—the Dutch-German "Boxer"—was produced under international cooperation (see Appendix). They further note that "the lack of joint programs is largely due to the mixed feelings generated by experiences from past years, in particular during the 1990s" (p. 3) and conclude that this situation has taught us that cooperation needs to be based upon a really shared operational foundation but does not have to be an end in itself, nor the sole expression of a political scheme of European integration.

In 2012, a Spanish consulting firm released a report for the European Federation of Trade Unions, IndustriAll. It states that "European countries are traditionally favouring the principles of national sovereignty and comprehensive autonomy in defence-related issues" (p. 14) and that despite a trend toward some degree of consolidation, "compared to the USA land armament sector, the EU has 'too many' smaller nationally-based prime integrators producing the same type of products" (p. 41). The report continues: "This persisting lack of Europeanization of the industry (combined with a limited cooperation at EU level between enterprises) results in a number of undesired side effects from an aggregated European perspective in terms of unnecessary duplication of products, production structures and research and development efforts, shorter production runs ... excess capacity as well as a lack of standardisation of military equipments" (p. 42). Yet "it is important to recognise that some EU Member States (e.g. Sweden, Germany, United Kingdom) are moving from a biased sourcing strategy towards a more open and competitive procurement strategy seeking less 'tailored' products with specifications set from the start and with less/no bias towards national sourcing" (p. 42). From a corporate perspective also, "some of the leading enterprises within the European land armament sector are starting to develop new business models that allow them to work effectively across national borders" (p. 47). The authors then elaborate on two possible scenarios, either to place priority on the Europeanization of the land armaments industry or on the maintenance of existing national sovereignty and industrial capacities. The authors favor the first option, "the development of a stable European home market that clearly surpasses the current national market boundaries" (p. 109).

The article describes the European land armaments sector's features and trends and focuses on the main developments aimed at creating a more integrated industry. Even though there are good economic and political reasons for its current fragmentation and nationally-based production model, market and product changes put the industry's model into question.

Finally, a French report (Fleurant and Quéau 2014) also remarks on the issue of fragmentation. Unlike the 1990s, the 2000s were a flourishing period for this sector, it states. The multinational military operations in Afghanistan and Iraq, together with the economic growth of emerging countries, resulted in export revenue booms for Western producers. Such success did not favor industry restructuring. However, the year 2008 constitutes a turning point. The Afghan and Iraqi wars were almost completed and the economic situation of emerging countries deteriorated. European countries faced the mortgage subprime lending and debt crisis. The international economic environment became more competitive so that "as on the morrow of the end of the cold war, the European defense technological and industrial base today is in a situation of production overcapacity. The doubles are numerous in the catalogues of the various companies" (p. 35). Further, "the political issues at national level override a more market or European community driven trend" (p. 36). Duplication means higher costs at all levels (e.g., dispersion of R&D costs, redundant production lines, reduced economies of scales, higher maintenance costs) and risks becoming internationally uncompetitive. And yet, the authors note, "more than six years after the stock market crash, the situation remains characterized by a kind of wait-and-see policy that does not seem to foresee a significant reorganization of the European production capacities" (p. 38). They then detail four possible scenarios: (1) upholding the *status quo*; (2) a new phase of consolidation on a national basis; (3) transnational consolidation among European actors; and (4) the setting-up of strong industrial partnerships with actors from emerging countries.[1]

Empirical and theoretical lessons

The views just summarized permit one to characterize the recent history of the sector. Unlike the aerospace industry, the land armaments sector is nationally focused, largely due to its lower capital costs and prices. The end of the cold war disrupted the situation by a combination of two factors: a fall in Western military spending combined with a shift in production toward lighter, more polyvalent vehicles. Most of the European companies succeeded in tackling these issues because of strong growth in domestic and international markets during the 2000s. Although some changes occurred in the industry, this limited the scale of its restructuring. On the one hand, the changes that did occur demonstrate dynamism and adaptive ability to a completely new operating environment; on the other hand, as market forecasts darkened toward the end of the 2000s, the issue of restructuring came up again.

From a theoretical perspective, a picture emerges of the main modalities of regulation at work in the defense sector. From world war two to the early 1990s the armaments sector is characterized by a model in which arms companies retain strong ties with their respective national governments. Governments bear the financial risks and often finance the R&D. Emphasis is put on the performance of high technology weapons rather than on costs. With the end of the cold war, with the economic crisis of early 1990s, with globalization already at work in civilian industry, and with the continuing questioning of the role of government in private markets (since the 1980s), arms market pressure became significantly stronger. Labeled as the globalization of the defense industry, this led to doubts regarding national governments' preeminence over military affairs. In the case of the European Union, as a way to promote an integrated European defense technological and industrial base, a number of developments eventually led to a limited liberalization of the European armaments sector within the framework of a single European defense equipment market.[2]

Three modes of regulation can be distinguished. They will be used as an explanatory framework to understand the current situation of the European land armaments industry.

- *National level regulation*: No radical change compared to the previous operating environment; fragmentation remains important but does not necessarily reflect a lack of international connections and consolidation.
- *Pan-European level regulation*: Partial shift of responsibility from national governments to a supranational entity; more efficient resource allocation and markets; stronger strategic autonomy at the EU level, with some loss of national-level responsibilities and employment in some countries.
- *Beyond-EU, multinational level regulation*: Corporate shift from single-government dependency to multinational presence that allows firms to serve multiple home markets.

Table 1: European defense turnover by sector, 2006-2015, in 2006 constant EUR billions (in percent of total)

	Military aeronautics	*Naval defense*	*Land defense*
2006	30.0 (51.9%)	11.0 (19.2%)	17.0 (28.9%)
2007	43.3 (60.4)	14.4 (20.1)	13.9 (19.5)
2008	36.4 (54.6)	13.9 (20.8)	16.4 (24.6)
2009	38.0 (47.4)	17.3 (21.6)	24.8 (31.0)
2010	42.3 (50.4)	15.4 (18.3)	26.3 (31.3)
2011	37.4 (46.4)	16.3 (20.2)	26.9 (33.4)
2012	39.4 (48.6)	18.6 (22.9)	23.0 (28.4)
2013	41.4 (50.6)	18.0 (22.0)	22.4 (27.4)
2014	40.7 (50.8)	18.7 (23.4)	20.7 (25.9)
2015	40.1 (47.7)	44.0 (52.3)*	

Note: * For 2014, land & naval systems turnover are combined.
Source: European AeroSpace and Defence Industries Association (ASD), http://www.asd-europe.org/communication/publications/facts-figures.

Europe's land armaments market: Features and trends

Despite a general lack of quantitative data, two sources permit one to identify the main characteristics of the sector. In what follows, I first provide a sectoral overview and then address nationally focused firms' growing export dependency.

Overview

One overall source of sector information comes from the annual reports of the European AeroSpace and Defence Industries Association, or ASD for short (see Table 1). Available as from 2006, they provide sector-level figures for most EU members, including Turkey.[3]

The industry is dominated by military aeronautics. With one exception (in 2007), it generally accounts for about 50 percent of annual turnover. Next comes land defense, fluctuating between 25 to 33 percent (again except for 2007). Naval defense is in the third position, moving closer to land defense toward the end of the period.

The land armaments industry did not face a strong decline following the 2008 crisis. To the contrary, the sector enjoyed strong growth in 2009 (+51.2 percent as compared to 2008) and continued to grow until 2011. As from 2012, however, its turnover declined each year, down to EUR20.7 billion in 2014 (or 25.9 percent of total European defense industry turnover).

This confirms the observation made earlier about the end of an armaments cycle and a trend reversal as most European arms modernization programs now are completed. Moreover, contraction of land defense turnover as from 2012 is stronger than in the aeronautics and naval sectors. The latter have seen stabilization more than diminution of turnover. Figures for 2015 are not available for land armaments, but only for the combined "land & naval" category. At EUR44 billion, turnover is higher than in 2014 (EUR39.4 billion) but it is no longer possible to separate the shares of the land and the naval industries.

A second source of information is Eurostat, the statistical office of the European Union. Its industry classification code 29.6 comprises "manufacture of weapons and ammunition" (including military vehicles), according to the NACE classification for the period 1995-2008 (NACE Rev.1.1). Although some figures are missing, data for most of the main indicators are available for the largest producer countries. Due to a classification change in 2009 (NACE Rev. 2), the land armaments sector was divided into two main groups. The quality of the data weakens and some data are missing.[4]

For a handful of countries, Eurostat's available data are shown in Figure 1. The general trend shows stagnation until 2001, then growth until 2007, a decline after 2008, followed by stagnation or an up-tick thereafter. The consequences of the 2008 crisis are more marked in the Eurostat than in the ASD data (Table 1). The market is dominated by a lead group consisting of the United Kingdom, followed by France and Germany, then Italy. A second group, at a much lower level, consists of Sweden, Spain, and Poland. A third group, not shown, has significant capabilities in land systems but not of sufficient budgetary heft to be included in the figure: They are Austria, Croatia, the Czech Republic, Finland, Romania, Slovenia and, outside of the EU, Norway and Switzerland.

The search for export markets

To sustain its predominantly nationally-focused production model—and to side-step international consolidation pressure—European countries' export sales dependency has increased. This may prove difficult to sustain, economically and politically. Unlike U.S. companies, which are less reliant on exports, Europeans see exports as a way to reap cost reductions through economies of scale and larger production runs. Exports, however, may be a "vanishing lifeline" as they are uncertain and, above all, imply a progressive knowledge drain through technology transfers to future potential competitors.[5]

It is unclear what impact, if any, the continuing Ukrainian crisis may have on the land armaments market. European countries may be willing to increase cooperation due to tight defense budgets and growing security threats. But if the

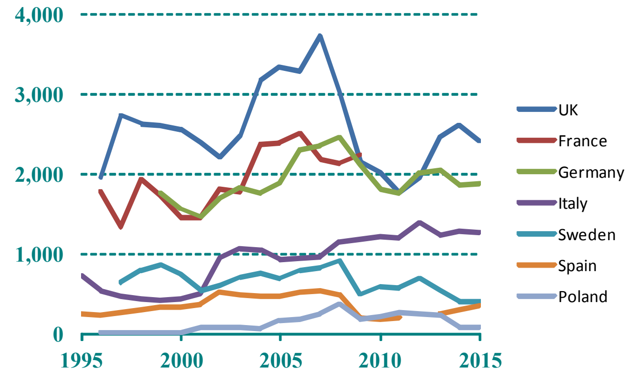

Figure 1: Inflation-adjusted turnover of the EU land armaments industry by main producing countries, 1995-2015, in 1995 constant EUR million. *Notes*: Data from 1995 to 2008 are those of Eurostat NACE Rev.1.1 Code 29.6, while data from 2009 to 2015 are the sum of NACE Rev.2 Code 25.4 and Code 30.4. Gaps mean that the data is not available. The inflation-adjusted turnover is calculated from the Consumer Prices— Annual Inflation series provided by the OECD for each of the seven countries (http://stats.oecd.org). *Source*: Eurostat (http://ec.europa.eu/eurostat/data/database).

European market for military vehicles were to exhibit growth, this may favor the *status quo*, as several Eastern European countries are accelerating their armored vehicle programs and, as one analyst writes, with a focus on "multiwheel-drive vehicles, as opposed to tanks, in a bid to significantly enhance the mobility capabilities of their respective land forces."[6]

Toward a more integrated industry: Recent developments

Interestingly enough, in the European land armaments sector, the first wave of cross-border consolidation was driven by a transatlantic perspective. Only recently have some ambitious intra-European consolidation projects materialized.

Transatlantic moves at the beginning of the 2000s

Perhaps surprisingly, the main actor so far in the consolidation of the European land armaments industry is a U.S. company, General Dynamics (GD). Headquartered in Virginia, GD is stock-market listed and one of the five major American defense contractors. Also active in civilian and military aerospace, naval systems, and military electronics, GD obtained a strong foothold in the European market in the early 2000s. GD's expansion in Europe is primarily linked to the need for a medium class and air-transportable wheeled vehicle, an equipment gap identified by the U.S. Army in the 1990s as a result of its war engagements in the former Yugoslavia. Despite the capabilities of the American defense industry, "because of limited funds and an immediate operational requirement, it was decided that the new MAV [Medium Armored Vehicle] should be an off-the-shelf item already available on the military vehicle market." It was in this context that in August 1999 the defense division of General Motors (GM) acquired a Swiss company, Mowag, while a few months later GD took a 25.1 percent minority stake in the Austrian company Steyr-Daimler-Puch. (For decades, these two small firms of a few hundreds of employees had been involved in the manufacture of affordable armored wheeled vehicles.) A U.S. Army tender in late 1999 resulted in a contract awarded to a GM/GD consortium for a Mowag-based vehicle. Subsequently renamed Stryker, the program produced over 4,000 vehicles in North America based on the European design.[7]

To further diversify, i.e., to reduce its dependency on the Pentagon, GD continued its European expansion. First it acquired the main land armaments manufacturer of Spain, Santa Bárbara Sistemas (SBS), in July 2001. Until then government owned, SBS was involved in a privatization effort, and the acquisition occurred when relations between the U.S. and Spanish governments were strong. In October 2002, GD then purchased a small private German company, specializing in mobile bridges for army engineers. Further, in March 2003, GD acquired the defense assets of GM, including Mowag. In October 2003, GD fully acquired Austria's Steyr-Daimler-Puch and, in spring 2004, attempted to set up in the United Kingdom with an offer to take over Alvis-Vickers, the main British armored vehicles manufacturer. Its failure against BAE Systems, however, put a brake on GD's European expansion.[8]

Privately-owned and stock-market listed, BAE Systems resulted from a 1999 merger between British Aerospace and Marconi Electronic Systems. Initially specialized in aerospace and electronics, it was BAE Systems that acquired, in 2004, the already consolidated British land armaments company, Alvis-Vickers as well as its military vehicle subsidiaries in Sweden and South Africa. This acquisition was a case of home market protection (against GD) rather than a case of strategic diversification. In 2005, however, BAE Systems acquired the American military vehicle and naval gun producer United Defense Industries (UDI), at the time the biggest acquisition of a U.S. defense firm by a foreign one. With UDI, BAE Systems inherited the Swedish gun producer Bofors, which became a UDI subsidiary in 2000. In 2007, BAE Systems expanded its presence in the United States with the further acquisition of Armor Holding, a company specializing in tactical wheeled vehicles.

BAE Systems' American strategy is quite clear: gain access to the world's largest defense market. Its involvement in the consolidation of the European land armaments industry through its inherited operations in Sweden occurred by circumstance. Subsequently, the company took on a global expansion. In 2008, it set up in Australia and, although without purchasing any local companies, also increased its foothold in India and Saudi Arabia. One notable failure, however, regards its attempted merger with EADS, the European aerospace group (now called Airbus), in the fall of 2012, mostly due to the opposition of the German government.

In land systems, BAE Systems is presently under economic pressure. In America, its prospects are unsure and depend on the success of one of its main future vehicle programs. In Europe, even as the company developed the SEP-type wheeled vehicle via its Swedish subsidiary, it failed to secure contracts from either the British or the Swedish governments who instead decided to purchase foreign vehicles to reduce costs. Despite these challenges and its relatively limited contribution to cross-border restructuring, BAE Systems remains the biggest actor in the land armaments industry in Europe.[9]

Recent moves toward increased consolidation

Following a decade of rumors, French state-owned Nexter and German family-owned Krauss Maffei Wegmann (KMW) formed a joint venture in December 2015. Initially blocked due to German reluctance to enter into an agreement with a foreign state-owned company, it was a first step toward a binational consolidation process. Both companies are armored vehicles specialists and produce, respectively, the Leclerc and Leopard main battle tanks. Named KNDS, short for KMW and Nexter Defense Systems, the joint venture is registered in the Netherlands. If the project reaches its intended conclusion, the new entity would be Europe's second-largest land armaments actor, after BAE Systems. Presently, the integration of these two companies is partial as only a limited number of functions will be pooled: supply chain cooperation, R&D, strategy, international marketing, sales, and communication. Both trademarks will remain. As former Nexter CEO Philippe Burtin stated when he introduced the project in France before the [lower house] Assemblée Nationale, "we must speak of a rapprochement, and not yet of a merger." The 2015 agreement plans for an initial five year period, after which the companies will decide whether or not to pursue the integration.[10]

To go further, the new entity will have to overcome several challenges. One is that the production lines of both companies overlap in several areas. Another is that Nexter is involved in a large modernization program for the French army so that KNDS will probably not be able to offer ambitious joint programs for the next decade or so. In the long-run, a third challenge lies in the need to strike a binational agreement on arms exports which, due to the different practices and sensitivities of the two countries, may be difficult to achieve. Finally, the recurrent issue of a possible privatization of Nexter and its modalities may constitute a stumbling block as well.

Despite these challenges, KNDS might be the first step toward an ambitious consolidation of the sector in Europe, with the possibility to integrate other actors afterward. For example, when in December 2016 Swedish group Volvo, owner of Renault Trucks Defence, announced its intention to divest from its French military vehicles subsidiary so as to focus on its core commercial truck business, the CEO of Nexter expressed interest in purchasing the Volvo military vehicles assets in agreement with its KMW counterpart.

In addition to a possible deepening of the Franco-German deal, in March 2016, the defense division of Norwegian defense and technology group Kongsberg announced its intention to purchase a 49.9 percent stake in the Finnish defense firm Patria (with the other shares held by the Finnish government). Created early in the 19th Century, Kongsberg is 50 percent owned by the state of Norway; the rest is publicly listed. A Kongsberg-Patria deal, if it were to go through, would constitute a strategic alliance rather than a merger since the two companies would continue to exist as separate entities. Already they cooperate through their joint venture, Nammo—a Nordic munition, propellant, and rocket motor producer established in 1998 and jointly owned, with equal shares, by the Norwegian government and Patria. (Together, they are the second-largest northern European defense group by turnover, after Swedish aerospace and defense company Saab.) Again, if the deal goes through, defense industry cooperation between the Nordic governments would deepen and would go beyond the land sector. Patria produces armored vehicles and Kongsberg is well-known for its remotely-operated weapons station for military vehicles, for example. The new entity would also be competent in aerostructures, aerospace engine and lifecycle support, aircraft and helicopter assembly, and naval systems. One analyst wrote that "the primary objective in ongoing consolidation and merger & acquisition activity is to enhance the Nordic defense industry's competitive edge to secure big-ticket domestic and regional contracts against expected increased interest and bids from 'foreign' rivals."[11]

Conclusion

One debate in defense economics concerns the evolution of relations between state and market in military production. Especially in the context of globalization, Europeanization, and the liberalization of the defense sector, the usual preeminence of governments over markets is challenged.

In this context, the land armaments sector remains less consolidated than the military aerospace and electronic industries because of certain specifics such as softer market pressures, lower R&D costs, and longer production runs. From a European perspective, this means that it remains a sector where public action can be fully exerted on a national basis, the necessary and sufficient condition being the ability to secure sufficient export orders to allow indigenous defense developments to be economically viable. However, this also means that national sovereignty of the sector is actually somewhat weak when compared to the other defense industrial sectors. Consequently, market contestability seems higher in the land armaments sector than it is in the aerospace, electronics, or naval sectors. This explains how the main driver of the initial consolidation of the European land armaments industry could be an American company (General Dynamics) which established a strong foothold in Europe at the beginning of the 2000s.

Appendix: An Example

The Boxer wheeled vehicle is, thus far, Europe's only joint military vehicle program. It also is the only vehicle program to be managed by OCCAR (the French acronym for Organization for Joint Armament Cooperation), an intergovernmental organization which facilitates collaborative armament programs between and among European nations. Despite a promising start, the limited scope of the Boxer program illustrates the difficulty of cooperation in this field.

In 1994, France, Germany, and the United Kingdom initiated a joint study to meet the three countries' requirements. Two competing tri-national consortia were formed. One pooled Krauss Maffei, Wegmann, and Rheinmetall (Germany), GKN (UK), and GIAT (France); the other grouped Henschel (Germany), Vickers (UK), and Panhard & Levassor (France). In April 1998, the three countries selected the first consortium, which subsequently took the name ARTEC (ARmoured TEChnology).

ARTEC, based in Munich, is a management and sales joint venture, production being undertaken by the participating national companies. In September 1999, however, France left the program to produce its own vehicle, the VBCI. Despite this withdrawal, a contract was signed in November 1999 by the U.K., Germany, and ARTEC for the development of the vehicle. Program management was transferred from the German procurement agency to OCCAR. The Netherlands, who received observer status in 1997, joined the program in February 2001. The ARTEC consortium then was equally owned by four partners: Alvis (UK), KMW (Germany), Rheinmetall (Germany), and Stork PWV (Netherlands), the last one being a management company set up to accommodate the Dutch involvement but without manufacturing capability. The U.K. then left the program in July 2003 on the argument that recent British military engagements showed that the vehicle under development did not fit properly into its military doctrine.

The project then became a Dutch-German venture, whereby the ARTEC consortium is 50 percent owned by the Dutch company Stork PWV, 36 percent by KMW, and 14 percent by Rheinmetall. 200 vehicles were ordered by the Netherlands and 270 by Germany. At this point, the program is marked by transnational consolidation that sees the small Dutch military vehicle industry being integrated into its German neighbor. In 2004, KMW acquired DDVS—the company in charge of assembling the Boxer vehicles for the Dutch army—and Rheinmetall purchased Stork PWV in 2008. At that point, ARTEC becomes an entirely German-owned joint venture between Rheinmetall (64 percent) and KMW (36 percent). In December 2015, the German Army ordered an additional batch of 131 Boxer vehicles. In August 2016, Lithuania signed a contract to buy 88 Boxers, thus becoming the third European country to actually acquire the vehicle.[12]

Notes

1. The French report is available only in French. Translations are by the author of this article.

2. Governments bear financial risks: Dunne (2009). Labeled: For instance, Devore (2013). Preeminence: Haaland Matlary and Østerud (2007). Single EU defense market: Castellacci and Fevolden (2015).

3. The ASD brochures do not include data on the military space sector. The inflation-adjusted figures are calculated from the OECD's "Consumer Prices—Annual Inflation" series available http://stats.oecd.org [accessed 14 February 2017].

4. Eurostat: Eurostat database, Structural Business Statistics, http://ec.europa.eu/eurostat/data/database [accessed 15 February 2017]. NACE: NACE is the French acronym used within the European Union industry classification system. It stands for "Statistical classification of economic activities in the European Community" http://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Statistical_classification_of_economic_activities_in_the_European_Community_%28NACE%29 [accessed 15 February 2017]. Classification change: Code 25.4 "manufacture of weapons and ammunition" and code 30.4 "manufacture of military fighting vehicles."

5. "Vanishing lifeline": Fleurant and Quéau (2014, p. 53).

6. Adamowski (2015).

7. Quote: Schulze and Zwilling (2007, p. 7).

8. GD's diversification: Fleurant and Quéau (2014, p. 42).

9. SEP is the Swedish acronym of Splitterskyddad Enhets Plattform which stands for Modular Armored Tactical System. The vehicle, however, remained at a prototype stage.

10. Quote: Linnenkamp and Maulny (2016, p. 3).

11. A remotely-operated weapons station is a weapons system (generally a machine gun) mounted on the top of a military vehicle and remotely operated by a gunner located inside the vehicle through a regular and a thermal imaging camera (https://www.kongsberg.com/en/kps/products/remoteweaponstation). Quote: O'Dwyer (2016).

12. Appendix based on Dirksen (2010), various press articles, and the ARTEC website: http://artec-boxer.com [accessed 15 February 2017].

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The European military helicopter industry: Trends and perspectives

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Abstract

This article discusses the European military helicopter market. It first recalls historical antecedents in the structural development of the main helicopter programs that helped to consolidate the industry and then reviews the industry's current major trends. A paradoxical situation is identified: While European countries presently are able to cope with both, the growing needs in helicopter capabilities and the maintenance of ageing fleets, no large helicopter programs for the future have been launched. Some uncertainties regarding how future helicopter procurement will be organized are identified. The current situation underlines the challenges that European states will face to maintain both industrial skills in the industry and sovereignty in military helicopter capabilities. A number of industry options are discussed: more exports, more cooperation, more dual use, and more reliance on support and service sales.

Military helicopters have become a major defense system, and states use them extensively in military operations. Helicopters—for combat, transport, or multirole uses—provide modularity and flexibility to project forces at home and abroad. Due to certain operating characteristics, e.g., the ability to take off and land vertically, hover for extended periods of time, and aircraft handling properties at low-speed, these weapons platforms are used to conduct missions that are not possible with other aircraft. Military needs for the use of helicopters are diverse. They now are used in escort missions, support missions, and ground force protection in conjunction with fixed-wing aircraft. Since the 1950s, military helicopters have become a key element of air mobility, based on the dual-named "terrestrial/rotary-wing" concept, the combination of being able to transport ground units carrying out operations while supporting them with scouting, transport, or combat capabilities. Depending on the type of mission (payload, distance to cover, and so on), helicopters have progressively become an alternative to manned fixed-wing aircraft.[1]

European countries involved in military operations use helicopters extensively. For example, French armed forces recently asked for a significant reinforcement with helicopters forces for the Barkhane operation in the Sahel sub-Saharan region. This involved a mix of Tiger (5 years old in 2016) and Gazelle (30 years old) combat helicopters as well as Puma (41 years old) and Cougar (25 years old) transport helicopters.

On the demand side, the need for aero mobility has increased. Military helicopters are among Europe's procurement priorities. This is especially true for transport helicopters, with 14 countries engaged in a purchasing or upgrading process since 2011. However, many uncertainties exist that affect this market's evolution. For instance, defense budgets are constrained and military helicopters require large investments in terms of acquisition and ongoing support. This requires constant examination of this industry in Europe.[2]

On the supply side, competition is fierce. The estimated world-wide market is about 1,000 platforms annually, with the American market representing roughly 66 percent of the total. In 2016, the market was shared among three American, two European (Airbus Helicopters and Leonardo Helicopters), and one Russian (Russian Helicopters, part of Oboronprom) manufacturers. In addition, two Japanese, one Indian, and one Chinese firm produce licensed platforms developed by the American, European, and Russian firms.[3]

In what follows, the two main sections of this article discuss, first, the history and current situation of consolidation in the European military helicopter industry and, second, options for its future. A final section concludes.

History and current situation

Prior to world war two, helicopter development took place in European countries such as France, Germany, Italy, Spain, and the United Kingdom. While the German Focke-Wulf FW-61 was the first operational helicopter to fly, in 1936, European production numbers were low. The first helicopter to reach industrial scale production was the American Sikorsky R-4, with a production order for around 100 aircraft in 1942, and it was the only Allied helicopter to serve in world war two. After the war, the transfer of U.S. helicopter technology through

Table 1: Military helicopter market (2015): Major actors and home countries in the European market

Manufacturer	*Military/ total sales (%)*	*Number of employees*	*Turnover (USD billions)*	*Number of platforms in Europe* [a]	*Share of European platforms (%)*
Europe					
- Airbus Helicopters (French, German, Spanish)	48	22,900	8.3	1,366	38
- Leonardo Helicopters (Italy)	42	13,000	5.6	383	11
United States					
- Sikorsky Helicopters	79	15,300	7.5	294	8
- Bell Helicopters	62	8,700	4.2	750	21
- Boeing Defense, Space, and Security	100	n/a	3.2 [b]	319	9
Russia: Russian Helicopters	90	42,000	3.5	371	10
Japan					
- Mitsubishi Heavy Industries	12 [c]	n/a	n/a	0	0
- Kawasaki Heavy Industries	n/a	n/a	n/a	8	0.2
India: Hindustan Aeronautics Ltd.	95 [c]	n/a	n/a	0	0
China: Changhe Aircraft Industries Corporation	n/a	4,300	n/a	0	0

Sources: Compiled from James (2016), Meddah (2016), SIPRI (2016), and manufacturers' data. *Notes*: [a] The number of platforms is for 2016 (IISS, 2016). [b] The figure is the turnover Boeing Defense, Space, and Security only. [c] The figure is for the entire company. n/a: Not available.

licensing agreements led to the emergence of four major European manufacturers: Westland (U.K.), Aerospatiale (France), Messerschmitt-Boelkow-Blohm MBB (Germany), and Agusta (Italy). Today only two European manufacturers remain, Airbus Helicopters and Leonardo Helicopters. Table 1 lists them in the context of the world's major manufacturers and shows various market and business indicators. In 2015, the two European firms shared half of the market in Europe, the three American manufacturers had 38 percent, and the Russian one had 10 percent. Airbus Helicopters produced 38 percent of all platforms in service in 2016 and Leonardo Helicopters 11 percent.[4]

French-British bilateral initiatives: The take-off of industrial integration

In 1915, the English town of Yeovil was known both for its gloving industry (glove production) and for its Petters diesel engine company. Petters placed its facilities and workforce at the government's disposal for the war effort. When it was suggested that the local sewing skills in the gloving industry, combined with Petters engineering, could be adapted to aircraft production, Westland was born. Following the war, the new firm designed a number of civil aircraft and, during the second world war, produced military aircraft (e.g., Lysander, Spitfire, Welkin). Between 1915 and 1955, a total of about 6,000 fixed-wing aircraft were built at Yeovil.[5]

In 1946 Westland negotiated a long-term agreement to build Sikorsky helicopters under license and made the strategic decision to specialize in the production of rotary-wing platforms. In the Royal Navy helicopters rapidly superseded fixed-wing aircraft in anti-submarine warfare and search and rescue operations. In 1960, twenty British aircraft manufacturers combined to form only two major aircraft manufacturing groups, the British Aircraft Corporation and the Hawker Siddeley Group. For rotary-wing platforms, Westland took the lead and successively acquired Bristol Helicopters, Fairey Aviation, and Saunders-Roe to to become Westland Helicopters, Britain's sole helicopter company. The partnership with Sikorsky continued with the production of the Sea King line of models.

Cautious French-British cooperation in the production of military helicopters started with an agreement struck in 1965. The needs were for tactical and transport helicopters and for a light observation and multirole helicopter (including for anti-submarine warfare and antitank missions). This gave birth to the Puma, Gazelle, and Lynx programs and was, for Westland, an important step in its development to become a major European helicopter company. Westland took on the design leadership for the Lynx, while the French partner, Aerospatiale, was responsible for Puma and Gazelle. Both companies, however, were to take part in the development and manufacture of all platforms. The three helicopter types have been extensively used by both countries in domestic and foreign operations—many of them are still in service—and were great export successes as well. (For example, more than 1,750 Gazelles were produced, and in past or current use by 27 countries.) Today, however, ageing and obsolescence raises maintenance cost and limits interoperability with other nations' military assets.[6]

Helicopters are part of today's strategic defense equipment. In the absence of any large, multi-nation, cooperative program to develop new military helicopters platforms in Europe, a major risk lies in the potential loss of defense industrial and technological knowledge, skills, and military capabilities. This article discusses the potential roles that export expansion, increased cooperation, dual-use production, or a focus on support and services may have in keeping European military helicopter firms "in play."

Italian-British initiative: The birth of AgustaWestland

In the mid-1970s, Westland decided to design a larger aircraft, the Westland 30, as a private venture for the civilian market. In part because of the limited success of these aircraft, the mid-1980s proved a difficult time for Westland and the firm considered a major link-up with Sikorsky, although European option was preferred. A partnership with Aerospatiale was envisioned but abandoned. In the end, Westland agreed with Agusta of Italy to collaborate on the production of a new helicopter—the AW-101 Merlin—which was to replace the Sea King. In 1986, Sikorsky acquired Westland. Then, in 1994, Westland became a wholly owned subsidiary of GKN, a British multinational automotive and aerospace company. Westland was merged with then-Finmeccanica's Agusta helicopter division in 2001. Finally, in 2004, Finmeccanica S.p.A. acquired GKN's share in the joint venture. As from 2016, the company is called Leonardo Helicopters.

The AW-101 Merlin program was launched by the United Kingdom to respond to national requirements for a modern naval utility helicopter. In 1974 already, the Royal Air Force and the Royal Navy had wanted to replace Westland's Sea Kings. Westland first proposed its own platform, derived from a civilian helicopter, but it was not selected. Meanwhile, in Italy, Agusta had joined a program in 1980 to replace the Agusta-Sikorsky AS-61 which was in service in Italy. Agusta and Westland then formed a joint venture, called Elicoterri Helicopter Industries (EHI), which gave birth to the AW-101 Merlin and subsequently played an important role in the integration of Agusta and Westland. The AW-101 entered into service in 1999. This medium-lift transport helicopter was initially developed for both military and civilian markets. A version was also developed for anti-submarine warfare. The platform has been deployed in combat in Afghanistan and Iraq. In 2016, 98 platforms were in service in 4 European countries (Denmark, Italy, Portugal, and the U.K.

French-German cooperation: The EC-665 Tiger program and the birth of Eurocopter (Airbus Helicopters)

To replace ageing Bo-105, Gazelle, and Puma helicopters, France and Germany started in 1974 to cooperate to produce a combat helicopter with anti-tank and night vision capabilities. Sud Aviation (later merged in Aerospatiale) and MBB had already worked together in the 1960s on a new rotor and composite blades, but not on a whole system. Moreover, following cooperation failures on European fighter aircraft and battle tanks, by the early 1980s the Tiger program appeared to be the only opportunity to cooperate with Germany. The Tiger program was exemplary in that all procurement segments were shared between countries. It also gave birth to joint training schools, both for pilots—training is particularly expensive in aeronautics—and maintenance personnel. In 2016, 97 platforms were in service in three European countries (France, Germany, and Spain) and in Australia (22 platforms).

In 1992 DASA (Germany) and Aerospatiale (France) merged their helicopter divisions into a new company, Eurocopter. In 2000, both groups agreed to merge and this consolidation included CASA (Spain), with its helicopter business (mainly producing Bo-105s under license) being integrated into Eurocopter. Eventually EADS rebranded itself and all its divisions, and Eurocopter change its name to Airbus Helicopters in 2014. By 2016 Airbus Helicopters had four main facilities in Europe (two each in France and Germany), plus 32 subsidiaries and other operations around the world.

The AW-101 Merlin and Tiger programs played a major role in the integration of Europe's military helicopter industry. AgustaWestland and Eurocopter emerged due to convergence between operational needs for different armed forces and a desire for industrial rationalization. The cooperative programs were an opportunity for firms to build concrete foundations to work together, share skills, knowledge, and infrastructure. This gave birth to what today are two leading European military helicopter companies, Leonardo Helicopters and Airbus Helicopters.

European multilateral programs

In addition to the (mostly) bi-lateral programs already described, recent multilateral programs such as NH-90 illustrate the limits of European industry consolidation.

Contrary to programs such as the AW-101 Merlin or Tiger, the NH-90 program had limited effects on integration.

Joint efforts on the NH-90 platform began in late 1970s. As suggested by its name—NATO Helicopter 90—NATO needs influenced this program, which was a response to the main requirements of the so-called Ditchley Park agreements: building a medium transport and multirole helicopter, also capable of operations in naval environments. The NH-90 was developed and manufactured by NH Industries, an industrial cooperation of Airbus Helicopters, Leonardo, and Fokker Aerostructures.[7] The program involves several countries. On the supply side, R&D and production costs were shared among four countries: France, Germany, and Italy carried around 30 percent each and the Netherlands 6 percent. Belgium and Portugal contributed to production costs only, at about 1.5 percent each. Given the total cost, it is likely that the countries would not have been able to afford a platform with such strong technological innovation. On the demand side, as of 2016 a total of thirteen states have placed more than 500 orders for the NH-90. Two versions—one marine, one terrestrial—have been developed.

While impressive, the program has its limits. First, in early service, the NH-90 suffered from technical set-backs, which in turn delayed active deployment by some operators. Second, because of lack of rationalization in terms of the needs of national armies, the NH-90 today is in service in 23 versions, which limits rationalization of maintenance. Third, in the production process itself, little industrial rationalization is noted. Because of the application of *juste retour*, assembly lines are spread across several countries. Fourth, no merger between industrial actors in the European helicopter industry have taken place during, or after, the scheduling of this program. Contrary to the experiences of the AW-101 Merlin and Tiger programs, for instance, the NH-90 program did not have an effect on Europe-wide military helicopter industry consolidation.

Lack of new European military helicopters programs

Europe's military helicopter fleets are ageing. A proxy for aging is the date of entry into service. Thus, by 2016, the oldest helicopters are the Bell-204 and Bell-205 Iroquois (first flight in 1956; entry in service in 1959), with a total of 367 platforms in service. The youngest fleet is the AW-159 (first flight in 2009; entry in service in 2015), with a total of 49 platforms in service. Around two-thirds of Europe's military helicopter platforms are based on designs that are more than 35 years old. More precisely, of a total of 3,586 platforms the oldest helicopters (defined here as pre-1980 entry into service) represent 65 percent of the number of helicopters in service in 2016. Another 11 percent came into service between 1980 and 1990, 14 percent between 1990 and 2000, and the remaining 10 percent since then. This age profile and the increasing demand for helicopter capabilities have led to discussions regarding new helicopter programs and replacement solutions.

In Europe, no new common, large programs, such as Tiger or NH-90, are currently planned. In the United States, the Joint Multi-Role Program Helicopter (a multirole platform with vertical take-off, highspeed, and tiltrotor) groups major American manufacturers—Bell, Sikorsky, and Boeing—to develop a demonstrator, which is supposed to fly in 2017. The U.S. also launched a large program of about USD100 billion to replace several ageing platforms including the Chinook, Black Hawk, and Apache. This prompted the acquisition of Sikorsky by Lockheed Martin in 2015 because the latter firm wanted to penetrate the helicopter market. (A demonstrator was built.) In Europe, to avoid dependency on American systems, it would be of interest to take a similar approach to the development of new capabilities and base them on Airbus Helicopters and Leonardo Helicopters, and possibly other countries with which two majors have developed industrial cooperation such as Poland, Spain, or even Turkey.

However, Europe appears to be focused on national initiatives, where several helicopter replacement programs have recently been launched. In 2013, in France, the Ministry of Defense has set up a Joint Light Helicopter program (Hélicoptère Interarmées Léger, HIL). This program aims to develop a family of helicopters based on a dual-use platform. Several versions with different specifications would be put into service in the different services of the armed forces and other government departments (e.g., police and customs). Because of budget cuts and changes in budget planning, the program has been delayed. The platform is not expected to be in operation before 2020-2022. In Italy, in late 2016, Parliament's defense committee approved a funding envelope of EUR487 million to design and develop the successor to the 1980s flagship of AgustaWestland's production, the AW-129 Mangusta attack helicopter (first flight in 1983; 43 platforms in service in Italy in 2016). The design phase of the new platform will involve universities and research centers and the prototype will be built at Leonardo Helicopters's Vergiate factory. The new helicopter will replace the army's AW-129 Mangusta in 2020. The platform has be announced as "all-Italian," but this seems unlikely as Italy does not have an appropriate engine producer in Italy and missiles will have to be sourced from foreign suppliers since the only ones produced in Italy are under foreign license and thus subject to re-export controls.

In short, Europe faces a paradoxical situation: Helicopters are among the most extensively used pieces of equipment in military operations today but there exists a lack of large, new programs to address future needs and capabilities. The support of states with large equipment programs (upgrading, retrofitting, or developing new platforms) is crucial. In spite of a history of major military helicopter programs, nothing comparable to current U.S. efforts is found in Europe. The situation is nationally based and only national programs are launched in the light helicopters segment such as multirole and multi-mission platforms to replace ageing light platforms. There is a substantial risk of losing industrial skills and knowledge dearly acquired by European firms and countries between the late 1960s and the mid-1990s.

The future of Europe's helicopter defense industrial base

The following subsection review four options that European military helicopter firms and countries may consider.

Exports: Is the future outside Europe?

In the current context (declining defense budgets make purely domestic programs unaffordable; no new large expected multi-country, cooperative programs), cooperative ventures aimed at exports could enlarge the market, maintain industrial skills, and also further industrial integration. But market competition is intense, involves many uncertainties and, depending on the type of export or cooperation, one can also see risks for some strategic skills to leave Europe.

First, European manufacturers can search for export markets in Europe, outside their own domestic market. East European countries are potential candidates, for exports and for joint work. They have growing defense budgets and growing needs in helicopter capabilities (they perceive threats from Russia). For example, Poland needs to replace its ageing Russian platforms, which constitute more than 60 percent of the total number of platforms in service in the country in 2016. The Polish market for 70 multi-mission helicopters is valued at EUR2 billion. Airbus recently lost the Polish market for its EC-725 Caracal when Poland selected 21 Sikorsky S-70 Black Hawk helicopters. Poland also launched a tender for 30 attack helicopters. The choice will be between the Airbus Tiger, Boeing AH-64, and Leonardo Helicopter's AW-129. Another call for tenders has been launched for around 20 special forces helicopters with an offset requirement concerning in-country maintenance of selected platforms. Again, Sikorsky, Airbus Helicopters, and Leonardo Helicopters are in the competition. Many uncertainties cloud these tenders and last minute changes of terms complicate the picture but the strong suggestion is that a European procurement preference should not be presumed to hold for some countries such as Poland for example. This is unlike the case of northern European countries (e.g., Finland, Netherlands, Norway) that clearly have selected the NH-90 helicopter to modernize their fleets.

Cooperation

A second option is to intensify the current degree of integration and gain access to new markets while preserving skills and knowledge. But what are the prospects? A merger between Airbus Helicopters and Leonardo Helicopters is unlikely since this would lead to the creation of a civilian helicopter monopoly in Europe. Programs with Russia (e.g., in the heavy transport helicopter segment or even for attack helicopters) or China (an attractive but embargoed market) also are unlikely in the current context. A transatlantic venture is difficult to realize as the prospects for European platforms in the U.S. market are more limited for military than for civilian platforms. The former Aerospatiale did sell some civilian platforms in the U.S. and today, in its legal form of American Eurocopter (the subsidiary of Airbus Group in North America), the manufacturer continues to deliver the UH-72A Lakota (a militarized version of the EC-145, produced in Mississippi) to the U.S. Army. However this is an exception as the Pentagon's market has been hard for European manufacturers to break into (in competition with Bell Helicopters). One should not expect that the military platforms of Airbus Helicopters (e.g., Tiger or NH-90) will make it in the U.S. market.[8]

Regarding Leonardo Helicopters, the VH-71 Kestrel (an adapted version of the AW-101), was developed in cooperation between Lockheed Martin and AgustaWestland to serve in the U.S. presidential transport fleet. The European firm was chosen because, at the time, the American one did not have industrial skills in the design of military helicopters and was more of an electronics specialist dealing with onboard systems and systems integration. However, the program was cancelled due to its expense (more than four billion dollars for nine platforms). This could have been the first step toward a merger between Leonardo and Lockheed Martin, but it failed. Leonardo is also a partner of Bell Helicopters (i.e., Boeing) to develop the AW-609 with a tiltrotor taken from the Boeing-Bell V-22 military helicopter (expected on the market in 2018).

A transatlantic company is unlikely to emerge. Recall that in 2015 Sikorsky was acquired by Lockheed Martin. It is conceivable that AgustaWestland or Airbus Helicopters might have done the acquisition, but neither did. Instead, Lockheed Martin burst into the helicopter sector, even without industrial consolidation at the U.S. national level. If one looks beyond an American option, new partnerships in emerging or developing countries need to be examined. Airbus Helicopters currently exports to (and produces in) Asia. China is a major market for civilian and para-public helicopters (Airbus cooperates on civilian models, for example the H-175), and India is a defense market. Further, Airbus Helicopter has developed a partnership with South Korea (the KAI Surion, based on a Super Puma platform) and signed contracts to sell its EC-725 Caracal to Thailand and Singapore. Airbus Helicopters is also increasing its exports to Kuwait (30 Caracal), Qatar (which is expected to finalize a contract for the purchase of 22 NH-90), Brazil (Caracal), and Mexico (NH-90).[9]

For its part, Leonardo has developed partnerships to produce its new generation of helicopters with, for example, Turkey (mainly for civilian platforms) and Poland (at the PZL Świdnik plant) and it is also interested in the African market: The firm recently concluded a joint venture in Algeria (Aïn Arnat) to produce light and medium helicopters (transport, Search and Rescue, and scouting).

Cooperation in its various forms makes it possible to maintain industrial skills and knowledge, true, but in the long run there is a risk for strategic skills, although maintained in the short term, to be off-shored. Ultimately, this would weaken both European firms and states in the helicopter sector.

Dual-use helicopters

Militarized versions of civilian helicopter platforms—dual-use helicopters—may offer several acquisition and support-related advantages. First, sharing the same basic platform, both versions share design and R&D costs and come off the same assembly line. The resulting economies of scale spread out the fixed costs and therefore reduce unit acquisition costs. Second, economies of scale also increase the efficiency with which spare parts can be supplied, thus lowering support costs. Third, availability of relatively inexpensive spare parts can contribute to decreased helicopter downtime, again saving costs.[10]

Since European helicopter firms are less dependent on military markets (their average military sales dependence is 45 percent) than their American competitors (80 percent), dual use would seem a good option. In addition, the macroeconomic context also matters. For their civilian platforms, the European firms struggle to cope with decreased demand from the oil and gas sectors of the economy. Oil companies represent around half of Airbus Helicopters civilian sales, for example, and no orders were received from this segment of the market in 2015. Leonardo Helicopters, likewise, faces an unfavorable civilian market, although it did have some commercial success with its latest civilian platform, the AW-189. Moreover, European helicopter manufacturers already tend to militarize civilian platforms. The H-145 of Airbus, for instance, initially built for the police, has been militarized and sold to Germany and the Royal Navy of Thailand. In Italy, the HH-139A is a militarized version of the AW-139 civilian platform and is mainly used for search-and-rescue tasks on national territory. And the French future Joint Light Helicopter (the HIL program) will probably be based on a civilian platform designed by Airbus Helicopters.

But can one use militarized versions of civilian helicopters in combat? What in fact are the costs of militarizing a civilian platform and are they less than those of the development of a purely military platform? Military and civilian platforms differ in several ways. First, helicopters for military use need more protection. If passive protection (stealth, armored protection) is too hard to add to a civilian platform, active protection can be arranged for with add-on kits (self-defense systems, sensors, missiles). For example, the AB-212 helicopter was based on civilian standards but is now a combat unit with self-defense systems and in use by Italy's armed forces. Second, weight and load capability play an important role in dual-use helicopter configurations. Third, the use of dual-use helicopters is less effective and efficient for combat mission with ballistic contact than it is for logistical and tactical transport missions.

More broadly speaking, military, security, and civilian users have different needs on three linked dimensions: requirements, price-quality relationship, and time to market. The militarization of a civilian platform is usually a long, complex, and costly process. Armed forces often seek to replace several existing platforms with a single new one. The problem here is that this entails an increase in the number of specifications that are linked to various (and sometimes contradictory) operational and mission needs, and this leads to a more complex and costly platforms, both in acquisition and maintenance. Dual-use helicopters appear better-suited to sovereign missions that are not purely military but more on the security end of the defense–security continuum or to training tasks (e.g., the U.K.'s Defence Helicopter Flying School or France's outsourcing of training fleets).[11]

Of course, one can reverse the question and ask about adapting a military platform to civilian purpose. Many interesting cases can be found in recent history. The Puma and Super Puma helicopters have civilian versions for transport, and many civilian operators use the AW-101 platform for passenger transport. A platform designed to basic military specifications could then remove, case by case, everything that is not in accordance with civilian customer requirements.

The key role of services in helicopter fleet support

For helicopter manufacturers, the aftermarket or MRO industry (Maintenance, Repair, and Overhaul) has become an important component of the value chain. MRO provides support to users through day-to-day maintenance and required upgrades. Given the lack of investment in new large military programs, a source for both future growth and sustained industrial know-how thus lies in extended support of the existing fleets. This should also appeal to governments: As systems have become more costly to buy, keeping ageing fleets in service longer would contain cost and raise readiness. "All-inclusive MRO solutions" with flight hour contracts, in-support service contracts, performance contracts, and so on, are appealing. (And in this the helicopter industry would follow a trend already well-established in other industries: Sell the follow-on service more than the platform.)

For example, Airbus Helicopters won a training contract from the British Ministry of Defence for about GBP500 million on a fleet of 32 helicopters—29 H-135 and 3 H-145—with MRO services included (over 17 years to supply 28,000 hours of training each year). This activity is growing and the company currently provides military helicopter training services for the Royal Air Force at Shawbury, England (38 Squirrel and 14 Griffin helicopters). In 2015, service activities represented almost half of Airbus Helicopters' turnover, a figure that is expected to increase in future.[12]

Already such an evolution toward services is more fully developed in the civilian market (e.g., Ubercopter). Innovations in this sector will probably affect the military sector in years to come. This opens up new market perspectives for European helicopter firms who have produced half of the platforms currently in service (by 2016) and who, according to the International Institute for Strategic Studies, are expected to fulfill some 92 percent of future European helicopter orders. Needless to say, original manufacturers will be better placed than competitors to offer tied-in service packages to their military customers.[13]

Cooperation in MRO will increase in the future and become a crucial issue. Since Europe has not been able to launch and support a common program in the field of military helicopters, cooperation, at least in the short to medium term, is an opportunity to reduce costs and raise platforms readiness. This might be seen as a bottom-up approach for building European defense. Cooperation in maintenance leads to agreements to share stocks of spare parts and of specialized tools and infrastructure, the exchange of specialized workforces, and improved economies of scale by negotiating larger contracts as well as in the training of joint units. Recent European experiences, including the NH-90 and Tiger programs, illustrate the various combinations of possible pooling in the area of support. That said, Tiger helicopter cooperation could be improved with, for example, joint purchases to create a European pooled fleet shared by France, Germany, and Spain. One should also think of concentrating training on a dedicated site instead of using two schools, one in France and the other in Germany.[14]

The European Defense Agency (EDA) is particularly involved in the area of cooperation. In the helicopter sector, it launched a pooling and sharing initiative for skills, knowledge, and experience among European countries with the objective to lower the cost of training through multinational exercises, annual symposia, and training of multinational formations. Between 2009 and 2016, some 206 helicopters, 1,320 aircrew members, and 10,000 infantry deployed to the exercises, held in Belgium, France, Italy, Portugal, and Spain. During this time period, 590 aircrews from 12 countries graduated from the EDA Helicopter Tactics Course and 43 Tactics Instructors from 5 nations graduated from the Helicopter Tactics Instructors Course.

In northern Europe, helicopter maintenance cooperation appears more developed than in the western part of Europe. Northern countries modernize their fleets and have to cope with high infrastructure costs, especially for the newest platforms such as the NH-90s or Black Hawks. To share costs, Denmark, Finland, Norway, and Sweden signed the 2009 Nordic Defence Cooperation (NORDEFCO) agreement to promote military cooperation in the region. In addition, Finland and Sweden recently signed a support agreement for the maintenance of Black Hawk helicopters for 2015–2017 (with possible extension to 2020).

Conclusion

Helicopters are part of today's strategic defense equipment. In the absence of any large, multi-nation, cooperative program to develop new military helicopters platforms in Europe, a major risk lies in the potential loss of defense industrial and technological knowledge, skills, and military capabilities. This is a crucial issue for the future of European defense, where, for example, no equivalent for the American Joint Multi-Role Program Helicopter is identified.

This article discussed the potential roles that export expansion, increased cooperation, dual use production, or a focus on support and services may play in keeping European military helicopter firms "in play." These options are at best medium-term solutions because sooner or later, governments will need to replace existing platforms, notably for heavy military helicopters. Hence, Europe has to think deeply about how to define the role of the military helicopter of the future. The evolution of technology can create breakthroughs at either extreme of the market: heavy and light platforms. For medium and heavy platforms, high-speed helicopters have become a reality. Now flying at more than 310 km/h (the theoretical limit of classical helicopter platforms), for many missions they will compete with fixed-wing aircraft. This creates a new market for helicopter manufacturers, half-way between light aircraft and heavy helicopters. In recent years, Bell, with its V-280 Valor, and Leonardo Helicopters have invested massively in the necessary technology. Regarding light platforms, the evolution of technology also changes the market and here the threat comes from the development of Unmanned Aerial Vehicle platforms. UAVs compete increasingly with light helicopters and light aircraft for intelligence, surveillance, and reconnaissance (IRS) or even combat missions.

Europe has launched a preparatory action (EUR90 million for 2017–2019) and planned a budget line of EUR3 billion for upcoming 9th Framework Program for Research (FP9) starting in 2021 (it runs over 7 years' time). In September 2016, the President of the European Commission, Jean-Claude Juncker, announced the creation of a European Defense Fund to support defense investment expenditure. This might be a signal that Europe should invest the necessary R&D funds to define and study convergence toward common capability needs and to start thinking about the production of a common military helicopter platform.[15]

Notes

1. Terrestrial/rotary-wing concept: Marrone and Nones (2015).

2. Demand-side need increased: DGRIS-IRIS (2015). 14 countries: IISS (2016, p. 62).

3. 66 percent: Meddah (2016).

4. For historical aspects, see Sheil (1984). Sikorsky: The United States' first military helicopter production contract was actually signed by Georges de Bothezat in 1921. However, it did not lead to any actual industrial-scale production. Market shares: The Russian platforms are in service in Central and East European counties such as Romania, Poland, Bulgaria, Hungary. The share of the Japanese, Indian, and Chinese firms is insignificant.

5. Details about the history of Westland helicopters are taken from http://history.whl.co.uk/.

6. Puma, Gazelle, Lynx: See Bousquet (2016).

7. The aim of Ditchley Park agreements (1975) was to create coherence between helicopter needs among various European armed forces and to reorganize the helicopter industry in Europe. The agreements were signed by a small group of European countries, including France, Germany, and the U.K., and can be considered as the historical starting point of Europe-wide cooperation in helicopters programs.

8. Aerospatiale: See Sheil (1984).

9. H-175: This is Airbus Helicopter's new designation for the former EC-175, which is the same aircraft.

10. Dual-use: Marrone and Nones (2015, p. 7) write: "'Dual-use helicopters' refer to platforms that have been designed in compliance with certain standards and are structurally built so that they can satisfy civilian, military or security users with only minimal adjustments or additions."

11. Contradictory: For example, heavy armor for the Army versus high speed for the Air Force. On this paragraph, see Belan (2016).

12. Expected to increase: James (2016).

13. Future orders: See IISS (2016).

14. Bottom-up: Droff and Bellais (2016). Dedicated training site: DGRIS-IRIS (2015).

15. European Defense Fund: This fund has not been defined either in its objectives or mechanisms.

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The European space-industrial complex: New myths, old realities

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Abstract

This article is an economic analysis of the main factors affecting the evolution of the European space industry. The critical role of the government is analyzed with regard to both military alliances and civilian intergovernmental collaboration. The analysis explores how moving from a pure public goods paradigm in collaborative projects toward a commercially-oriented, competitiveness-enhancing paradigm leads to duplication of effort and rivalries within the space agencies and other organizations. Drawing on the example of defense alliances such as NATO, the article illustrates cooperation challenges faced both at European and transatlantic levels as competition and rivalry result from inter-alliance specialization and the difficulties involved in the allocation of benefits.

This article focuses on the European military and civilian space-industrial complex and various related alliances and partnerships. Space is a dual-use industrial environment both on grounds of operations and in terms of the firms that provide civilian and military space-related products and services. Considering certain market failures associated with space-industrial cost characteristics and the security implications of the relevant goods and services, there exist critically important interactions between commercial and government markets. Over the years, the fundamental nature of these interactions has remained unchanged with governments playing a leading role as regulators, customers, technology partners, and technology sharers.

Any analysis of the economics of this sector has to include geopolitics and the institutional landscape in European security and space affairs. It is therefore natural to consider European institutions such as the European Space Agency (ESA) and the European Commission (EC) as focal points. Within the industry, consolidation has resulted in just one major European space integrator (Airbus), but there also exist several satellite manufacturers, like Thales-Alenia Space (TAS) and OHB, and many other firms in the lower tiers. Despite its multinational nature, Airbus facilities and plants maintain much of their pre-consolidation geography, making it a decentralized entity of a multinational character in governance and value-added.

Governments are heavily involved in the space industry as buyers, technology suppliers, regulators, and in other roles, and because of the numerous and significant market failures that overshadow the operations of the private sector. The main difference to the aerospace sector is that the "pure" space sector is (even) more dual-use and opaque than is aerospace. And while tremendous future potential exists for the industry, challenges related to the use of the outer space commons arise that may crimp the development of the space sector. Although increasing, the limited number of space-faring nations and the relatively small size of the sector—compared to its importance in defense policy and the role of national governments in it—make it difficult to analyze individual countries or themes without also considering the wider international context.[1]

This article presents an economic analysis of important factors affecting the evolution of the space industry in Europe. It points out how moving from the nearly-pure public good nature of space-related goods and services in collaborative projects toward project selection focusing on industry and business competitiveness can lead to duplication and rivalries within collaborating entities such as ESA. Drawing on an analogue from NATO, the article also illustrates how in future such rivalries may develop within European collaborative security organizations and programs.

The next section presents stylized facts regarding the size and structure of the industry that to a large extent define the space-industrial complex. The section thereafter examines market failures that characterize the industry, with much of the focus placed on issues regarding innovation, the "new space" concept, and the role of governments. The penultimate section considers the economics of specialization, hegemony, and alliance effects in space where military and civilian activities and behaviors differ. This is followed by a short conclusion.

The space-industrial complex: An overview

The space industry or space sector (the terms are used interchangeably here) is characterized by the presence of government-chartered space agencies that act on behalf of governments as producers of space goods and services, act as customers, and also as supporters of the industry. The need for the creation of space agencies like the National Aeronautics and Space Administration (NASA) in the United States or the European Space Agency in Europe emerged due to perceptions of duplication and waste associated with uncoordinated government departments (including military branches) within a given country or, in Europe's case, among countries pursuing rivalrous space activities and programs. ESA, in particular, sprang from early collaborative European efforts when it was deemed necessary to obtain the necessary scale for developing launchers and satellites. (A similar approach was taken at the industry level for joint ventures like Airbus, prior to it becoming a fully integrated company.)

ESA and NASA are considered "civilian" space agencies. In the case of the United States, the security and military dimensions of space are placed in the care of its Department of Defense (DoD) and enjoy budget appropriations on par with NASA. For Europe, no such equivalent with military space activities exists. Exceptions, even at the operations level, are negligible. For one thing, membership of sovereign states in ESA and the EU differ and despite calls for ESA to turn into a space agency under the aegis of the European Commission (EC)—the EU's executive body—the relation between them is still developing, the idea being that the EC would assume operational control of space systems and services and act as a partner (in effect, as both, principal and customer) to ESA.[2]

In contrast to the competition-enhancing nature of the EC, ESA operations are based on a traditional inter-governmental model whereby national inputs to a collaborative scheme are matched by equivalent-value contracts to the national industry. This institutionalized *juste retour* (fair return) process is the ESA's main decisionmaking and implementation characteristic. (Similar approaches linking regional industrial returns with high-level space programmatic decisions are found in the lobbying activities and political representation in the U.S. Congress where local political representatives seek territorial returns and value-added from federally-funded space activities.)

Space agencies are expected to coordinate and consolidate space efforts and be a point of contact for the space industry. Large parts of the setting of space objectives, and of program and prime contractor selection, are determined by power struggles. This is crucial for an understanding of European space efforts as ESA's initial mandate pertained to the development of technology—and to the pooling of the resources of the various nations that comprise it—alongside the advancement of science. A good example of this is the development of the Galileo and Copernicus programs. Analogous to the United States' GPS/NAVSTAR system, Galileo started out as a public-private partnership to build a

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satellite-based, commercially-oriented geopositioning system. Following significant delays, lack of interest by the private sector to engage in operations, and security challenges given NATO's support of the U.S. GPS system, Galileo was reprofiled from a private-public partnership into a public entity, with the public sector fully funding the program's R&D and operations.[3]

Economies of scale and scope are extremely important in manufacturing products (e.g., satellites, launchers, ground stations, and equipment) and providing related services (e.g., telecommunication, remote-sensing information, meteorology, positioning and navigation signals). Respectively, product and service development are complemented by economies of learning and joint economies of learning. But savings from such economies are limited in that most space companies are nationally confined and, like military equipment, subject to export restrictions. In countries like the U.S. this falls under the rubric of International Trade in Arms Restrictions (ITAR). In Europe, under the Wassenaar Agreement and under national legislating, the situation has come to the point where industry associations are openly calling for a streamlining of procedures, at least for the intra-EU trade.[4]

Military and security concerns have led governments to support space autonomy as a critical objective. Consequently, a limited number of products are produced by many national industries, leading to fragmentation and multiplication of effort. Product manufacturing is subject to high R&D intensity and high fixed costs, and production methods are customized in nature rather than mass produced. Mass production is the exception, with the best examples occurring in Germany during world war two (e.g., the A4 or V2) and the Soviet Union/Russia (the Soyuz). In the Soviet Union, the high demand for expendable launch vehicles came about because of the then-limited image recording technologies (prior to the displacement of film by digital methods) requiring remote-sensing satellites to carry film onboard which, upon reentry, would be retrieved by intelligence agencies. The satellites' life time therefore was very short but, economically, made mass production of launch vehicles feasible. In time, of course,

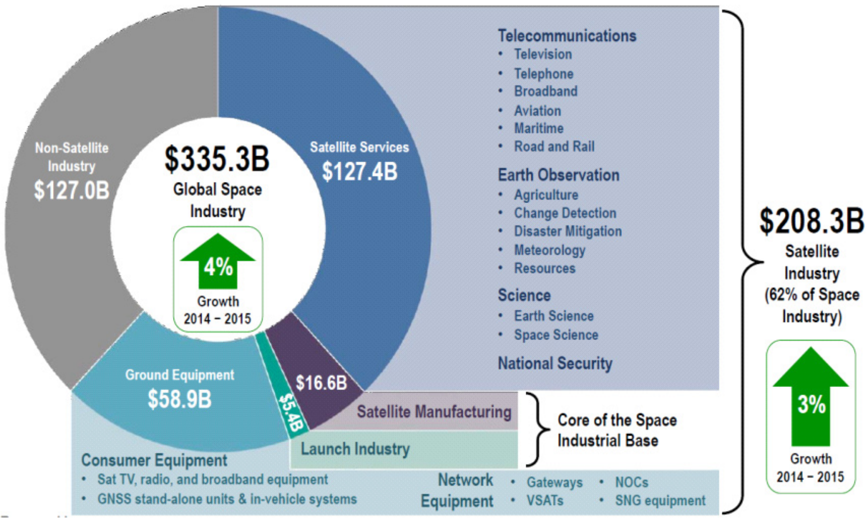

Figure 1: The global space industry. Source: SIA (2016).

digitization and encrypted image transmission led to changes in satellite technologies that shrank the relevant demand for launchers.[5]

Regarding space-based services, the most developed pertain to telecommunications. During early satellite development, Intelsat was formed, an intergovernmental consortium comprised, for the most part, of national telecommunication monopolies. Its natural monopoly status for fixed-satellite communications reflected significant scale effects. With technological change and the commercialization of telecommunication services and organizations, the consortium lost its natural monopoly status and became but one of today's major telecommunication service providers such as SES and Eutelsat.[6]

Perhaps the industry's most visible activity is launch vehicle manufacturing and satellite delivery services, followed by satellite manufacturing and ground support equipment and supplies. Yet launch vehicles account for but a small fraction of turnover. In 2013, this was USD5.4 billion worldwide, compared to an industry total of nearly USD260 billion. Indeed, the definition of the space sector is itself neither uncontroversial nor uniform, as shown in Figure 1. Collecting space industry-related data is challenging because of the limited number of standard industrial classification codes assigned to the sector and because space business is often embedded in defense-aerospace consolidated figures in Europe and in the United States. International data collection also suffers because different classification systems are in use and because of security considerations and the noncommercial nature of many space activities. Effectively this means that aggregation and cross-country comparisons, for instance for purchasing power parity measures, become problematic.[7]

In the early 2000s, following the end of the cold war, the U.S. industry consolidated into two main space integrators, Lockheed Martin and Boeing. Meanwhile in Europe, Airbus (satellites and launchers) emerged along with TAS (satellites), OHB System, and others. European consolidation took place in two discrete steps. First, national champions emerged in countries like Germany, Spain, and the U.K. Second, these then merged into cross-national corporate entities (e.g., the French-Italian TAS, the French-German-Spanish-British Airbus' Space Systems, and the German-Italian OHB System). Despite this, the companies mostly maintained their national production plants. Due to technical differences among satellites, launchers, and aircraft, other countries, like Russia, have kept their space and aerospace businesses separate.[8]

Airbus and TAS employ about 60 percent of the total space industry's labor force (about 38,000 employees in total versus an estimated 250,000 in the U.S.). Another 20 percent are distributed across OHB System, RUAG, Telespazio, and Safran, with the remainder dispersed across a number of smaller firms. Apart from the key manufacturers, launch-service providers like Arianespace and leading telecommunication service providers like Eutelsat and SES/O3B form the core of Europe's space-related industry, notwithstanding the fact that institutions like ESA maintain their own manufacturing and technical facilities (ESTEC), as is habitually the case in the space sector. Arianespace's main product line is the heavy-lift Ariane 5 launcher (manufactured by Airbus-Safran Launchers, a joint venture between Airbus and Safran) and the lightweight Vega, with the medium-weight Soyuz-Frigate (a Russian-based launcher) complementing the spectrum of launchers from French Guiana's launchpad facilities. Intelsat and SES/O3B, based in Luxembourg, are the leading civilian telecommunication service providers, followed by Inmarsat, Eutelsat, and others.[9]

Leading telecommunication service providers, like SES, increasingly carry government payloads of a dual-use nature onboard their satellites. The dual-use nature of satellite telecommunications is illustrated by the use of private finance initiatives—which despite their name are a form of public-private partnerships. For example, Paradigm Secure Communications (currently owned by Airbus) was set up to own and manage the U.K.'s Skynet military telecommunication system and allocate spare capacity to commercial markets, while also serving NATO needs. The entry of Airbus into the telecommunications service sector, and the links between civil telecommunication operators and military payloads, highlight the integrative nature of the main companies, with fuzzy limits between manufacturing and service provision and between military and commercial work at the corporate level. This is not unique to telecommunication services. Remote sensing, for instance, also sees expanding business for imaging value-added services taken up by service subsidiaries of satellite manufacturers. Similarly, remote satellite servicing extends to areas of specialization with, presently, a French dominance in optical systems and a German focus on radar technologies.[10]

All this suggests that in regard to manufacturing the European space industry is in the midst of further changes in its corporate governance regime—led by heightened competitiveness in global launching services—while still being heavily influenced by ESA's *juste retour* approach whereby national delegations at ministerial conferences support programs and allocate appropriations by considering industrial competitiveness factors along with country-based security and social needs. This has profound implications for the choice and processes of the programs followed, and also for the industrial structure, conduct, and performance of firms dependent on collaborative institutions and alliances.

The government-institutional framework and its alliance and strategic implications are examined next.

Market failures

With the end of the cold war, an initially reduced demand for military space applications saw a move toward civilian arenas, spearheaded by efforts to commercialize and develop new space markets and activities. The example of Intelsat was described earlier, but the flagship programs of the early 1990s were associated with space-based mobile telecommunications whereby (prior to the advancement of terrestrial networks) satellites were the driving force in mobile telephony architectures. The bankruptcy of the Iridium cellular satellite network in the early 1990s proved to be a turning point in the fortunes of satellite-based communications. The underlying technical challenges associated with direct-to-satellite links (energy requirements, line-of-sight), pressures for national control of telecommunications, and the economic return provided by auctioned frequencies all played key roles in the decline of satellite-based mobile communications and the subsequent mushrooming of terrestrial networks.

The recent emergence, predominantly in the United States, of so-called "new space" endeavors driven by an international class of high-net worth individuals such as Jeff Bezos (U.S.), Elon Musk (South Africa), and Richard Branson (U.K.), alongside traditional space integrators, has renewed interest in the commercial development of space through civilian applications, particularly the exploration and colonization of celestial bodies. Some of these endeavors reflect infant industry characteristics in that despite private funding directed to the development of new space capabilities like launchers, the main customer and supporter of technological know-how is the public sector. The role of government is therefore instrumental and deserves attention. Concentration in the industry, resulting from economies of scale and scope, is limited by government security concerns in a manner similar to the defense industry, but with the same companies serving commercial markets and operations of critical importance to the overall economic network. In addition, spin-offs from space programs are seen as vital to lead to high-tech economic growth and development, while space assets are crucial in supporting networks of high economic value and also for security/military operations. Space-based positioning signals are supporting digital-age applications found in logistic chains and commercial devices in their unencrypted form, while the encrypted, military ones are instrumental for precision military operations alongside remote sensing and telecommunication information that form the backbone of command, control, communication, and intelligence systems.[11]

Such externalities and public good effects, as well as the security concerns, provide justification for governments to support the industry. Efforts to commercialize space capabilities, technologies, and assets depend to a great extent on governments to create demand conditions that will support newcomers, given the high minimum efficient scale found in production. Thus projects tend to be privately funded but government dependent, following a national autonomy model rather than an international business one. For example, SpaceX—a prominent firm—is calling for a bigger market share of U.S. government payloads based, in part, on an argument of U.S. autonomy and independence from Russian rocket engines supplied to its U.S. competitors.

Plans of internet companies such as Google and Facebook to build large constellations of satellites that would operate in layered orbits to provide access to internet and communications on a global scale would seemingly act in competition with existing architectures (SES/O3B and others). This carries internet governance implications, but is otherwise similar in nature to the Iridium experience mentioned before. Yet nationally confined industrial partnerships with firms that would develop such networks could or would also render security services—as described by the military-Operationally Responsive Space (ORS) or other relevant doctrines—at lower cost while offering increased security and overall economic benefits.[12]

In dealing with the industry, governments and their space agencies tend to act in what can be characterized as a two stage process. In the first stage, general decisions and appropriations are determined. Agency and industry share similar objectives in government bids. In the second stage, however, the space agency is supposed to share the government's objectives of rent control and cost minimization in industrial contracts. This is a key element of the space-industrial complex and reflects principal-agent relations that have developed over time.

In Europe, the intergovernmental nature of ESA presents significant challenges. In view of the high R&D-to-production cost ratio and the typical low technology-readiness levels at the feasibility stage of space projects, fixed-price contracts would seem unsuitable compared to cost-reimbursement ones. The latter would necessitate a structured monitoring mechanism similar to the those found in U.S. federal procurement policies such as the Earned Value Method System. In the past, however, fixed-price types of contracts have been extensively used by ESA, to be modified *de facto* by Contractual Change Notices in later stages of the contract life cycle. To avoid this high-transaction cost practice, novel contractual mechanisms have been developed. One of these is the Ceiling Price to be Converted to Fixed Price-type of contract. It contains a maximum price liability clause, followed by a fixed-price contract for the later, more mature, stages of a project's life cycle. The political objectives underlying the negotiations within ESA's ministerial council—comprised of representatives of all member states (over 20 countries)—would, or should, have much to do with the challenges associated with monitoring cost-reimbursement contracts. More importantly, the process is likely to give rise to significant bureaucratic power in view of the inflexibilities associated with the infrequency of meetings and also with the size of the governing ministerial body. Added to this is the lack of transparency, in terms of public information disclosure, as all member states would have to agree for the relevant figures and information to be released.[13]

The importance of ESA's role in the European space-industrial complex has become clearer with the recent policy of institutionalizing its involvement in the selection of lower-tier contractors by the prime in the contracts it manages. While this has allowed ESA to control the distribution of value-added according to the *juste retour* principle along the value chain of the industry, this arrangement is expected to raise issues of lack of accountability (within a principal-agent framework) of the prime contractor.[14]

Public policy clearly is instrumental in determining the structure, conduct, and performance of the industry. This is apparent in Europe's success in commercial launchers (which has overshadowed failures in its space programs, like Hermes), which resulted from an aggressive European presence in commercial markets and a clear export orientation. This was borne out of necessity as the European markets were limited in size, relative to the United States, and an inter-NATO alliance specialization that had been taking place. Given the cost characteristics discussed earlier, European industry in the commercial space markets was at a disadvantage relative to more experienced players such as the U.S. and Russia. Policy and incentive alignment seem to have been critical in reversing this. Specifically, the U.S. policy of supporting the Space Shuttle (STS) in its early stages of operation at the expense of expendable launch vehicles (U.S. Delta, Atlas launchers) led to a period where commercial markets were best serviced by the most suitable expendable launch vehicle that remained on the market, the European Ariane 4. As the U.S. space industry enjoys a lucrative domestic military and civilian market, the country has less of an incentive to participate in the competitive commercial markets than its European counterparts.[15]

In recent decades, space agencies have included in their mandate an objective concerning the enhancement of industry competitiveness in commercial markets. This has led them to develop market-enhancement institutions for relevant technologies, even in the absence of a proper market mechanism. Thus, for example, NASA and ESA are involved in the transfer of technology and play a supporting role for entrepreneurial activity through activities such as licensing, release of experienced technical personnel and facilities to private industry, and specialized incubation centers to support innovation and entrepreneurship. As part of defense, military space budget appropriations are covered under the DoD budget in the United States, while in Europe, national space agencies and multilateral programs are of a more fragmented nature. Thus, ESA's enhanced skills and institutional facilitation led it to take on, along with the EC, a more defense-oriented role through security-related programs and projects, with resulting governance and access issues. Increasingly, ESA thus finds itself at the center of economic activity, much of which it directly controls, including the selection and evolution of winners and losers, often beginning with any project's start-up stage. Thus the public sector, through its bureaucracy, determines the structure, conduct, and performance of the sector throughout the supply chain, along with its overall development path.

Specialization in alliances: Military space and hegemony

As noted, much of the consolidation and centralization of space efforts have been driven by collaboration at governmental level. It has also been driven by action at the industry level, to avoid duplication and to maintain efficiency. The resulting alliances and institutional partnerships like ESA, NATO, or within the EU, while necessary developments, do not always work as expected. An alliance can be compromised by hegemonic behavior within a group and may enhance autonomy rather than specialization. Rivalries and duplication can result. This is evident in the development of European strategic capabilities in areas traditionally served by U.S. assets within the NATO alliance (space-related, mostly, such as geopositioning services like Galileo). While supported on the grounds of commercial competitiveness, they have been controversial. As Europe develops its security capabilities, frictions arise within single-body institutions like ESA as a result of domestic policy pressures and the different security concerns of the constituent countries. This adds systemic costs of partnerships to the generic collaborative costs in projects.[16]

Allowing for strategic interdependency within alliances, behavior that considers others' welfare as affecting one's own, complicates economic analysis. For example, when Europe's Galileo system introduced its civilian services, the cost of commercial market space-based, radio-navigation positioning services fell. Thereupon, the U.S. abandoned its policy of quality-restricting its military GPS signal for commercial use. Altogether, this not only significantly decreased costs for civilian users who did not use terrestrial signals or other techniques to augment positioning accuracy but (probably) also increased U.S. *military* costs. The reason is that what matters for the U.S. military is its position *relative* to a rival who is now assumed to be enjoying a commercial-quality signal. This can be jammed, but at an additional cost to the U.S. military. Or, as two analysts commented: "From a techno-nationalist, geostrategic perspective Galileo is an indicator of power. But it does not, nor is it intended to, place Europe in competition with the USA as a global military power. It does, however, impinge on a strategically important area in which the USA has previously dominated."[17]

Within NATO, overlapping competencies caused by hegemonic instability and challenges lead to duplication and potential rivalries. On the one hand, while some space assets are not entirely of a pure public goods nature, significant discretion remains in regard to sharing space-based assets and related information. On the other hand, going one's own way results in duplication costs and challenges inter-alliance specialization that can lead to rivalries within. European calls for autonomy and independence from reliance on U.S. launchers were behind the development of European launch activities and the early development of the Ariane family of launchers, but the more recently development of Galileo was based on arguments regarding signal security, i.e., not having to rely a U.S. GPS system for European security and economic activity. This led NATO to affirm its exclusive use of the U.S. GPS as its positioning service provider, with Galileo used for related services on frequencies initially intended to overlap with the U.S. military ones. Thus the U.S. would find it challenging to locally jam the Galileo signal without also compromising its own capabilities. This "case study" indicates how specialization is critical for alliance performance and stability, yet also benefits the participants.

By analogy, the ESA experience was based on the development of technology and exploration of space with data and goods of a public good nature among the participating members. The now-expanding nature of ESA into a promoter of economic benefits to industry and developer of security systems will challenge this public good nature. Development of business incubators and selection of programs based on commercial returns and industrial benefits to member states inevitably will lead to resource allocation patterns that skew benefit distribution among members. This, in turn, carries implications for the affected industries that are competing in commercial markets. By introducing commercial/industrial enhancement and competitiveness objectives both at the level of program selection and at the level of technology diffusion, new rivalries may emerge while specialization becomes critical for the commercial competitiveness of member states. This may, again, lead to cost duplication and rising instability as already experienced within NATO.

Conclusion

As networks and systems in the broadly-understood security and commercial sectors continue to grow, outer space is becoming ever more important to earthly commerce and governance. An extensive, ongoing discussion surrounds the "new space" initiatives in the United States, how they would affect efficiency and what would be their implications for the wider space sector. At least some of the impetus for these developments has been the speed of developments in space technologies and capabilities from space-faring nations in general and new actors, such as China, Russia, India, and Japan in particular. Historically, European space efforts are characterized by military reliance on the alliance with the U.S. within NATO. At the same time, civilian and security developments are taking place at the EC and ESA-levels, complementing commercial space activities and orientation. Interestingly, Europe has been able to show more autonomous behavior within the NATO alliance through its Ariane program and, more recently, through its partnership, with China, in the early stages of the Galileo program and, with Russia, in the marketing of Soyuz. (Among others, Russia and China also are engaged in developing partnership with countries such as South Korea for launching and satellite technologies.) The intra-European dynamics are important to the economic health of the sector, but the processes to choose partnership arrangements and the selection of future programs are neither transparent nor obvious in terms of their dynamics. Given the implications for the relevant industries, and also for the wider economic and security arenas, further analysis of the inter-European (ESA) and inter-NATO alliance specialization is crucial.[18]

In sum, this article has examined the space-industrial complex. The intra-European dynamics (e.g., ESA and the industry) and inter-alliance dynamics (i.e., NATO) are related and at a crossroads in view of developments both within Europe—as the EC becomes more engaged in space-security and other matters—and as global partnerships and heightened capabilities emerge. Reconciling the tensions among military, commercial, and wider economic objectives, where efficiency is considered as more important than relative political gains, is an important focus for future research. This is made difficult by the role of the public sector and the lack of transparency in the space-industrial complex. Finally, inter-alliance implications for efficiency and competitiveness of the contributing partner industries, whether within inter-governmental space agencies like ESA with significant security-enabling undertakings, or defense organizations such as NATO, need to be better understood.

Notes

The author thanks the editors and an anonymous reviewer for helpful comments and suggestions. The usual disclaimer applies.

1. Defense policy: See, e.g., NAS (2016) for the security challenges and implications of space. Besides defense criticality, for space-faring nations space and aerospace are also perceived as economically critical, including export performance, with interactive dynamics between these two areas (see Hartley, 2014; O'Neil, *et al*, 2016; *TehranTimes*, 2016).

2. Negligible exceptions: Whereas civilian space collaboration in Europe is institutionalized at the EC and ESA levels, collaboration in military space activity is episodic and fragmented on account of changing time-limited partnerships at the bilateral and multilateral levels (see, e.g., Pasco, 2009). Notable military space programs and budgets in Europe are those of France and the U.K. (The anticipated withdrawal of the U.K. from the EU might lead it to reinforce its space capabilities and industrial base, both at national and collaborative levels.) The EC and ESA are increasingly involved in security-related space arenas, while evolving their roles and relations within Europe and at a global level. Recent calls for the establishment of a "Govsatcom" partnership have been made (Henry, 2016).

3. ESA's initial mandate: ELDO, the European Launcher Development Organization, and ESRO, the European Satellite Research Organization, merged in the 1970s to form today's European Space Agency. NATO's support: Zervos and Siegel (2008). Copernicus: Until recentluy, Copernicus was known as Global Monitoring for Environment and Security (GMES). It comprises the European contribution to the Global Earth Observation System of Systems (GEOS). Copernicus is a partnership between the EC and ESA and is an Earth observation program using data from about thirty satellites mostly related to remote sensing, scientific, meteorology, and others purposes of military, civilian, and commercial pedigrees.

4. Economies of learning: See Zervos (2001). Streamlining: See EC (2016).

5. Expendable launch vehicles (ELVs): They are one-off launch systems employed for space transportation purposes such as satellite payloads. This is similar to intercontinental ballistic missiles (ICBM) where the payload is one or more warheads. Based on ICBMs, EVLs exploit economies of scale and avoid R&D duplication. Elements of ELVs have historically been re-used in the case of manned spaceflight (, e.g., the capsule module). More recently, modules are being used to reduce launch costs by private companies like SpaceX, Blue Origin, and others. Fully reusable launch vehicles (RLVs) have not yet been widely developed, but semi-reusable ones have, like the space shuttle system (STS), Buran, and the more recent unmanned X-37. Custom versus mass production: In contrast, the European Arianespace's Ariane 5, for example, has a serial production capacity of about 7 to 8 launchers per year.

6. Natural monopoly: Snow (1987).

7. Turnover: OECD (2014). Definition of space industry: See Zervos (2001) for a review of space industry-related data and figures. Standard industrial classification code: Space industry definitions vary, with space-based services sometimes included in the estimation. For example, positioning services from GPS signals can be used to qualify terminal applications like bank ATMs or mobile phone devices.

8. OHB System: Originally, Otto Hydraulik Bremen GmbH (OHB). Today, the name of the overall group is OHB SE, with a space division and an aerospace and industrial products division. It is still headquartered in Bremen, Germany.

9. Employment numbers: Eurospace (2016). Arianespace: As of December 2016, Arianespace is majority-owned by Airbus and Safran, with the passing on of shares previously held by the French national space agency, CNES. See Arianespace (2016).

10. Dual-use: See Defence Industry Daily (2015). A similar fusion among commercial, military, and government civilian services is experienced in the less commercially developed Earth observation market (i.e., remote sensing) through relevant partnership arrangements and also through reliance of military services on commercial entities (e.g., U.S. Digitalglobe). Airbus includes such services in relevant satellite constellations, while in the U.S. the policy has been to promote commercialization of remote-sensing data services since the 1980s through various acts of law (e.g., the Land Remote Sensing Commercialization Act of 1984).

11. High-net worth individuals: The entrepreneurial approach to space program development now has extended to Europe and other countries, e.g., China, where individuals contemplate investing in space technologies and development (de Selding, 2016). Overall economic network: Commission (2001).

12. ORS: The U.S. DoD's operationally responsive space doctrine calls for fast response times in space development and the replenishment of assets in case of a "space Pearl Harbor." This carries profound dual-use implications (see Butler, 2015; ISU, 2010; Commission, 2001).

13. Principal-agent relations: Zervos (2001).

14. Lack of accountability: Zervos (2015).

15. Export orientation: Export contracts resulted also from the need to maintain autonomous access to space for defense (satcom, Earth observation) and the need to preserve industrial and technological competencies for deterrence when military production was stopped. Competitive markets: Zervos (2001).

16. Driven by collaboration: In addition, given the public perception of space as a civilian technological enabler, the space sector has also been able to act as a political mechanism to enhance security and cooperation among political adversaries (e.g., the Apollo-Soyuz docking in the 1970s). Duplication and rivalries: In that respect, rivalrous, or precautionary behaviors, even within alliances, would call for duplication of assets and development of autonomous capabilities. Systemic costs: Hartley (2014).

17. Galileo: The high-precision signal that is commercially available in mobile consumer devices mentioned earlier is a spin-off from an all-military positioning program that started in the U.S. (NAVSTAR-GPS, also initiated in the USSR as Glonass; both are operational today) several decades ago. Until the 2000s, the military exercised selective availability for civilian purposes. This was to prevent potential adversaries enjoying the same level of information as the privileged encrypted military signal. To a lesser degree, the difference in signal properties and quality continues to this day. Selective availability and control over commercially sensitive assets was the backbone of the European argument to develop its own commercially-oriented system, Galileo. For analysis, see Zervos and Siegel (2008). Jamming: Clearly, in evaluating the relative costs and benefits from commercializing signal technologies, the economic benefits from accurate positioning for the whole economy are expected to create wealth, and tax revenues. These benefits might well compensate for the cost of jamming or other perceived losses of positioning-related military advantages over adversaries. Quote: Johnson-Freese and Erickson (2006, p.18).

18. Extensive, ongoing discussion: See, e.g., NASA (2014); ASAP (2014). Soyuz: Arianespace is the only major company that is launching foreign launchers from its launch center in Kourou, in French Guiana, having built specialized facilities and purchasing batches of Soyuz to this purpose. Dynamics: ESA follows a decisionmaking approach based on a ministerial conference where relevant programs and budgetary appropriations are decided. However, in terms of following up on programs, decisions and processes, besides limited transparency (certainly, as compared to NASA) on contracting information, there is also limited exposure of significantly delayed, or cancelled programs like Galileo or Hermes. Galileo experienced significant cost overruns and delays, but also saw the withdrawal of private sector actors and the reprofiling of the venture as a public partnership with the EC. As for Hermes, the famous Ariane 5 program that appears to be rather uncompetitive in terms of price and cost for commercial operations. Initially built to support a manned ESA space program with a small scale "space shuttle," called Hermes, it was eventually cancelled. The U.S. is relying on its Government Accountability Office (GAO) to control processes and ensure transparency, with program decisions to cancel or approve dependent on the political process. In Europe, ESA has instigated the institution of the inspector-general, but with minimal public transparency owing to the intergovernmental nature of ESA.

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The European defense market: Disruptive innovation and market destabilization

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Abstract

The global defense industry is shifting toward a new paradigm in which an emphasis on technology-driven capability development is being undermined by disruptive innovations emanating from the commercial sector. This evolution is likely to result in important effects on the defense market, lessening barriers to entry and turning upside down the approach to innovation. For the defense sector this entails that shifts in the organizational behavior of firms and military establishments are required if the full benefits of innovation are to be captured and integrated into defense capability development processes. This article analyses this shifting paradigm with the European defense market as a departure point. Briefly exploring the shifts in defense industrial processes since the 20th century, this article outlines the benefits of integrating the defense and civilian technological and industrial bases.

One branch of defense economics looks at defense equipment markets. Usually, this is done sector by sector and focuses on a category of capabilities so as to understand the viability of companies in a given market, the level of competition, or the effects of international sales. During the cold war era, defense markets were marked by a degree of stability, as underlined by the theory (or, at least, the story) of the military-industrial complex. Indeed, most changes in the equipment markets were related to issues such as market concentration, the balance between supply and demand, or export competition.[1]

But exogenous events can alter the functioning of defense markets beyond the endogenous behavior of firms or the policies of their customers, and this dimension of markets has been almost completely underestimated over the past decade or two. Markets have progressively given way to a new understanding, based on increasing levels of innovation in defense capabilities. Since the beginning of the 21st century three dimensions seem to have profoundly modified the dynamics of defense markets. First, some of the dominant technologies involved in aeronautics or land vehicles such as combustion engines, aerodynamics, alloys, avionics, composite materials, and communication systems have become increasingly difficult to improve. Second, due to the weight of asymmetric conflicts and disruptive innovation in terms of capabilities [e.g., hypervelocity or Anti-Access/Area Denial (A2/AD)], the demands on military forces have moved toward new kinds of capabilities and innovation. Third, the relationship between defense and manufacturing activities is evolving due to an ongoing transformation of the core dimensions of industry.

All these dimensions are intrinsically linked to innovations that affect both the demand and supply sides of the market. Therefore, it is impossible to understand the evolution of the European defense technological and industrial base without considering the dynamics of innovation in defense capabilities. In particular, defense innovation and disruptive technologies have the potential to alter systems design and manufacturing processes. Technologies such as robotics and artificial intelligence can lead to new defense technologies and industrial processes. European defense technological and industrial bases have been characterized by stability since the 1960s, since mergers and acquisitions did not truly modify the fundamentals of the industry. Today, however, one can expect that a radical transformation of the defense industrial base is possible and, to a certain extent, mandatory, if the needs of militaries are to be met. Thus, it is important to understand the fundamentals of this transformation.

To this end, this article is organized into three sections. First, it looks at the historical evolution of defense innovation and charts how the defense market has changed since 2000. Second, it analyses how military-industrial actors can behave within a context of transformation and disruptive innovation. And third, it moves to a broader analysis of industrial change. It examines how the European defense market can adjust given the industrial changes being experienced in many developed economies, often labeled as the Fourth Industrial Revolution or Industry 4.0. With an eye to the future, the article then concludes with reflections on how Europe could position itself in the global defense market in the coming years.[2]

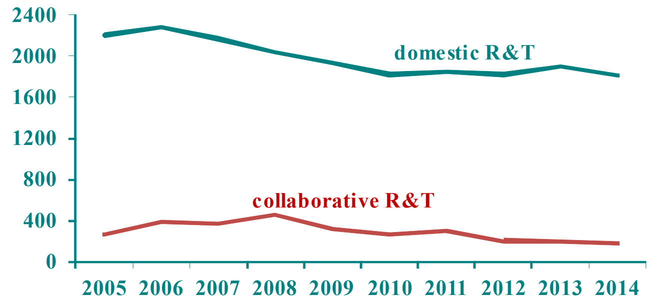

Figure 1: European defense R&T, 2005–2014 (EUR millions)
Source: Statistical database of the European Defense Agency.

The global defense industry is entering a new paradigm in which the current emphasis on technology-driven capability development is being undermined by disruptive innovations emanating from the commercial sector. This likely lessens barriers to entry and changes the sector's approach to innovation. Shifts in the behavior of defense firms and military establishments are required if the benefits of commercial innovation are to be captured and integrated into defense capability development processes.

The drawbacks of a technology-driven defense industry

Innovation always has played a major role for military dominance but the 20th century was marked by a particularly rapid evolution of defense capabilities. Prior to world war one, soldiers could spend decades, even their whole careers, using the same equipment. But between the world wars, scientific progress and innovative defense systems emerged, merged, and solidified. This convergence bled over into the cold war era, a period of time characterized by a technological arms race in which arms-producing countries invested heavily in R&D to achieve dominance on account of technologies with incredible military potential.[3]

Since they are responsible for national security, militaries expect to have an industrial and technological base at their disposal to deal with crises (not just with security of supply). Some production units are seen as strategic resources and have to be preserved through continuous, follow-on contracts. The follow-on principle has two main consequences. It permits *technological continuity* in defense capabilities because of the growth potential of such technologies and, thanks to their mastery of the predominant technologies, it provides the main arms-producing companies with a degree of *commercial continuity* and stability. For instance, the French Rafale aircraft is a next-generation platform derived from the Mirage 2000. Its development was launched when the Mirage 2000 entered production in the late 1970s. The strong technological continuity between both systems was explicitly conceived for two reasons: to maintain strategic dominance through state-of-the-art systems and to preserve industrial capabilities.[4]

Continuity does not mean that significant improvements between two generations of platforms are absent. Major improvements do take place along a technological continuum and successive systems are positioned at the front-edge of many technologies that characterize the platforms they replace. But continuity does go some way to explain why the military-industrial complex "has endured for several decades, in some cases dating back to the second world war, despite the ebbs and flows, the booms and busts in defense spending." The follow-on principle introduces a procurement bias; it induces a tacit agreement among government, military, and defense companies, and it leads companies to promote the renewal of existing systems that are based on assets, technology, and know-how they already master.[5]

Already in the 1980s, however, it became clear that this model of interaction between militaries and firms resulted in several shortcomings. Even though advanced technologies can support missions and help maintain strategic dominance for arms-producing countries, defense R&D became increasingly expensive while generating fewer disruptive technologies. In 1985, one pair of authors calculated that the real unit cost of major arms systems had increased by 6 to 13 percent annually since the end of the second world war. Similarly, more than 20 years ago, another author pointed out that incremental defense R&D innovations within existing technology trajectories are increasingly difficult to achieve, and at increasing cost. Today, virtually all modern defense programs related to complex systems are encountering major challenges concerning either technological developments or budgetary targets.[6]

In part because of cost reasons, most arms-producing countries have become progressively unable to sustain a purely domestic defense industrial base. In Europe, this is reinforced by decreasing domestic budgets for defense R&D since the end of the cold war. But neither have European arms producing firms engaged in much cross-country cooperation to share the costs of developing new advanced systems. For example, data from the European Defense Agency (EDA) for domestic and collaborative R&T (research and technology) show a slight decline since the 2008 global economic and financial crisis which deeply affected European defense spending and led to the subsequent imposition of austerity policies. Both national and cooperative R&T is declining across this period. But the data also show that European countries appear unable to consistently engage in collaborative efforts (see Figure 1). They thus appear to maintain the domestically-based model of follow-on innovation inherited from the cold war.[7]

As defense R&T (as well as the larger rubric of defense R&D) investments have decreased, one wonders if continuing such investments is still useful for achieving the expected innovation levels. The defense economics literature shows that the effectiveness of defense R&D results from both the spending *level* on a given technology as well as from how this spending is *managed*. In fact, threshold effects result from the evolution of defense-related technologies. One pair of analysts who explored investments in integrative technologies in a dynamic optimization framework find that under nonlinear, convex development costs it is not optimal to build military forces using a myopic, short-term approach. In other words, it is difficult to transform the military within just a few years. Consequently, early investment in technology infrastructure is required because the entry cost is high and the transformation period ranges over more than a decade. If a country's investment in a given technology is too limited, it cannot expect to keep pace with the state of the art, and it is not worth investing in that technology in the first place. The EDA data shown in Figure 1 would seem to bear on this argument and suggest that defense R&D is not optimally used because resources are fragmented throughout Europe rather than pooled among committed countries to leverage scale effects.[8]

Beyond the technology argument one needs to probe the cost argument to understand the limits of today's defense R&D. Specific market features lead armed forces to struggle with a situation in which rising unit costs result in a symmetrical reduction of quantity. Reports from public audit offices in France (Cour des Comptes), the United Kingdom (National Audit Organisation), and the United States (Government Accountability Office) show that governments or their militaries often choose immature or unproven technologies even if they jeopardize the delivery of capacities and when the technology specifications are not essential for achieving most military requirements. A systematic bias in defense procurement favors quality even if this results in a reduced quantity of systems. An industrial environment is nurtured in which enterprises are encouraged to promote advanced technology rather than minimize unit costs. Today's upward drift in R&D costs thus continues to reflect the business model that has characterized the defense industry since world war two. Much of the blame should be put on the technology-centric paradigm that defines the essence of this industry.[9]

The endless quest to stay on the technological frontier becomes less sustainable when the underlying technologies mature. Today's major defense capabilities rely on technology born from the 1920s (e.g., aeronautics) to the 1960s (e.g., electronics, computer science). But because incremental performance comes with complex solutions, technological uncertainties, and numerous problems during the development stages, it has been suggested that any 5 to 10 percent of additional performance results in a 30 to 50 percent increase in extra cost. For various kinds of platforms, procurement costs have increased at an intergenerational real-cost growth rate of 4 to 8 percent. The desire to procure next-generation technology is a key driver of cost escalation, which to a large extent explains the dynamics behind one of Augustine's laws.[10]

In our view, the currently predominant defense technologies have reached a cost plateau. As it becomes increasingly difficult to improve on already-achieved performance *within a given technology envelope*, any additional improvement inevitably comes with higher marginal cost and limited operational benefit. R&D efforts concentrated on the marginal increase of technological performance absorb a large share of investments. To address the capability needs of armed forces, this does not mean that there is no need for innovation in the field of defense. It just means that the core question should not be *if* but *how* to innovate. Simply targeting all available R&D resources on the improvement of *existing* systems (technology envelopes) appears not only difficult but inadequate and inappropriate in regard to the effective needs.[11]

Additionally, the defense technological and industrial base (DTIB) can no longer operate in a vacuum whereby it develops capabilities with limited interaction with the rest of the economy. Many commercial sector innovations possess potential applications to defense systems. As defense-related technologies themselves have reached a plateau, the industry has to look for technological inputs from outside the DTIB and focus on (re)combining existing component knowledge through innovative knowledge architecture. In their foreword to a recent book on *Creative Disruption*, William Lynn and Adm. James Stavridis note: "Google's recent acquisition of Boston Dynamics, a DARPA-funded organization that develops some of the world's most innovative robots, served the Pentagon with an unsettling notice: the centre of gravity in cutting edge, military applicable research is shifting abruptly away from the defense establishment to relatively new commercial firms with loads of cash to invest."[12]

'Ostriches' cannot survive in a transformative market

The defense sector is not immune to the broader technological evolution taking place in the commercial sector. Disruptive innovation may alter the defense sector in profound ways. Technologies such as nano- and biotechnologies, robotics, artificial intelligence, and new forms of advanced manufacturing can greatly affect the development of new and existing weapons technologies. Advanced manufacturing in particular may play a significant role in how the defense sector functions in the future. Innovative new production processes, such as 3D/4D printing and ongoing miniaturization, challenge existing processes and the manufacturing time scale. They may lead to more resilient and flexible components, could provide more production flexibility in general, and could possibly lead to mass manufacturing right on the battlefield.[13]

If it is correct to suggest that disruptive innovation is about "new suppliers dealing with new customers," challenging questions are raised for a defense sector traditionally marked by monopsony. Importantly, disruptive innovation affects both military and defense-industrial transformations, but these do not necessarily coincide. Adaptation need not be synchronized and thus can disrupt established customer-supplier relations in the defense sector. So the challenge of the sector lies not only in the task of generating innovative products *per se* but also in its ability to adapt new commercial technologies for the benefit of its military customers.[14]

An additional challenge is that new technologies tend to have a knock-on effect for services and business models, too. They do not always imply a concomitant shift in business models, of course, but it is important to note that government agencies and firms can alter policy and business practices, respectively, in response to disruptive innovation. Since the defense sector traditionally has not been as responsive to innovation as the commercial sector has been, much scope exists for military-industrial actors to rethink the ways in which they generate, capture, and use new knowledge.[15]

Despite the fact that prime contractors focus on high-value activities such as systems integration and defense R&D, the traditionally closed-off form of technology development within the defense sector no longer reflects present and future market realities, and most military establishments do not possess a monopoly on technology advances anymore. Given that most disruptive technologies now emanate from the commercial sector, emphasis should be placed on breaking into the commercial R&D realm. Crucially, defense industry and governments must refocus their energies on *technology integration* rather than *technology production*. This is no easy task but heralds a complete shift in the required behavioral and/or organizational dimensions of defense procurement and defense innovation if the defense sector is to benefit from disruptive innovation. Also note the inherent misalignment between the standard time-horizon for defense procurement (10 to 30 years) and the break-out of disruptive technologies (usually far fewer years). The required behavioral shift presumes that military-industrial actors can effectively integrate disruptive technologies into ongoing procurement developments as and when they emerge.[16]

For military-industrial actors, the advent of disruptive technologies emanating from the commercial sector poses a three-pronged challenge: first, how to integrate disruptive technologies into existing or planned capabilities in an effective and time sensitive manner; second, how to adjust organizational behavior to capture commercially-driven innovations; and third, how to foster relations between the military establishment and nondefense commercial firms and their research clusters (e.g., high-technology firms in Silicon Valley). None of these are easy to address and the second and third, especially, take on great relevance in a context where the broader industrial landscape is being reshaped. While the dual-use concept has been around since the cold war era as a way of linking defense and commercial efforts, the term veils the complex relationship between defense and commercial innovation. A successful relationship between the defense and commercial sectors requires each to understand better the socio-technical bias and approach of the other. This presumes willingness and ability to learn and to change behavior. Innovation is not merely and simply about inventing and producing technologies; it is equally—if not more so—about the learning processes of an organization itself.[17]

The new behavior that is required can be illustrated by thinking about decisionmaking within the procurement system. Traditionally, the hierarchical structure of defense ministries and procurement agencies has meant that individuals such as high-ranking military officials shape the military's attitude toward new military innovations. But having gatekeepers in place to encourage, direct, or dissuade technology integration in the defense sector runs counter to much of the literature and practice of Open Innovation, an organization's ability to combine internally- and externally-sourced ideas. Based on decentralized and fairly evenly distributed innovation management within firms, this form of innovation is a major challenge for a defense sector used to secrecy, the guarding of innovation, and maintenance of hierarchical control over decisionmaking.[18]

That said, a number of large and medium-sized defense economies are transitioning toward a more open approach to defense innovation. For example, the United States' Third Offset Strategy seeks to drive investment in paradigm-breaking technologies and to shift the mentality of the DoD. For multiple reasons, including the need to decrease overall personnel spending, the DoD is presently trying to bring its defense and civilian bases closer together. In addition to the work of DARPA, the establishment of a "civ-mil" innovation interface—called the Defense Innovation Unit Experimental (DIUx)—is opening hubs in places such as Palo Alto (California), Boston (Massachusetts), and Austin (Texas) to profit from commercial technology advances. The DoD believes that investment in technologies such as autonomous systems, robotics, and directed energy weapons will give the U.S. a military edge over its actual and potential adversaries and allow its forces to combat the proliferation of precision-guided weapons and A2/AD 'bubbles'.[19]

Yet despite this drive toward more integration between the commercial and defense technological and industrial bases, the DoD faces significant challenges in harnessing the disruptive abilities of firms located in places such as Silicon Valley. For one thing, many high-tech firms are cautious about what closer links with the DoD will do for their public image. For instance, when Google bought Boston Dynamics—a DARPA-funded organization—it ensured that none of its newly acquired robotics projects were being used for DARPA programs. Indeed, Google pledged never to pursue military contracts. Another challenge relates to intellectual property rights (IPRs). A dual-use system of innovation may leave space for an IPR regime that stimulates defense-commercial collaboration, but designing a regime that allows commercial firms to secure IPRs in a context where military establishments are loath to share IPRs is extremely challenging.[20]

It is not just the U.S. that is investing in defense innovation through closer collaboration with the commercial sector. Evolving defense innovation patterns in China, Israel, Japan, and South Korea also are important. For example, reform of China's defense innovation model began in the late 1980s with a view to fusing its civilian and military technological and industrial bases. (A prevalent element of its innovation effort has been to copy from other countries.) While its military development has not traditionally been at the high-end of the technology frontier, this fusion has led to an R&D push that has seen the rapid development of aviation capabilities such as the Shenyang J-31 stealth fighter. China's innovation model is geared toward leap-frog advances in the military domain based on an undisclosed amount of investment in defense R&D and copycat strategies. While China may require a few more decades to fully exploit science and technology, an emerging strategy has been to initiate a science education system aimed at inculcating science throughout the public system as well as to rapidly establish new commercial R&D hubs.[21]

Faced with increasing global competition in the defense innovation domain, Europe also must grapple with the military-technological evolution underway. The challenge for Europe is that its defense industry remains fragmented and that it suffers from chronically low investment on collaborative defense R&D. Interestingly, recent steps taken by the European Union (EU) to start investing in defense research has given rise to new possibilities for European defense innovation. While still on a relatively small scale when compared to the U.S., the EU is looking to invest EUR3.5 billion in defense research from 2021 to 2027. As a pilot to its defense research efforts, the EU has invested EUR1.4 million in three programs related to urban combat intelligence, detect-and-avoid sensors for autonomous systems, and autonomous nonlethal dissuasion technologies. Should these projects prove worthwhile, the intention is to invest a EUR90 million over 2017-2019 in further programs. The real added-value of this funding will emerge if investments lead to an integration of Europe's defense and commercial technological and industrial bases.[22]

Adjusting the defense sector to the overall transformation of industry

Innovation remains at the core of defense capability development. Even though the DTIB is no longer entirely driven by the trajectories of old technology envelopes, nor quite as subject to long-term planning constraints as in the past, new threats emerge and actual or potential foes can rely on a large and rapidly expanding knowledge base to create innovative military capabilities or threats. Therefore, the DTIB must reinvent itself so that it can respond in a timely and effective way to requests the military forces may express. This again raises the question of the convergence between the DTIB and civilian industry. Indeed, this question arose first in the late 1980s and early 1990s when the concept of the DTIB emerged. With the end of the cold war, defense budget cuts led to a crisis in the arms industry and resulted in industrial overcapacity. Although important, budgetary aspects turned out to be a short- to medium-term issue that masked the industry's long-term structural deficiencies. Segregation from the rest of the economy engendered inefficiencies and failures.[23]

Civilian and military technological regimes are supposed to have intrinsic properties that distinguish them from each other, primarily because specific user interests impose different technology requirements. This separation was reinforced by strict segregation of defense firms from the global economy to prevent the Soviet Union and its allies from accessing state-of-the-art western technologies. But protection also deprived the industry from receiving the benefits of civilian research and manufacturing. The concept of the DTIB was a means to help overcome segregation by favoring convergence with the civilian industrial and technological base. This one-sided approach was not entirely successful because convergence was thought of as a safeguard strategy rather than as a systemic transformation to really merge the defense and commercial industries. Today's DTIBs do have better leverage over civilian technologies and the commercial sector, and while these interactions contributed to the greater integration of civilian technologies into defense systems and to lower production costs, they did not, however, lead to an overall transformation of the fundamentals of DTIBs, both in conception and in production.

To an extent, the current setup of European DTIBs (as for most other arms-producing countries) corresponds to the optimal use of the industrial approach that resulted from the Third Industrial Revolution. It is characterized by a quite linear development approach in which technology evolutions are structuring a generation-based conception of systems, leading to a kind of planned obsolescence. Additionally, large sunk costs associated with system conception and production setup due to the complexity and specificity of related technologies imply that efficiency relies on industrial techniques of mass production whereby homogenous products are produced in large quantity, leading to volume-based barriers to entry. All this would favor incumbent companies and the follow-on principle approach. The key challenge, then, lies in adjusting the DTIB to a Fourth Industrial Revolution, one that is likely to induce radical changes over all dimensions of industrial activities. In a word, the defense industry must change if it wishes to respond to the expectations of the military and to the ways civilian industry operates. No longer can systems conception be based on planned obsolescence resulting in decade-long developments. And production volumes have decreased so much in DTIBs that mass production techniques appear less effective and very expensive.[24]

As a defense-oriented Industry 4.0 emerges, the rules of the defense market game are bound to change. The past stability of the DTIB was possible because incumbent companies were protected from competition by strong barriers to entry that prevented newcomers from breaking into defense markets (particularly hit-and-run strategies were near impossible to pull off). In terms of systems development and production, these barriers were ontologically linked to characteristic features of Industry 3.0 which have become a legacy, or even an outright burden, as DTIBs generally do not rely on the best industrial approach and practices to address military needs.

Transformation of innovation expectations and of industry fundamentals lead to a level playing field in which the fastest and most adaptive firms can secure potential defense market contracts. In the absence of unbearable sunk costs, entry in defense markets is likely to become contestable, at least for an increased share of defense acquisition. It therefore seems likely that in-depth transformation of the DTIB will be painful, especially for incumbent companies. Of course, even as the creation of an Industry 4.0 DTIB approach appears essential, it cannot be taken for granted that non-DTIB companies will in fact be interested in serving the military (as the Google example referred to earlier illustrates). It would therefore seem necessary that states set up industry and technology policies that support both the transformation of current defense-oriented firms and that attract purely commercial ones to the field of defense capabilities.

Increased convergence of the defense and commercial technological and industrial bases will be a key element in the renewal of the defense sector. This is especially true in Europe. We mentioned the Third Offset Strategy promoted since 2014 in the U.S., but this does not necessarily open the U.S. market to European companies. European DTIBs could be put in jeopardy without an equivalent initiative on its side of the Atlantic. However, one can expect recent European initiatives to be leveraged, even though its resources and ambitions will be well below the massive efforts mobilized in favor of the United States' Third Offset Strategy.[25]

Conclusion

The Europeanization of defense R&D efforts and a more European approach to consolidating the European DTIB could help Europe adjust to the emerging Industry 4.0. The EU has overcome some of its decades-long aversion to investment in the defense sector, for instance with an initial EUR1.4 million investment in swarms, robotics, sensors, and autonomous systems launched in 2015. These initial defense research investments are designed to test whether EU institutions can work effectively on defense research and whether they can develop an IPR-regime that works for Europe's defense market. Should these initiatives succeed, the plan is to integrate a fully-fledged European Defence Research Programme (EDRP), worth potentially EUR3.5 billion over 2021-2027, into the EU's Multiannual Financial Framework. All this is still at an early stage but, if calibrated correctly, shows great potential to reshape the European defense market.

EU-level investments may make it possible to encourage convergence of Europe's defense and commercial markets by influencing the types of defense capabilities developed and by encouraging much closer collaboration between traditional defense firms and broader, civilian, actors such as research institutes. There will, however, be limits to what EU investments in defense research can achieve. First, EU efforts should not replace national investments in defense R&D: this is precisely why EU investments should be co-financed in order to secure buy-in from member states. (While the policy objective of the European Commission may be to move in an evolutionary way toward a single European defense market, and while EU defense research spending may evolve in this direction in the future, at present the amount of money being tabled by the Commission—EUR90 million until 2020—would not be enough to cover national spending on defense R&D.) Second, it will take time before EU investments in defense research can change the mentality of military-industrial actors in Europe. Adopting a more open behavioral and organizational approach to defense innovation will need time to succeed and cannot rely solely on EU investments.

Longer term, good opportunities to seriously augment the EDTIB may be on the horizon. The European Commission's European Defence Action Plan (EDAP) has not only stressed the importance of the defense procurement and defense transfer directives, but it has also tabled the idea of having a European Defence Fund (EDF). The EDF would support EU member states with defense capability development with a view to linking up defense research efforts with broader defense capability programs. This may provide a financial incentive for European countries to work closer together. Bringing together the EDF and any future EDRP could become vital ingredients for any deep transformation of the EDTIB.

Finally, the EU has signaled important policy initiatives that could be elaborated further in the future. As a follow-up to the EU Global Strategy published in June 2016, the High Representative/Vice President presented the Security and Defence Implementation Plan to EU member states. It not only calls for an EU Innovation Initiative to manage potentially disruptive technologies, but also foresees the creation of a Coordinated Annual Review on defense that may see closer coordination of defense planning among European countries. Elsewhere,[26] we have called on the EU to coordinate the technology roadmaps of member states, not only to improve coordination and cooperation, but to also provide valuable foresight for future technological and industrial trends. It seems that the EU is now well-placed—provided political will exists—to push for closer European cooperation in the defense-industrial domain. If Europe is to manage disruptive innovation and market destabilization then such efforts cannot come too soon. Otherwise non-European companies will not only compete with European firms on international markets but even in Europe itself.[27]

Notes

1. Military-industrial complex: Adams (1989).

2. Industry 4.0: Schwab (2016).

3. Whole careers and emerging convergence: Wright Mills (1956). Scientific progress: See the ample literature on the so-called Revolution in Military Affairs: Henrotin (2013).

4. Follow-on principle: Kurth (1972). Rafale: This does not mean that there is no major innovation or new technology in the Rafale, just to say that launching this program did not result from a strategic or technological imperative.

5. Technological continuum: See, again, Henrotin (2013) on the Revolution in Military Affairs. Military-industrial complex: Some authors limit the concept to capitalist economies but it has also been applied to planned economies since it is not necessary that a country relies on market/capitalist mechanisms to generate a military-industrial complex. While the channels differ, the results are quite similar in terms of power and resource capture. Quote: Kurth (1993, p. 307).

6. Real unit cost: Kirkpatrick and Pugh (1985). Another author: Serfati (1995).

7. R&T is part of R&D. It includes basic research, applied research, and advanced technology but not capability development. While it would be useful to have R&D data, the EDA only releases detailed figures on domestic and collaborative spending for R&T.

8. One pair of analysts: Setter and Tishler (2006, 2007).

9. Unproven technologies: For instance, it is often held to be true that the armed forces of the U.K. seek the best kit—proven U.S. frontier technology systems—but that the U.K. government then overrides with political pressure to "buy British", supporting local jobs and investment. In the U.S., GAO assessment of major, complex defense systems over at least the past decade argues that the DoD pushes for the launch of production even as key technologies have not yet reached maturity. The F-35 is an emblematic example. Systematic bias: Rogerson (1990). Nurtured: Serfati (1995).

10. Technological frontier: Gansler (1989, p. 218). Rely on technology: Bellais and Droff (2016). It has been suggested: Adelman and Augustine (1990); Augustine (1997). Various kinds of platforms: Kirkpatrick (2004, 2008); Davies, *et al.* (2012). Augustine's laws: Law 16 states that defense budgets grow linearly but unit cost of new military aircraft grow exponentially. He writes: "In the year 2054, the entire [U.S.] defense budget will purchase just one tactical aircraft. This aircraft will have to be shared by the Air Force and Navy 3½ days each per week except for leap year, when it will be made available to the Marines for the extra day" (Augustine 1997, p. 107).

11. Plateau: Bellais and Droff (2016).

12. FitzGerald and Sayler (2014, p. 5).

13. Hammes (2015).

14. Quote: Christensen (1997). On disruptive transformation, see Dombrowski, Gholz and Ross (2002, pp. 16).

15. Knock-on effect: Markides (2006). Scope to rethink: Börjesson and Elmquist (2012, p. 189).

16. The paragraph relies on Stowsky (2004).

17. Presumes: Pierce (2004, p. 1). Socio-technical bias: te Kulve and Smit (2003).

18. Traditional hierarchical structure: Jungdahl and Macdonald (2015). Open Innovation: Mortara and Minshall (2011). Innovation management: Chesbrough (2003).

19. Simón (2016).

20. Google pledged: Fiott (2016). IRPs in dual-use context: Bellais and Guichard (2006).

21. China: Cheung (2009, p. 17). Leap-frog and copycat: Hannas, Mulvenno, and Puglisi (2013). Defense R&D: Middleton, *et al*. (2006). Science education: Song (2008). R&D hubs: Walsh (2007).

22. Fiott and Bellais (2016).

23. Gansler (1989); Chesnais and Serfati (1992).

24. Planned obsolescence: Bellais and Droff (2016). Fourth industrial revolution: Brynjolfsson and McAfee (2014).

25. Not necessarily: Fiott (2016).

26. Fiott and Bellais (2016).

27. Defense planning: Council of the EU (2016, pp. 5, 23).

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Global perspectives on the European arms industries

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Abstract

The authors of this article offer perspectives on the symposium on the European arms industries published in volume 12, number 1 of *The Economics of Peace and Security Journal*. The symposium contributions cover the history, current situation, and likely future prospects of the European naval, land armaments, military helicopter, aerospace, and outer space industries. The perspectives then comment on the articles as a group and do so from a global vantage point inasmuch as the commentators constitute a group of prominent researchers and policy analysts drawn from around the world.

The authors of the symposium on the European arms (and space) industries published in this issue of *The Economics of Peace and Security Journal* all work in the Francophone context, specifically in Belgium and in France. This is by happenstance but raised the question of how scholars residing in different regions of the world might view the five articles in the symposium. The editors thus invited prominent researchers and policy analysts from around the world to each contribute a "perspective" of about 1,000 words in length.

–The Editors

RICHARD BITZINGER

Perspective: The European Defense Industry's Never-Ending Death Spiral

A certain melancholy descended over me as I read the articles in the symposium on the European arms industries in this issue of the journal. All are fine works and excellent analyses, yes, but the themes and arguments were painfully familiar.

Do not blame the authors. Four articles provided excellent discussions of recent trends and developments in four key sectors of the European defense technology and industrial base (EDTIB): naval shipbuilding (Bellais), military helicopters (Droff), land armaments (Caralp), and space (Zervos).

The fault, if there is one, lies more in the nature of the European defense industry itself, which has been in a state of perpetual crisis—a never-ending death spiral, as it were—for several decades. The problems and challenges facing European arms manufacturers, as laid out in these articles, were as familiar 10, 20, or 30 years ago as they are today.

To be sure, many of the authors describe an apparently thriving European defense sector. For naval shipbuilding, armored vehicles, and helicopters, business is booming—for now. But these articles also strongly insinuate that the current business model is unsustainable over the long run. As such, the European defense industry faces an uncertain future.

If anything, the problem today is likely worse than it was 15 or 20 years ago. In the 1990s and early 2000s, the Europeans were awash in new defense projects, including three different types of combat aircraft (the Rafale, Eurofighter Typhoon, and Gripen), two heavy-lift utility helicopters (the EH-101 and the NH-90), a transport aircraft (the A-400M), and several missile programs. Today, however, the European defense industry faces a more fragile future. While factories are currently humming, there is a dearth of new defense projects in the works. (Josselin Droff notes, for instance, the lack of new helicopter programs.) At the same time, defense innovation is languishing. European spending on defense R&D has fallen by

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around 20 percent over the past decade, while spending on basic research—the "seed corn" of future production—has dropped by nearly one-third. Moreover, much of the EDTIB, as in the case of shipbuilding and armored vehicles, remains highly fragmented along national lines. Barely nine percent of EU defense R&D is currently allocated to collaborative programs, resulting in duplicative, competing programs.[1]

If the challenges facing the European defense industry are well-known and long-standing, so too are the solutions often put forth: further consolidation and rationalization, expanded intra-European and transatlantic arms collaboration (including transnational mergers, acquisitions, and joint ventures), the promotion of arms exports, and the expanded spin-in of commercially sourced dual-use technologies. In fact, all of these schemes were attempted during the 1990s, but by the early 2000s most of them had run out of steam. Particularly when it came to cross-border tie-ups, the process seemed to reverse itself in cases (as Renaud Bellais points out for the case of ThyssenKrupp's divestiture of Kockums).

It is easy to be cynical, therefore, of initiatives that were already attempted and which turned out to be so dissatisfying. At the same time, the stakes are too high not to do anything. Unless Europe can find a way out of its troubles, it runs the risk that, over the next two or three decades, the EDTIB could lose its high ranking within the global hierarchy of arms producers. Take just one example, advanced combat aircraft: Europe has not initiated a new jet fighter development program in over 30 years; there is simply no money to fund a fifth- or sixth-generation combat aircraft. Except for retrofits and upgrades, by 2030 Europe could consequently be out of the fighter jet business altogether. Asia, meanwhile, has six new combat aircraft in development: the Chinese J-20 and J-31, the Japanese X-2, the Korean KF-X, and India's Advanced Medium Combat Aircraft (AMCA) and Fifth Generation Fighter Aircraft (FGFA, a collaborative project with Russia).

In the fifth article in the symposium, Renaud Bellais and Daniel Fiott offer a new approach, one that takes a page from the United States' third offsets strategy that seeks to leverage "disruptive innovation" in advanced (and mostly commercial) technology sectors such as autonomous systems and robotics, nanotechnologies, big data, and additive manufacturing. As they put it, the EDTIB "can no longer operate in a vacuum whereby it develops capabilities with limited interaction with the rest of the economy ... the industry has to look for technological inputs from outside the DTIB to focus on combinatory innovations rather than on traditional defense-technology driven ones."

This initiative has its own problems, however. In the first place, "disruptive innovation" has come under considerable criticism lately, both as an idea and as industrial policy. In addition, leveraging commercial dual-use technologies has been tried before, and with little to show for its efforts.[2]

All this, of course, is not to argue that it is fruitless to try to reform the European defense industry. At the same time, however, one should recognize that many of the ideas being put forth to restructure, revitalize, and reorient the EDTIB are not particularly novel. *Plus ça change, plus c'est la même chose*—and don't get your hopes up.

AUDE FLEURANT AND YANNICK QUÉAU

Perspective: Challenges and constraints faced by the European arms industry

Since the early 2010s, a growing sentiment among observers of the military-political economy of the United States and of Western Europe is that the arms industries of these countries are on the verge of entering, or perhaps already are in the midst of, a new transformation phase. This perception comes from a variety of factors that shape both state demand and industry behavior such as changing geopolitical conditions, defense budget resource limitations (especially for procurement and research and development), and the interest shown by military institutions in emerging and disruptive technologies developed by the civilian sector for military applications which, in turn, pose challenges to states' capacity to control their dissemination and their uses.[3]

The current situation of the West-European arms industry appears to be a direct continuation of important transformations that have been ongoing since at least the 1970s and 1980s, driven by both economic and political pressures. Privatization of publicly owned companies and state arsenals was followed by large, nationally-based combinations of arms producers, creating larger entities concentrating more capabilities within a single segment. The massive process of mergers and acquisitions that first took place in the 1990s in the United States then drove an agenda of greater supply-side cooperation and integration in Europe in the late 1990s and early 2000s as well. The intent was to support and upgrade first-tier, complex weapons systems production and integration capabilities under European control, which meant amalgamating the resources of the large arms-producing countries.

By examining the current situation of specific production segments, four of the articles in the symposium on the European arms industry in this issue of the journal highlight that despite major changes that have occurred since the 2000s, European arms producers and their respective national ministries of defense have not resolved enduring issues and tensions associated with the outcomes of decisions made in earlier periods. Renaud Bellais' paper on the European naval industry underlines shortcomings of the European defense integration project that was at the top of the agenda for the larger arms producing countries. It also exposes tensions between economic constraints and the desire to maintain broad national control over arms production capabilities, an uncomfortable dilemma that is also present in other military production sectors. Adrien Caralp's examination of the European land armaments industry also comes to the conclusion of excessive production capacity for that segment, but he cites different reasons for this capacity surplus. Whereas naval production overcapacity is linked to states' ability to maintain autonomy of supply, land systems duplication is attributed to lower barriers of entry, combined with growth in demand in Europe during the 2000s. Both authors agree, however, that it is difficult to determine whether this overcapacity is sustainable in the longer term.

The military helicopter case study presented by Josselin Droff emphasizes long-standing, structural issues which the European arms industry as well as the defense ministries have been facing on a recurring basis, notably the absence of new, sizeable national modernization programs, and the inherent difficulties associated with large cooperation programs such as the N-90 helicopter. The industry has few options. Droff suggests that, besides modernization and cooperation, turning attention to more versatile and dual-use platforms could support the military helicopter industry. Vasilis Zervos' article on the European space industry provides an overview of an inherently dual-use (civilian-military) and opaque sector. Considered by large military powers to be an essential and, in some instances, highly sensitive component of their defense and security arsenals, space-related systems often are labeled force multipliers or enablers of modern military forces. However, the importance of civilian activities in space has given this industry a very different profile than those observed in other military production segments. Finally, Renaud Bellais and Daniel Fiott explore the possibility of a paradigmatic change in how the arms industry could be transformed (or transform itself) by leveraging civilian innovation capabilities and by combining forces to develop new, disruptive capabilities.

The detailed examinations of specific arms production sectors in Europe presented in this set of symposium articles provide valuable, facts-based descriptions and analyses of current trends and potential future evolutions as well as suggest alternative ways to address some of the challenges that these industries face now and in the future. They stress some of the major consequences of the constraints with which the industrial actors have been dealing, such as the need to export to make up for insufficient domestic demand. As is often the case, however, they also leave some concomitant issues in the dark. Notably, a closer examination of demand-side drivers would seem warranted—especially in the current geopolitical environment where increased threat perceptions and interstate tensions in several parts of the world, including Europe, may affect military expenditure and weapons requirements. Similarly, from the supply side, the internationalization of the European arms industry through major export contracts and associated offsets, which has led some European companies to establish a long-term production presence in recipient countries, raises questions about how this internationalization process would or could interfere with any European integration project. Finally, it would be interesting to compare the current U.S. push for a rapprochement between military and civilian producers to a similar attempt made in the 1990s in the context of the Revolution in Military Affairs.

KEITH HARTLEY

Perspective: An Economist's View

The five articles in the symposium deal with important and under-researched aspects of the European defense market, namely, the military helicopter industry, naval shipbuilding, land armaments, the space industry, and the impact of innovation on the defense market. These are sectors which continue to be characterized by fragmented national markets, the remaining scope for industrial restructuring, the challenges of maintaining a future industrial capability, and the need for defense firms to adjust to change. In contrast, the European aerospace industry has achieved substantial restructuring and progress in arms collaboration (e.g., collaborations in Typhoon, the A-400M airlifter, and missiles).

Typically, economists address the issues around the European defense market by asking what is the problem, why does it arise, and what are the policy solutions?

The policy problem

Problems arise because national defense budgets have to fund the acquisition of increasingly costly defense equipment and military personnel. Equipment costs often rise at rates of up to 10 percent per year for combat aircraft and at rates of four to six percent per year for tanks and warships. These rates usually exceed the growth rates for military expenditure, leading to long-run reductions in quantities bought. Already thirty years ago, commentators forecast a future of a single-ship navy, a single-tank army, and a single "Starship Enterprise" for the air force.[4]

In addition to economic pressures on military budgets, new technology means that defense contractors have to adjust to change. The long-run trend is toward the creation of a smaller number of larger arms firms involved in supplying a range of traditional and new arms markets (e.g., cyber- and security markets). However, European nations continue to prefer supporting their national arms industries and their national champions: They prefer and are willing to pay the price of independence. As a result, within Europe, there remains substantial duplication of military R&D and relatively small production runs failing to exploit economies of scale and learning. These features arise in European land armaments and naval shipbuilding industries.

Why is there a problem?

Two features are dominant, namely, rising unit equipment costs and support for a national defense industrial base. Rising costs reflect military pressure for high-technology equipment where the armed forces demand equipment which is technically superior to that of its potential enemies (a tournament good). Rising costs also affect the military personnel required for an all-volunteer force.

Economists predict that rising unit costs will lead to incentives to substitute cheaper factor inputs for costlier ones. For example, costly combat aircraft might be replaced by cheaper missiles, tanks replaced by attack helicopters, and naval frigates replaced by maritime patrol aircraft and unmanned aerial vehicles (UAVs). Similarly, costly soldiers might be replaced by cheaper reserves and civilians (e.g., private contractors). Such substitutions might have implications for the traditional monopoly property rights of each of the armed forces when, for example, land-based aircraft and UAVs replace naval frigates for anti-submarine roles and air forces are being replaced by armies and navies.

The problem also arises from European nations (and others) being willing to pay the price of an independent national arms industry. For aerospace, European nations have sacrificed some independence through their support for collaborative programs with one of the most successful collaborations in the civilian aircraft Airbus. Even here, though, the Airbus management of the collaborative A-400M airlifter has been much less successful.

The willingness of European nations to collaborate on military aerospace programs reflects their costly R&D and the economic benefits of pooling national production orders. European collaborations have been less prevalent in land and sea systems. This probably reflects the relatively lower R&D costs of these systems compared with aerospace projects and the fact that national orders allow some economies of scale and learning so that independence is not too costly. Independence is also sustainable where arms firms obtain export orders, so increasing their national output. Also, shipyards are often located in high unemployment areas so there are political gains from awarding naval contracts to such regions. State ownership of arms firms will reinforce nationalism.[5]

A further feature of arms markets also explains the preference for nationalism. Governments are central to arms markets. They are major buyers of arms (sometimes the only buyer) and they can use their buying power to determine the size, structure, performance, and ownership of national arms industries. Public choice analysis predicts that government choices will be influenced by politicians with their pursuit of votes, by bureaucracies (armed forces) in pursuit of larger budgets, and producer groups (arms firms) seeking incomes and profits from arms contracts.[6]

The solutions

A range of policy solutions exists, each with different benefits and costs. Examples include more industrial restructuring involving national and international mergers both within and between European arms firms and between European and U.S. firms. Again, such restructuring will be constrained by the preferences of national governments. Or, national defense markets can be extended through more military outsourcing allowing arms firms to bid for work traditionally undertaken in-house by the armed forces (e.g., military helicopters).

There are challenges for European arms industries. New technology could mean that the center of gravity in defense R&D is shifting away from traditional defense firms to new commercial firms. This raises questions about the ability of defense firms to adjust to change and whether the defense firm has a future. If so, what might the future defense firm look like? While the future is characterized by uncertainty, it is likely that the future defense firm will be radically different, just as today's arms firms are completely different from those of the year 1900. Outer space offers future possibilities for new markets and opportunities for new entrants (e.g., a Star Wars future?).

Europe has a further challenge. Maintaining national defense industries is not confined to buying from them. They have to be retained during periods when there are gaps in development and production work (e.g., helicopters). Key labor skills and specialist production facilities will need to be retained for future orders. Retaining such assets is not cheap. Alternatively, releasing resources when contracts end requires substantial costs to be incurred when recreating such specialist assets.

Economics offers a solution. The economic principles of competition and trade based on comparative advantage could be applied to Europe's armed forces and its arms industries. The result would be armed forces and arms industries specializing by comparative advantage with arms contracts allocated on the basis of competition. But such solutions would require trust among nations through their participation in a military alliance or membership of a political union. There remain major political constraints on an economically efficient European defense market.

WILLIAM HARTUNG

Perspective: Comparative prospects for the European and U.S. defense industries

The five articles in the symposium on the European arms industry in this issue of the journal stress a number of common themes affecting the key military-industrial sectors in Europe, including shipbuilding, land armaments, and the helicopter industry. Important factors that bear on the future of these industries include relatively tight defense budgets and resistance to industry consolidation rooted in issues of national sovereignty and economic concerns. Each of these, and other, factors undermines the current approach of a fairly fragmented industry relative to available market opportunities.

Potential counter-balancing forces include the possibility of consolidation (despite a history of failed or partially failed initiatives), continued or increased reliance on export markets, expansion of civilian and dual-use lines of business, and a focus on maintenance and after-service opportunities, which over time can match or exceed the size of the market for initial procurement. Another wild card will be the extent to which European defense budgets increase due to new challenges emanating from Russia, and whether increases in spending by East and Central European countries like Poland and Hungary will lead to new sales by Western European firms.

Similar forces are at play in the U.S. defense industry, but they are less severe due to the sheer size of the U.S. market. Despite the slight dip in the Pentagon's main budget that resulted from budget caps imposed by the Budget Control Act of 2011, the roughly USD600 billion per year of U.S. military spending remains at historically high levels—higher, adjusted for inflation, than at the peak of the Reagan buildup of the 1980s, and larger than the military budgets of the next seven countries in the world combined. Roughly one-third of this USD600 billion total is devoted to weapons procurement and R&D.[7]

To give just one indicator of the relative scale of U.S. and European spending, the new Trump administration's proposed USD54 billion military expenditure *in*crease alone, for fiscal year 2018 (October 2017 to September 2018), is roughly equal to the entire military budget of the United Kingdom, and slightly larger than the military budgets of France or Germany. The advantage of U.S. defense firms is further underscored by U.S. dominance of the global arms market. From 2009 to 2015—the bulk of President Barack Obama's two terms in office—the Pentagon brokered nearly USD300 billion in new arms offers to foreign clients for U.S. firms under the Pentagon's Foreign Military Sales (FMS) program. This is a larger figure, adjusted for inflation, than any U.S. administration since the second world war. Not all of these offers will result in final sales, and a significant portion of the value of each deal is for support services and training rather than weapons procurement, but exports represent a potential bright spot for the top U.S. defense firms such as Lockheed Martin, Boeing, Northrop Grumman, Raytheon, and General Dynamics. This is particularly true because deals concluded now will take years to complete, potentially resulting in a steady flow of contracts to U.S. arms makers for the next five years or more, independently of how many new orders are placed in that time frame. For example, a Saudi order for over 70 Boeing F-15S aircraft was first put on offer in 2010 and resulted in its first delivery of a finished aircraft in December 2016.[8]

Another factor likely to lock in significant sales for U.S. firms for the longer term is the F-35 program, which includes European partners in Denmark, Italy, Norway, Turkey, and the United Kingdom, as well as partnerships with Australia and Canada. Other deals concluded or in the works include F-35 sales to Israel, Japan, and South Korea. The F-35 program has been plagued by cost and performance problems, but so far the Pentagon is staying the course with production rates at about three dozen aircraft per year. Although well below the 100 or more aircraft per year originally projected at this point in the program, if the experience with recent U.S. aircraft programs like the F-22 and B-2 are any guide, the ultimate number of F-35s purchased by the United States could end up being perhaps half as many as the 2,400-plus currently planned. But even at these reduced levels, the F-35 will be a boon to the U.S. industry for the next two decades, particularly for prime contractor Lockheed Martin and major partners like Northrop Grumman. The impact will spill over to the European industry via shared production, with a particularly strong role for BAE Systems due to the U.K.'s role as the primary U.S. partner in the F-35 program. The pattern of F-35 sales will make U.S.-European competition for military aircraft sales in markets such as the Middle East and South Asia (primarily India), where the F-35 is unlikely to be sold, all the more fierce in the coming decade or more.[9]

As for the U.S. shipbuilding sector, the Trump administration's pledge to begin the process of building the U.S. Navy up from its current level of 272 to 350 combat ships will make exports—which have never been a major factor for the U.S. shipbuilding industry—even less important for the foreseeable future. Armored vehicle production also is likely to receive a boost from the Trump buildup, given his pledge to add hundreds of thousands of personnel to the Army and Marines, especially since tanks and light vehicles are produced in the key electoral states of Ohio, Michigan, and Wisconsin—states that were pivotal in Donald Trump's victory in the 2016 presidential race. Trump already has suggested that he will help areas that helped him, and doing so in the sphere of military procurement is hardly a new phenomenon.[10]

The space sector of the U.S. defense/aerospace complex is poised for a more significant transformation than other sectors of the U.S. arms production industry. This is due to the introduction of competition into the space launch business, with Space-X challenging Boeing and Lockheed Martin, which until recently had a monopoly on U.S. military satellite launches via a joint venture known as the United Launch Alliance. The novel element of the competition is that Space-X, owned by entrepreneur Elon Musk, produced its launch vehicle without U.S. government R&D or production funding. The introduction of new players into the space sector may pose short-term risks, such as when a Space-X rocket crashed in a recent launch effort, but for the longer-term competition in this growing field could yield benefits in both price and innovation.[11]

An important caveat to all of this is, of course, that the Trump administration's proposed budget is likely to be substantially altered as it works its way through Congress, with concerns about the federal government budget deficit and opposition to deep cuts in spending on diplomacy and domestic programs serving as possible curbs on the kinds of Pentagon-related spending increases the Trump administration is seeking. Moreover, some major U.S. arms clients, like Saudi Arabia, seem to have put some big deals on the back burner for now, suggesting that some of them may fail to materialize, undercutting the export revenues of key U.S. firms.

STEFAN MARKOWSKI AND ROBERT WYLIE

Perspective: Military innovation and military industrial capabilities

In the concluding article of the symposium on the European arms industry in this issue of the journal, Renaud Bellais and Daniel Fiott argue "that the global defense industry is shifting toward *a new paradigm* in which an emphasis on technology-driven capability development is being undermined by disruptive innovations emanating from the commercial sector" (our emphasis). The previous paradigm was essentially that of the cold war era, characterized by "a technological arms race in which arms-producing countries invested heavily in [military-specific] R&D to achieve dominance [based on] technologies with incredible military potential." Now, with "the advent of disruptive technologies emanating from the commercial sector" the military-industrial actors face the three-pronged challenge of how to: (a) "integrate disruptive technologies into existing or planned capabilities"; (b) "adjust organizational behavior to capture commercially-driven innovation"; and (c) "foster viable relations between the military establishment and commercial firms and their civilian research clusters." In this comment we review this proposition having regard to the other symposium contributions as well as to wider considerations.

For much of the cold war era the imperatives of nuclear retaliation, as reflected in the doctrine of Mutually Assured Destruction (MAD), made both cold war superpowers accept that no degree of technological superiority made a third world war a winnable proposition. Thus, as Bellais and Fiott suggest, the two superpowers and their respective allies invested heavily in military research and technology (R&T) to produce strings of technology demonstrators including, for example, then-U.S. President Ronald Reagan's Star Wars challenge in the 1980s. Had these demonstrators been developed further, and had they been deployed and allowed to mature, they could have disrupted the military and industrial capabilities of the two military blocs much more than has in fact been the case. Instead, acceptance of the MAD doctrine fostered at least a tacit realization that any significant military advantage achieved in arms conflict with weapons of mass destruction (WMD) between the two superpowers would have triggered a globally catastrophic nuclear devastation. Paradoxically then, the cold war era was a period of restraint where non-WMD capabilities of the two dominant military blocs were deployed in a relatively limited way on the fringes of their respective spheres of influence (e.g., in Viet Nam and Afghanistan). In this strategically stable environment, the prudent defense tactic for both military blocs was to engage in a technological know-how race but not in an actual arms race. Military platforms were built for adaptation and endurance, and industry capabilities were formed to support long runs of equipment production and through-life development and adaptation. In this relatively stable strategic and non-adventurous political environment evolved what Bellais and Fiott call, with reference to James Kurth, "the flow-on principle," based on "a tacit agreement between the military and defense companies" that "leads companies to promote the renewal of existing systems that are based on assets, technology, and know-how they already master."

This relatively permissive environment allowed Western Europe to develop national variants of platforms and systems

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within the trajectories of non-WMD technologies established by cold war imperatives. This also allowed Western Europe to experiment with various models of international technological collaboration and with various mixes of public and private investment.

However, the post-cold war world is strategically far less benign. In today's multipolar environment, the nuclear capabilities are still in place, but there are many more fingers on the nuclear triggers and the powers of deterrence are far less effective than before. New, aspiring regional powers, such as China, Iran, and the Russian Federation, are essentially old imperial countries that seek their own spheres of dominance, often in regions which they have dominated in the past. This challenges the United States as the world's sole superpower. In response, the U.S. has continued to invest in military-specific R&T, such as space-based weapons systems, directed energy weapons, and high-velocity interceptor technologies. None of these could be fashioned in the civilian domain, even if they incorporate many elements of civilian high-tech knowledge. The competition among states for military advantage will ensure that these technologies are highly classified by national governments and will only be developed and produced in dedicated facilities that satisfy governments' stringent industrial security requirements. The same imperatives will lead the U.S. and other governments to protect their technological advantage by continuing to intervene in the market for such technologies and control, or at least delay, their diffusion.

This is not much different from the old cold war era except that there is much less confidence that the "new cold war" adversaries, such as the Russian Federation, Iran, or even China, are able to restrain their military hawks and mitigate their appetite for regional conflicts. And this means that the old cold war scenario, whereby each aspiring imperial power limited its sphere of influence and stopped contesting the status quo, was the best-case scenario. Containing the arms race, they could stabilize investments in military and military-industrial capabilities. In contrast, the new cold war scenario is that of the U.S. continuing to invest in massive surveillance, first strike, and retaliatory capabilities, which would keep its mainland safe even as their use would have devastating direct and collateral effects in other parts of the world. Rather than looking to the commercial sector to generate the new and inherently disruptive technologies required to prevail in this fluid strategic environment, we believe it likely that U.S. capability managers will continue to foster a U.S. military technological innovation system that is based on a dynamic symbiosis of both public and commercial investment. At any point in time, the technological product of this symbiosis—and the balance of commercial and public investment involved—will be shaped by the specific nature of the perceived threat or security challenges demanding a response. This leads us to suggest that, for the United States at least, Kurth's flow-on principle needs more nuanced treatment. Moreover, the U.S. government's enduring incentive to control the diffusion of military-related technology, irrespective of its public or commercial origins, suggest that, despite the political and economic impediments, European governments will have a commensurately strong incentive to continue searching for pan-European solutions to requirements for novel military capabilities.

Another major change from the old cold war era concerns the proliferation of asymmetric conflicts, many with religious overtones, in which asymmetric adversaries are highly tolerant of civilian and combat casualties. They are adept at using low-tech know-how to weaponize civilian technologies although, in some areas they may also use high-tech know-how to weaponize high-tech civilian information technology and telecommunication assets (e.g., cyberspace). This is the area where the civilian sector has knowledge and resources which the military could usefully tap to acquire radical, disruptive technologies and where the new technological paradigm described by Bellais and Fiott may partially apply. Clearly, the military are keen to scan civilian know-how in all areas of potential military applicability, especially those where currently open conflicts necessitate military and political responses, even as it recognizes limits to the degree to which it can rely on civilian technology suppliers in areas such as signals intelligence that really matter for military advantage in the field. While more potentially disruptive technologies may be acquired from civilian sources in years t come, they will be refracted through military-specific R&D facilities and will be militarized. This, especially in the western-style democracies, is a long way from day-to-day civilian business. For as long as defense remains a public good, national governments and the citizens that elect them are likely to demand some measure of security and accountability over the development and application of such technologies for military purposes, whether originated in the defense or the civilian-commercial sectors.

Notes

1. Dropped by nearly a third and barely nine percent: European Defense Agency (2014, p. 5).

2. Considerable criticism: Lepore (2014).

3. Military-political economy: When assessed in terms of arms sales, the largest arms companies as well as those that provide the most sophisticated weapon systems and technologies are, in their vast majority, based in mature military-industrial countries such as the France, Germany, Italy, the United

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Kingdom, and the United States. See https://www.sipri.org/databases/armsindustry.

4. Commentators: See, e.g., Kirkpatrick and Pugh (1985), Augustine (1987, p. 140).

5. Pooling of national production orders: Hartley (2017).

6. Public choice analysis: Hartley (2014, 2017).

7. Next seven countries combined: Freeman and Eoyang (2016). Roughly one-third: DoD (2016, p. 46).

8. Proposed USD54 billion increase: Shear and Steinhauer (2017). Military budgets in France, Germany, U.K.: Perlo-Freeman, *et al*. (2016). Foreign Military Sales: Weisgerber and Houck (2017). Saudi order: Jennings and Peacock (2016).

9. Other deals: Lockheed Martin (2017). BAE Systems: BAE Systems (2017).

10. U.S. military shipbuilding: Capaccio (2016).

11. Space-X challenging: Dillow (2016).

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Incumbent policy, benefits provision, and the triggering and spread of revolutionary uprisings

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Abstract

This article analyzes revolutionary uprisings, such as the Arab spring of 2011. Revolutions occur with an inherent probability dependent on a country's characteristics. A country's incumbent leader can decrease this probability by providing benefits to a population, e.g., public goods such as necessities of life, health care, safety, and education. We equate the probability of revolution with Granovetter's equilibrium proportion of a population that joins a revolution. Decreased benefits provision increases the share of revolutionaries which, in turn, decreases the cost of revolt which helps resolve the free-rider problem implicit in revolting. The article quantifies how the incumbent chooses whether or not to provide benefits, and how many benefits to provide. We account for the unit cost of providing benefits and for the effects of the benefits provided, adjusted for whether the inherent revolution probability is low or high. Combining the modeling approaches, i.e., how revolutions spread and how the incumbent provides benefits, enriches our understanding of which factors affect revolutions and of how populations and their incumbent leaders interact. The model helps to understand the logic of revolutionary uprisings and how they can be curtailed.

We consider an incumbent leader's strategic benefits provision to a country's population. The population's choice of whether to initiate a revolution is first modeled probabilistically, endogenously affected by the incumbent's provision of benefits. To make individual involvement in revolution worthwhile, a sufficient number of people need to participate. A threshold has to be exceeded. The population's coordination problem is present, in part, in the revolution probability itself but we also model the coordination problem by assessing how a decrease in the incumbent's benefits provision increases the share of would-be revolutionaries, which would decrease citizens' average cost of revolting. Hence the free-rider problem, where citizens hope that others incur the cost of revolution, is alleviated.[1]

Since limits exist for what an incumbent can do, we distinguish between a country's characteristics and the incumbent's benefits provision. A country's characteristics, such as unemployment, inequality, ethnic fractionalization, institutional quality, presence of lack of human rights, implicit governmental repression, and so on, are given a parameter value which affects the revolution probability. Additionally, this probability depends on the incumbent's benefits provision. Benefits may be public goods such as health care and education, basic necessities of life, safety and security, political and socioeconomic rights, human rights, employment opportunities, education, or various privileges. Revolutions often, but not always, take place in countries where benefits such as these are not provided excessively, driven either by the form, nature, traditions and history of government, low GDP, or other factors. Mancur Olson argued that dictators provide public services only to the extent that GDP is increased. Accordingly, benefits provision is defined here as benefits exceeding GDP-enhancing benefits, with the objective of decreasing the revolution probability. The model intends to capture the tradeoffs and the range of possible outcomes better than does the current literature.[2]

Background and prior literature

Background

The Arab spring caused the eventual disposal of a number of autocratic leaders in the Middle East and North Africa (MENA) region. For many years, autocrats either held fraudulent elections (e.g., Tunisia) or no elections at all (e.g., Libya). In Tunisia, the population revolted and the autocrat relinquished power. A revolution may be sparked by how an incumbent reacts to an instigating event. Such an event lowers the cost of contribution for at least some rebels, may raise the benefits of contribution for at least some, may raise a rebel's potential share of the collective good, and may raise the probability of a successful revolution.

Examples of instigating events are of a street vendor harassed by police and unleashing untapped frustration causing revolution (as in Tunisia on 17 December 2010), or any event where an incumbent has to decide whether to react with strategies such as no benefits provision or accommodation, or fraudulent elections generating results stirring the population. Such elections are typically held by autocrats and usually involve violence and manipulation.[3]

In 2012, Syria experienced economic disenfranchisement of young adults, including high youth unemployment. After the 2012 uprising the government was criticized, for instance, for repression and lack of human rights. Revolution has been described broadly as "any and all instances in which a state or a political regime is overthrown and thereby transformed by a popular movement in an irregular, extraconstitutional and/or violent fashion," and narrowly as entailing "not only mass mobilization and regime change, but also more or less rapid and fundamental social, economic and/or cultural change, during or soon after the struggle for state power." In Eastern Europe, the end of the cold war and the collapse of the Soviet Union brought a new wave of revolutions which saw the overthrow of the communist regimes in these countries. The revolutions during the cold war era and the collapse of the Soviet Union caused the decline of Marxist ideology, the liberalization of Eastern European countries from the communist system, and the introduction of market-oriented economic reforms. The 2014 Ukrainian revolution pertained to a struggle over orientation toward Moscow or Europe. Further East, the 2014 Thai revolution pertained to a desire for political reform.[4]

Literature

Although tentatively related approaches may have been made, the combined approach of the incumbent's benefits provision weighted against the probability of revolution appears not to have been considered in the literature in this manner. Grossman (1991) considers insurrections, and whether they can be deterred, as economic activities that compete with production for scarce resources. Accordingly, potential revolutionaries assess the time allocated to insurrection versus the time allocated to alternative activities, and they then choose an equilibrium with the highest expected income. Furthermore, Grossman (1999) assesses revolutions as kleptocratic rivalry where the incumbent chooses an optimal tax rate, striking a balance between production, funding soldiers, and suppressing revolutions, while assessing the revolutionaries' skills and preferences relative to the incumbent soldiers' skills. Grossman's (1999) choice of a tax rate has an impact similar to the incumbent's choice of benefits provision in this article, which affects whether or not revolutions occur.[5]

Revolutions occur with an inherent probability dependent on a country's characteristics. A country's incumbent leader can decrease this probability by providing benefits to a population. Decreased benefits increase the share of revolutionaries which, in turn, decrease the cost of revolt which helps resolve the free-rider problem implicit in revolting. The article quantifies how the incumbent chooses whether or not to provide benefits, and how many benefits to provide. The model helps to understand the logic of revolutionary uprisings and how they may be curtailed.

The literature on political revolutions is substantial and considers many facets. Kuran (1989) presents a theory of how political revolutions could occur in unanticipated ways. Examples include the 1789 French revolution, the 1917 Russian revolution, and the 1978–1979 Iranian revolution, all of which are often deemed to have come as a surprise. Bailyn (1992) considers the ideological origins of the 1765–1783 American revolution. More recently, the series of Arab spring revolutions were equally unanticipated. Beissinger (2007) develops an approach to understanding modular political phenomena such as revolutions, which occur as an emulation of the prior successful example of others, such as the post-communist revolutions of 2000–2006 and the Arab spring revolutions. Foran (1993) analyzes the earliest revolution theories and argues for the need to move to a new paradigm based on modeling economic, political, and cultural processes. Besley and Persson (2010) focus on conflict within the context of state capacity and development.[6]

Tullock (1971, 1974) made seminal contributions to our understanding of revolutions perceiving them mythical because of the free-rider dilemma (Olson, 1965) that an oppressed people will rise against a tyrannical ruler. A substantial literature has emerged explaining why and how revolutions nevertheless occur. If revolution is successful, the incumbent is replaced with someone else. For example, after 23 years in power, Tunisian President Zine El Abidine Ben Ali fled to Saudi Arabia on 14 January 2011, 28 days after the 17 December 2010 uprising.[7]

The following sections present our model, analyze how revolutionary uprisings are triggered and spread, and solve the model. The final section concludes.

The model

All incumbents fear revolution. We therefore consider an incumbent making a single strategic choice, namely, how many benefits, $G \geq 0$, where G is a real, noninteger number, to provide to the population while assessing the risk of revolution. The incumbent's unit cost of benefits provision is g. The incumbent is assumed to estimate the revolution probability, p, as

$$(1)\ \ p=p(G)=\frac{1}{\alpha+\gamma G}, \frac{\delta p}{\delta \alpha}\leq 0\,,$$

with the first and second derivatives of G given by

$$(2)\ \ \frac{\delta p}{\delta G}=\frac{-\gamma}{(\alpha+\gamma G)^2}, \frac{\delta^2 p}{\delta G^2}=\frac{2\gamma^2}{(\alpha+\gamma G)^3}\,.$$

Equation (1) reflects the inherent revolution probability, where $\alpha \geq 1$ and $\gamma \geq 0$ are parameters specific for a given country. Without benefits provision (i.e., when $G=0$), equation (1) simplifies to the benchmark $p=1/\alpha$, where α is an average population satisfaction, well-being, prosperity, bliss, or societal happiness parameter. When $\alpha=1$, people are unsatisfied, unhappy, and sometimes vengeful, resentful, vindictive, rebellious, and hostile, with the consequence that $p=1$, and revolution occurs with certainty. The more content the population, the larger is α, and therefore the smaller is the probability (p) of revolution.

The benchmark revolution probability $p=1/\alpha$ when $G=0$, is deemed high when unemployment, inequality, and ethnic fractionalization are high, institutional development is lacking, and implicit government repression is high. Further factors affecting $1/\alpha$ are colonial origins and a country's resources, especially natural resource, the ready availability of which may make an incumbent less likely to adhere to the population's concerns. Included in α is the common occurrence that incumbents apply surveillance, supervision, indoctrination, spies, bribes, punishments for treason, and so on, to prevent revolutions (Tullock 1971, 1974).

The population observes the incumbent's choice of benefits provision, G. Whether the population chooses to start a revolution depends probabilistically on the incumbent's choice of G. (The next section considers the actual behavior of citizens.) Beyond $1/\alpha$, the incumbent is assumed to be able to decrease the revolution probability by providing benefits, G. The benefits impact parameter, γ, weighs benefits G against α and reflects the extent to which the incumbent's benefits provision affects the population in the sense of decreasing the revolution probability, p. The γ parameter also depends on the country's characteristics. For example, when $\gamma=0$, benefits provision, G, does not affect the revolution probability, p, a case that can be interpreted as extreme implicit government repression. More realistically, when $\gamma>0$, the country's situation is such that the incumbent may have incentives to choose positive benefits provision, $G>0$, although that depends on the total cost, gG, of benefits provision which has to be weighed against the incumbent's benefit of avoiding revolution. For the extreme events of $\alpha=1$ and $\gamma=0$, or of $\alpha=1$ and $G=0$ when $\gamma>0$ (since the incumbent cannot afford benefits provision), revolution is guaranteed. Commonly $\alpha>1$, and when α increases as a country's situation improves, revolution becomes less likely. Similarly, when G increases, the revolution probability decreases. A revolution is less probable when α, γ, and/or G are large.

The incumbent benefits if no revolution occurs (or if it is unsuccessful). This occurs with probability $1-p$. We assume that the incumbent benefits in proportion to $1-p$. That is, if revolution is unsuccessful, the incumbent obtains benefit proportional to 1, and incurs a total cost, gG, of providing benefits to the population. In contrast, if the revolution is successful, with probability p, the incumbent obtains benefits proportional to 0, which corresponds to being ousted from government and being replaced with someone else, and incurs total cost, gG, of benefits provision to the population.

Accounting positively for the benefit $1-p$ of no revolution, and subtracting total cost, gG, of benefits provision to the population, the incumbent's expected utility, U, is given by

$$(3)\ \ U=1-p-gG=1-\frac{1}{\alpha+\gamma G}-gG \ if\ \frac{-\gamma g G^2+(\gamma-\alpha g)G+\alpha-1}{(\alpha+\gamma G)}\geq 0$$

and 0 otherwise, where g is the unit cost of benefits provision which then scales total cost, gG, against the probability, p. The if-condition in equation (3) follows from requiring positive expected utility $U\geq 0$. When $G=0$, the if-condition simplifies to $1-1/\alpha \geq 0$, which is always satisfied since $\alpha \geq 1$. Because of the quadratic term, $-\gamma g G^2$, the if-condition is not satisfied when G is arbitrarily large. Hence an upper limit exists for G. The if-condition in equation (3) can also be written so that the incumbent does not provide benefits, G, when $p \geq 1-gG$, i.e., when the revolution probability is high. However, increased G decreases the revolution probability. Later in the article we will see that provided that the incumbent has an incentive to choose positive $G\geq 0$, the expected utility cannot be negative.

When $p=1$ in equation (3), the first term with $1-p$ is 0 since the incumbent loses the revolution, gets no benefits, but incurs the cost, gG. In contrast, when $p=\epsilon>0$, where ϵ is arbitrarily small but positive, which occurs when α is arbitrarily large, the incumbent earns $1-\epsilon$ at the total cost of gG. If α is large, even modest benefits provision in the form of low G has the effect of lowering p. In contrast, if α is small, modest benefits provision G may increase p noticeably.

Summing up, the incumbent chooses benefits provision, G, to curtail the probability, p, of revolution. The revolution probability decreases as G increases, but providing G entails a cost, gG, which has to be weighed against the possible benefit of preventing the revolution.

How revolutionary uprisings are triggered and spread

Analysis and linkage to Granovetter

During a revolution, we observe participation by the population in riots or collective behavior which grows over time until the revolution succeeds or fails, and also depending on how the incumbent reacts. The dynamics of this collective behavior, analyzed by Granovetter (1978), can be linked directly to the parameters of the probability of a revolution. In Tunisia, the revolution began when vegetable vendor Mohammed Boazizi set himself on fire on 17 December 2010 in reaction to ill treatment by public officials and the police. President Ben Ali had earlier, in 2009, run fraudulent elections. In 2011, he then faced a revolution sparked by the eventual death of Mr. Boazizi from his burns.

We assume that the growth in the size of the participating crowds in the riots is proportional to the revolution probability, p, in equation (1). That is, growth is inversely proportional to the characteristics of the country captured by the parameter α, and inversely proportional to the incumbent's benefits provision, G, as moderated by parameter γ. When the denominator in (1) is low, and it cannot be below 1, then probability, p, of a revolution is high. If the country has high information and communication technology connectivity and developed media channels, then crowds have easier access to information and can mobilize more rapidly.

We now link our model to Granovetter's exposition. As mentioned, participation by the population in collective behaviors such as riots can grow over time until such time that it succeeds or fails depending on how the incumbent reacts. The bigger the crowd, the more likely is revolution. Therefore, we analyze how revolution can grow and spread within the country or region. The Arab spring revolutions of 2011 began in Tunisia and then spread to other parts of the MENA region, such as Bahrain, Egypt, Jordan, Libya, Morocco, Saudi Arabia, and Syria.

As in Granovetter (1978), consider the Boazizi incident which sparked the revolution. The revolutionaries reacted by taking to the streets demanding justice and, eventually, that President Ben Ali leave power. Denote the threshold for a revolutionary uprising by z. Then the frequency distribution is $f(z)$. The proportion of the population having a threshold less than or equal to z is given by a cumulative distribution function $F(z)$. Denote the point in time when a proportion of the population has joined the uprising with t, and let $r(t)$ be the proportion of the population which has joined at time t. Granovetter (1978) shows that the process of riot participating follows the difference equation

(4) $r(t+1) = F[r(t)]$

with an equilibrium at

(5) $F(r) = r$.

There then is a value of the probability of participation in a revolutionary riot, $F(r)=p$, at which the revolution succeeds. We thus link our model to Granovetter's analysis with the following definition.[8]

Definition: Assuming that the share of revolutionaries is proportional to the winning probability, p, the probability of participation in a revolutionary riot, $F(r)$, equals p when the revolution succeeds, i.e.,

(6) $F(r)=r=p=\dfrac{1}{\alpha+\gamma G}$.

Justification: Equation (6) follows from the argument above and from equations (4) and (5).

The definition reformulates Granovetter's (1978) approach using the terminology of this article. It shows how the incumbent, by adjusting benefits provision, G, can affect participation in a revolutionary riot. The riot spreads as described by Granovetter (1978) but, additionally, is affected by the inherent revolution probability, the incumbent's potential benefits provision, and the effect these benefits have on the population. Combining the two modeling approaches provides richer insights into how revolutions spread, and how incumbents can govern, amplify, suppress, or ignore their spread.

Incumbent's benefits provision and the free-rider problem

To show how a decrease in the incumbent's benefits provision, G, helps resolve the free-rider problem, we start with Figure 1 which uses equation (6) to plot the revolution probability, p, as a function of benefits provision, G. Due to irrelevance for the argument, scaling along the axes has been suppressed. (That said, Figure 1 uses equation (6) to plot p for α=1.2, γ=1, where G=high=3 and G=low=1.) Figure 1 and equation (6) illustrate that decreased benefits provision, G, increases the proportion $r=p$ of the population which has joined the revolution at time *t*. To show that this alleviates the free-rider problem we introduce the time dimension by considering three subsequent points in time, referred to as periods 1, 2, and 3.

In period 1, which may or may not be an equilibrium situation, the incumbent chooses high benefits provision, *G*, and the share of revolutionaries *r*=*p* happens to be low (see Figure 1). In period 2, we assume that the incumbent and a citizen in the population play the ordinal simultaneous move cooperation/defection 2x2 game in Table 1. Cooperation for the incumbent means to provide highly costly benefits, *G*=high, to the population, including the citizen. Conversely, the incumbent defects if *G*=low. If the incumbent chooses defection in period 2, we assume that the citizen's cost of revolting remains the same since the players choose their strategies simultaneously. This is realistic in practice since the share of revolutionaries does not change instantaneously from *r*=*p*=low to *r*=*p*=high when the incumbent changes from *G*=high to *G*=low. Period 2 is thus not depicted in Figure 1. Cooperation for the citizen means not to revolt, which is not costly, and the citizen defects when revolting, which is costly. Assume uncontroversially that each player prefers the other player to cooperate. That is, the incumbent prefers the citizen not to revolt, and the citizen prefers high benefits, *G*=high. Further assume that the parameters are such that the incumbent finds it more costly to provide high benefits, *G*=high, than low benefits, *G*=low, and overall prefers the latter to the former, regardless of whether the citizen revolts or not. Analogously, assume that the citizen finds it more costly to revolt than not to revolt, and overall prefers the latter to the former, regardless of whether the incumbent provides high or low benefits. The ordinal ranking of payoffs 4, 3, 2, and 1 from high to low for the two players are thus as in Table 1. The payoff before the comma in each cell is for the incumbent in the row. The payoff after the comma in each cell is for the citizen in the column.

The ordinally preferred payoff for each player for each possible strategy of the other player is shown in **bold typefont**, causing the Nash equilibrium 4,2 in the lower-left corner in period 2, i.e., payoffs 4 and 2 to the incumbent and citizen, respectively. This contrasts with period 1 depicted in the upper-left corner and payoffs 3,4 which are not an equilibrium in period 2. That is, in the transition from period 1 to period 2, the incumbent decreases his benefits provision from *G*=high to *G*=low, increasing his payoff from 3 to 4. The payoffs 4,2 in Table 1 constitute a Nash equilibrium in period 2 so long as the citizen continues not to revolt. As time elapses and we move to period 3, the period 2 Nash equilibrium becomes controversial since the incumbent's decrease of benefits provision, *G*, from high in period 1 to low in period 2 has consequences. More specifically, according to equation (6), decreasing *G* from high to low eventually increases the share *p* of revolutionaries from low to high causing point *B* in Figure 1.

Figure 1: Revolution probability *p* as a function of benefits provision *G*.

Table 1: Cooperation/defection game between the incumbent and a citizen in a population

Citizen / *Incumbent*	*Cooperate (not revolt, which is not costly)*	*Defect (revolt, which is costly)*
Cooperate (provide highly costly benefits, G=high, to population)	3,**4**	1,3
Defect (provide less costly benefits, G=low, to population)	**4**,**2**	**2**,1

Table 2: Games between any two citizens 1 and 2 when *G*=high and *p*=low (left panel) and *G*=low and *p*=high (right panel)

	G=high; *p*=low		*G*=low; *p*=high	
Citizen 2 / *Citizen 1*	*Not revolt*	*Revolt*	*Not revolt*	*Revolt*
Not revolt	**2**,**2**	**4**,1	1,1	3,**2**
Revolt	1,**4**	3,3	**2**,3	**4**,**4**

To illustrate this phenomenon we proceed with the two games in Table 2. The ordinal 2x2 game on the left-hand side panel in Table 2 between any two citizens 1 and 2 in the population shows the game with high incumbent benefits provision, G=high, causing a low share r=p of revolutionaries, as in period 1. Accordingly, the cost of revolting is high, in fact so high that each citizen prefers not to revolt regardless of whether the other citizen revolts or not. However, each citizen prefers that the other citizen incurs the high cost of revolting since a revolution may benefit both. Collectively, joint revolt is preferable to joint non-revolt. This gives the familiar prisoners' dilemma with the unique Nash equilibrium in the upper-left cell, where no citizen revolts.

In contrast, the ordinal 2x2 game on the right-hand side panel in Table 2 between citizens 1 and 2 assumes low incumbent benefits provision, G=low, causing a high share r=p of revolutionaries, as in point B in Figure 1. We may assume that the high share, r=p, exceeds the critical k-threshold (Granovetter, 1978) for participation in the revolution. Since many other citizens, aside from the two in Table 2, have already started revolting, the costs of citizens 1 and 2 also joining the revolution is lower. In fact, assume that the cost of revolting is so low that each citizen in Table 2 prefers to revolt regardless of whether the other citizen revolts or not. This is possible when the benefits and probability of revolution are both high. Furthermore, each citizen prefers the other citizen to revolt regardless of whether oneself revolts. This gives the coordination game with the unique Nash equilibrium in the lower-right cell, where both citizens revolt. Table 2 illustrates how the incumbent's decrease of benefits provision from G=high to G=low helps overcome the free-rider problem inducing more citizens to join the revolution.

Social media and revolution

Social media enable revolutionaries to coordinate their activities quickly. The emergence of digital and social networking technology gradually overcomes various spatial divides in the spread of uprisings within a country or region. These media channels help swell the ranks of riots rather rapidly causing a likely unstoppable revolutionary situation for the incumbent. For example, Tunisia has a large population using mobile telephony, which facilitates communication.

The social networking capability also enables the information on an uprising in one geographic region to spread rapidly to other regions, thus engulfing an entire country. This ability also enables information to be transmitted to other countries in the neighborhood or with similar autocratic leadership, thus sparking a revolution in those countries as well. This describes what happened in the MENA region in 2011 and 2012. The spatial and temporal effects highlighted by Granovetter are lessened or altogether overcome by these technological enablers.

A literature has emerged in this regard. First, Starbird and Palen (2012) consider Twitter retweeting during the 2011 Egyptian uprising, revealing interaction between activists on the ground in Cairo and others elsewhere. Applying qualitative and statistical description, they show how the crowd expresses solidarity, and engages in recommendation and filtering, and how retweet-recommendations can be used together with other indicators from the ground to identify new information. Second, O'Leary (2016) analyzes cooperative retweeting settings, such as during the Arab spring revolutions, as games between retweeters, applying tit-for-tat strategies for retweeting, and considers retweet hijacking. Third, Pena-Lopez, Congosto, and Aragon (2014) consider networked citizen politics, involving decentralization and swarm-like Twitter action, among Spanish *Indignados* on 15 May 2011 and thereafter, one week prior to local and regional elections, and links to formal democratic institutions. Fourth, Lysenko and Desouza (2012) analyze the April 2009 Moldovian revolution. Initial mobilization occurred through social network and short-message services. Twitter was mostly used late in the revolution, to communicate locally and globally. They find that a successful revolution can occur with limited prior offline organization.

Solving the model

Having analyzed how revolutionary uprisings are triggered and spread, we now proceed to analyze the incumbent's optimal benefits provision.

Theorem 1: The incumbent's optimal benefits provision, G, revolution probability, p, and expected utility, U, are

$$G=\frac{\alpha}{\sqrt{\gamma g}}\left(\frac{1}{\alpha}-\sqrt{\frac{g}{\gamma}}\right) \ if \ \sqrt{\frac{g}{\gamma}}\le\frac{1}{\alpha}, \text{ 0 otherwise;}$$

$$(7)\quad p=\sqrt{\frac{g}{\gamma}} \ if \ \sqrt{\frac{g}{\gamma}}\le\frac{1}{\alpha}, \text{ 1/}\alpha\text{ otherwise;}$$

$$U=\left(1-\sqrt{\frac{g}{\gamma}}\right)^2+(\alpha-1)\frac{g}{\gamma} \ if \ \sqrt{\frac{g}{\gamma}}\le\frac{1}{\alpha}, \ 1-1/\alpha \text{ otherwise.}$$

Proof: The incumbent chooses the optimal G by differentiating U in (3) with respect to G. Equating the derivative with zero, solving, and inserting into (1) and (3), give (7). The second-order derivative is always satisfied as negative, i.e.,

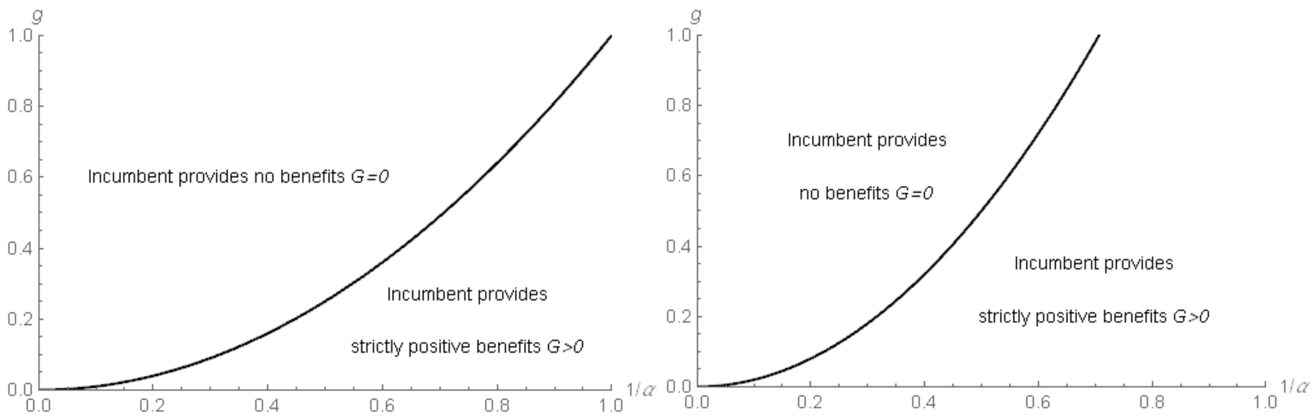

Figure 2: Two regions in the $(1/\alpha,\gamma)$ parameter space, separated by $g=\gamma/\alpha^2$, showing how the incumbent provides benefits when $g<\gamma/\alpha^2$, or does not provide benefits when $g\geq\gamma/\alpha^2$. Left-hand side panel: $\gamma=1$. Right-hand side panel: $\gamma=2$.

(8)

$$\frac{\delta U}{\delta G}=\frac{\gamma}{(\alpha+\gamma G)^2}-g=\gamma p^2-g=0 \; if \sqrt{\frac{g}{\gamma}}\leq\frac{1}{\alpha}, \text{ 0 otherwise;}$$

$$\frac{\delta^2 U}{\delta G^2}=\frac{-2\gamma^2}{(\alpha+\gamma G)^3}<0 \; if \sqrt{\frac{g}{\gamma}}\leq\frac{1}{\alpha}, \text{ 0 otherwise.}$$

The first-order derivative in equation (8) shows that for the incumbent's optimal benefits provision, G, the marginal benefit, γp^2, equals the marginal cost, g. This means that if the revolution probability, p, is low (high), squared, and multiplied with the benefits impact parameter, γ, then G is determined so that the marginal cost, g, is also low (high). Theorem 1 states that the square root of the ratio of the unit cost, g, and the benefits impact parameter, γ, has to be less than the inherent revolution probability, $1/\alpha$, for the incumbent to provide benefits, G, to the population. That is, providing benefits has to be sufficiently cheap, and/or the effect of the benefits has to be sufficiently large, for the incumbent to find it worthwhile to provide benefits. Provided that

(9) $G\geq 0 \Leftrightarrow \sqrt{g/\gamma}\leq 1/\alpha$,

the incumbent's expected utility, U, in equation (7) is always positive since it consists of a quadratic term and a positive term $(\alpha-1)g/\gamma$, where $\alpha\geq 1$.

Applying (7), Figure 2 shows two regions in the $(1/\alpha,\gamma)$ parameter space, separated by the curve $g=\gamma/\alpha^2$. When $g<\gamma/\alpha^2$, the first line in (7) applies, and the incumbent provides strictly positive benefits, $G>0$. That occurs when the unit cost, g, of benefits provision is low or the inherent revolution probability, $1/\alpha$, is high. Conversely, when $g\geq\gamma/\alpha^2$, the second line in (7) applies, and the incumbent provides no benefits, $G=0$. The left-hand side panel assumes $\gamma=1$, which gives a low curve with a large region for not providing benefits. The right-hand side panel assumes a γ twice as large, $\gamma=2$, causing the demarcation curve to increase more steeply, enlarging the region of benefits provision due to larger effect of benefits on curtailing the revolution probability.

Theorem 2: If $\sqrt{\frac{g}{\gamma}}\leq\frac{1}{\alpha}$ then

(10)

$$\frac{\delta G}{\delta \alpha}=\frac{-1}{\gamma}\leq 0,\ \frac{\delta p}{\delta \alpha}=0,\ \frac{\delta U}{\delta \alpha}=\frac{g}{\gamma}\geq 0,$$

$$\frac{\delta G}{\delta \gamma}=\frac{-\alpha}{\gamma^{3/2}\sqrt{g}}\left(\frac{1}{2\alpha}-\sqrt{\frac{g}{\gamma}}\right)\geq 0 \; if \sqrt{\frac{g}{\gamma}}\leq\frac{1}{2\alpha},$$

$$\frac{\delta p}{\delta \gamma}=\frac{-\sqrt{g}}{2\gamma^{3/2}}\leq 0,\ \frac{\delta U}{\delta \gamma}=\frac{\sqrt{g\alpha}}{\gamma^{3/2}}\left(\frac{1}{\alpha}-\sqrt{\frac{g}{\gamma}}\right)\geq 0,$$

$$\frac{\delta G}{\delta g}=\frac{-1}{2g^{3/2}\sqrt{\gamma}}\leq 0,\ \frac{\delta p}{\delta g}=\frac{1}{2\sqrt{\gamma g}}\geq 0,\ \frac{\delta U}{\delta g}=\frac{-\alpha}{\sqrt{\gamma g}}\left(\frac{1}{\alpha}-\sqrt{\frac{g}{\gamma}}\right)\leq 0$$

Proof: Follows from differentiating (7).

Theorem 2 provides nine insights. *First*, and perhaps most crucial as advice to any incumbent, the incumbent's benefits provision, G, increases as the inherent revolution probability, $1/\alpha$, increases (i.e., the population's satisfaction parameter, α, decreases), driven by the incumbent's desire to prevent revolution by providing benefits. *Second*, and relatedly, the incumbent's expected utility, U, decreases as the inherent revolution probability, $1/\alpha$, increases. This result is driven, in part, by the cost to the incumbent to be located in a country with high $1/\alpha$, but also by that it is costly to provide benefits, G. *Third*, the incumbent's expected utility, U, increases as the benefits impact parameter, γ, increases. This follows since any given amount of benefits provision, G, now has larger effect on decreasing the revolution probability. Thus, *fourth*, the revolution probability, p, decreases as the benefits impact parameter, γ, increases. Hence, *fifth*, and conversely, the revolution probability, p, increases as the incumbent's unit cost, g, of benefits provision increases. This follows since, *sixth*, a larger g causes a lower G, which fails to decrease the revolution probability, p. Hence, *seventh*, the incumbent's expected utility, U, decreases as the unit cost, g, of benefits provision, G, increases. *Eighth*, the revolution probability, p, does not depend on the inherent revolution probability, $1/\alpha$, since when the incumbent provides benefits, these benefits depend on $1/\alpha$, and p depends only on g and γ. Finally, *ninth*, the benefits impact parameter, γ, has a mixed effect on the incumbent's benefits provision, G. When $\sqrt{g/\gamma} \leq 1/2\alpha$, which occurs when the unit cost, g, of benefits provision is low, or γ is large, or the inherent revolution probability, $1/\alpha$, is large, G increases as γ increases. This follows since when it is cheap to provide benefits, and the effect is large, and the inherent revolution probability is large, then increasing the impact parameter, γ, induces more benefits to be provided. However, this no longer holds when $\sqrt{g/\gamma} > 1/2\alpha$. In that case, increasing γ causes lower G. Hence, as $\sqrt{g/\gamma}$ increases from less than to greater than 1/2 , eventually G decreases as γ increases.[9]

Conclusion

This article analyzes revolutionary uprisings such as the Arab spring. An inherent revolution probability is considered, dependent on a country's characteristics. This probability is affected, and potentially decreased, by the incumbent leader of a country providing benefits to the population, e.g., public goods such as health care and security. We analyze how revolutionary uprisings are triggered and spread, incorporating Granovetter's (1978) model of collective behavior and riots. The proportion of the population that has joined the revolution at a given time is modeled as a difference equation. The equilibrium proportion is equated with the revolution probability, affected by the inherent revolution probability and the incumbent's benefits provision. We show how a decrease in the incumbent's benefits provision helps resolve the free-rider problem where citizens hope that others will incur the cost of revolting. Lower incumbent benefits provision increases the share of revolutionaries joining the revolution. When others already revolt, the cost of revolting for aditional citizens is lower.

The incumbent leader of the country can decrease the revolution probability by providing benefits to the population, e.g., public goods such as health care, education, and security. The reasoning process of the incumbent, affected by the probability that the population revolts, is modeled. The article quantifies the incumbent's various considerations.

The incumbent chooses strategically, at any point in time, or after an instigating event, how many benefits to provide to the population. Positive benefits mean accommodation. Examples of instigating events are fraudulent elections or mass demonstrations. The incumbent weighs the benefit of obtaining a low revolution probability against the cost of providing benefits, while accounting for the effect of benefits provision. The incumbent does not want to obtain a low revolution probability at any cost. Thus a frequently observed outcome, such as no benefits provision combined with losing the revolution, may arise because it gives the incumbent the highest expected utility.

We find that the incumbent, through adjusting benefits provision, can affect the participation in a revolutionary riot. The riot spreads as described by Granovetter (1978), and additionally is affected by the inherent revolution probability and the incumbent's benefits provision. Combining the two modeling approaches provides richer insights into how revolutions spread and how incumbents can govern or ignore their spread. Such insight is useful for incumbents, populations, revolutionaries, opponents of revolutionaries, policymakers, and leaders and actors in neighboring countries. Our model is applicable as a tool for adjusting the parameter values to determine the development and outcome of revolutions. Future research may search for data to support the comparative statics performed in this article.

Notes

We thank two anonymous referees of this journal for useful comments.

1. Probabilistically: We do not model the armed forces as a separate player since so many possibilities exist for how it operates. Most commonly the incumbent controls the army, or the army chooses to be loyal to the incumbent. Yet examples also exist where the armed forces support the population. It is

also possible, at least in theory, that the armed forces may support the challenger. Our approach allows for all of these interpretations. Threshold: See Granovetter (1978).

2. Olson: Olson (1965).

3. Instigating event: For a survey on the causes of civil war, see Blattman and Miguel (2010) who describe studies of cross-sectional inference using country-level data and panel-data studies accounting for within-country variation. Fraudulent elections: Reasons for why instigating events may emerge more easily in the Middle East have been explored by Kuran (2010, 2012). He argues (Kuran 2010) that the doctrine of Islamic economics is simplistic, incoherent, and largely irrelevant to present economic challenges, and that (Kuran 2012) what slowed the economic development of the Middle East was that, since around the tenth century, Islamic legal institutions started hampering the emergence of features such as private capital accumulation, corporations, large-scale production, and impersonal exchange. Violence and manipulation: See, e.g., Hermet, Rose, and Rouquié (1978) and Schedler (2007). The cost to the population of flawed elections involves loss of life, physical and mental injury, suppression of freedom of speech, and human rights violations. The election process can strengthen democratic institutions, but can worsen conflict (Collier 2009). The violent nature of election processes can have links to colonial roots (Acemoglu and Robinson 2006). Ellman and Wantchekon (2000) consider situations where one strong party controls sources of political unrest. This party likely wins with asymmetric information about its ability to cause unrest. Other related studies include Alesina (1988), Alesina and Rosenthal (1995), and Calvert (1985). See Lindberg (2006) for an analysis of democracy and elections in Africa. See Zimmermann (2012) for theories of violence and revolutions, and Migdal (2015) for revolutions and social change in the third world.

4. Syria: For a survey on the determinants of government repression and human rights violations, see Davenport (2007). The nexus of economic inequality, revolutions, and conflict has been analyzed by Besancon (2005). Revolution has been described: Goodwin (2001, p. 9).

5. Soldiers: Such funding is a delicate balance. Acemoglu, Vindigni, and Ticchi (2010) observe a common phenomenon after world war two where, in weakly institutionalized polities, civilian governments due to fear of military coups may choose weak armies that cannot end insurrections, thus prolonging civil wars. Revolutionaries' skills: See Casper and Tyson (2014) for elite coordination and popular protest in a *coup d' etat*, and Edmond (2013) for information manipulation, coordination, and regime change. Soldiers' skills: The interaction between revolutionaries and regime has also been analyzed by Angeletos, Hellwig, and Pavan (2007). They consider coordination among attackers over time and learning, e.g., about regime survival.

6. Russia: McFaul (2002) considers the Russian revolution to be unfinished.

7. A substantial literature: See, e.g., Kurrild-Klitgaard (2003) and Lichbach (1995) for reviews. Incumbent is replaced: A contest between an incumbent and a challenger is analyzed by Besley and Persson (2011) who assume simultaneous choices of the sizes of the armies by the two players, which determines who becomes the new incumbent. After that determination, the new incumbent determines public goods provision and revenue transfers.

8. In Definition 1 we have for simplicity ignored thresholds, and the share of revolutionaries may in practice be S-shaped as a function of the winning probability, p. That can be incorporated in future research.

9. Theorems 1 and 2 can be used to summarize the effect of parameters α, γ, and g on variables G, p, and U. A tabular presentation with the relevant mathematical expressions is available upon request from the corresponding author.

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