Sources of inefficiency in the procurement of major weapon systems. Estimates for the German case

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Abstract

The objective of this article is to provide a rough estimate of inefficiencies in German major weapons procurement. It is possible to derive estimates of procurement inefficiencies for 2022 programs—arising from a failure to exploit economies of scale, the complexity of co-production projects, cost overruns and time delays, and low weapon utilization rates. As the necessary data is only partly available to the public, these estimates rely on several assumptions and so are presented as ranges. This article identifies two main causes of symptoms of inefficiency in German major weapons procurement: (a) technological requirements beyond the reach of arms producers at the time decisions on procurements were made, and (b) protectionism, i.e. the favoring of national arms producers. Overall, it is estimated that German taxpayers could have been spared a least a third of total procurement costs had these inefficiencies been avoided.

The procurement of major weapons takes up a large share of military spending in many countries. NATO member states are committed to spending at least 20 percent of their military expenditures on major weapons. Germany decided on a major spending program of EUR 100bn over five years following the Russian invasion of Ukraine in early 2022. At the same time, weapon system procurement is prone to being wasteful. The objective of this article, which is based on a study prepared for Greenpeace Germany,[1] is to provide a rough estimate of the scale of the inefficiency manifested in the quantifiable aspects of recent German arms procurement.

The procurement of major weapons is a complex process, not least because it is driven by various, partly conflicting, interests and objectives. Armed forces seek systems that are on the cutting edge of the technological frontier, tailored to their specific national needs. Arms producers have an interest in expanding their sales through international competitiveness, but also in protecting their national markets through their governments. Politicians with political bases in locations where major arms are produced have an interest in bringing major procurement contracts to their constituencies. Those who focus on security policy will see a benefit in joint production with allies—an objective that is particularly strong among member states of the European Union. Procurement authorities exercise the utmost cautiousness in an environment marked by manifold legal requirements and political interference, leading to arduous and lengthy procurement processes.

The multitude of interests and objectives at stake in major weapons procurement can lead to technical inefficiency, defined as a failure to procure weapon systems of a desired quantity and quality with a minimum expenditure of resources. Secondary objectives beyond the primary goal of providing armed forces with appropriate weapons can lead to time delays, additional production costs, and poorly performing systems. From the taxpayer's perspective, such technical inefficiency has consequences for allocation—money could be saved, and thus put to other purposes, if procurement of major weapons were focused on providing armed forces with appropriate and functioning systems at the lowest possible cost, rather than pursuing various additional objectives.

Data on recent German major weapon procurements allow for rough estimates of the scale of inefficiencies

1 Brzoska (2022).

stemming from three major causes: a preference for nationally produced (or co-produced) arms; the imposition of specific national requirements on international co-production projects (the "Germanization" of weapon systems); and overcomplexity of major weapon systems. When it comes to the German armed forces' weapon system inventory, these are reflected in non-competitive pricing, cost overruns and time delays, and low utilization rates. Much insight for cost overruns and time delays can be gleaned from the available official German data—the causes of non-competitive pricing, which can roughly be quantified based on the available data, include a failure to exploit potential economies of scale and overly complex co-production programs. Beyond the official data, this article relies on a number of assumptions to arrive at ranges of estimates of additional costs stemming from these four symptoms of German procurement programs current in early 2022.

Within the constraints of the publicly available data and consequent necessary assumptions, difficulties associated with the complexity of both weapons production and the weapon systems procured by the German armed forces were the largest source of inefficiency for Germany. Another important source was inefficiencies stemming from the organization of production, including Germany's preference for national production and its willingness to enter into complex forms of co-production. Major savings could have been achieved with better economies of scale through pooling procurement with partners or buying from producers with long production runs. Additionally, large savings would have been achieved had they been satisfied with achievable levels of technological advancement.

Symptoms and sources of inefficiency

There are various ways to critically assess the efficiency of procurement processes. One is to focus on the weapon systems procured with a given budget and to analyze whether they are optimal with regard to the assigned functions of national armed forces.

Another way—one that avoids the thorny issue of measuring the degree to which procured weapon systems fulfil the assigned functions of national armed forces—is to consider efficiency in procurement from the angle of minimizing financial input for a given output: in this case, major weapon systems. Here, no attempt is made to assess weapon systems with respect to their quantity and quality; rather, it is assumed that procurement authorities order an optimal number of weapon systems for military preparedness. Even when this is assumed, however, inefficiencies can arise for a number of reasons, for example when:

- governments buy weapon systems at prices that are higher than they could have paid;
- procurement processes last longer than planned, with consequences for both military preparedness and costs (thanks to inflation during the procurement period and the additional cost of maintaining outdated weapon systems); and
- weapon systems that were considered optimal with respect to quality when procurement decisions were made, do not function as advertised—leading to additional costs associated with improving them or buying alternative systems.

Economies of scale

There are many reasons for the first symptom of inefficiency listed above (procurement prices being higher than could have been paid), such as not having an overview of the major weapon system market or corruption in the procurement process. Another reason—one that is discussed in more detail and assessed in quantitative terms below—is a failure to exploit economies of scale. Larger production runs generally lead to lower unit costs, and thus buying major weapons produced in larger quantities is likely to be cheaper than those of the same quality produced

Table 1: Protectionism in German arms procurement

Procurement from German sources (national "key technologies")	*Procurement from European cooperation or global sourcing*
Artificial intelligence	Air defense
Cryptography	Fixed wing aircraft
Electronic warfare technologies	Helicopters
IT communication hardware	IT communication hardware
Naval shipbuilding (surface and submarine)	Missiles
Networked operations control	NBC defense
Protected/armored vehicles	Small arms
Protection technologies	Unprotected vehicles
Security-relevant IT and communications technologies	
Sensorics	

Source: Bundesregierung (2020).

in smaller numbers. Procuring weapons from smaller production runs, when larger runs were possible, produces *economies of scale inefficiency*.

Why would procurement authorities forego the savings that could be achieved through larger production runs? In the German case,[2] several factors have led to economies of scale inefficiency in the recent past.[3] One is the objective of maintaining national arms production capabilities, implemented through protectionist measures. A second factor is the German armed forces' preference for weapon systems that are tailored to their specific requirements. As a consequence, the German armed forces have often lobbied for German-produced systems ("Germanisation") which differ from the weapon systems procured by other armed forces and thus do not come with the same cost-saving benefits as systems produced on a larger scale.

A further cause is the objective of fostering European arms co-production. Producing arms jointly with other European nations increases production runs beyond national production but is also often protectionist against the formidable U.S. market—and this particularly so because co-production introduces costs of its own. Much depends on how co-production is carried out. In many cases, it is similar to national production through "Germanization" and an insistence on *juste retour* in production shares, as discussed below.

The interest in protecting the German arms industry in procurement decisions and agreements with partners on German work-share in collaborative projects has several sources: from the self-interest of arms producers to regional politics, and the widespread assumption that even if one is militarily dependent on a military alliance (such as NATO), having a national arms industry is strategically important. While allowing protectionist interests to influence procurement decisions is logical from the perspective of certain interest groups—such as politicians who are politically tied to constituencies where major arms are produced—they result in economies of scale inefficiency when

2 For an overview of German arms production capacities and policies, see Brzoska (2019).
3 Following the Russian attack on Ukraine in February 2022, the German government authorized a major fast-track procurement program of EUR 100bn, which could not be served by the German arms industry in major areas, leading to several foreign purchases, including F-35 fighter aircraft and CH-47 Chinook helicopters from the United States.

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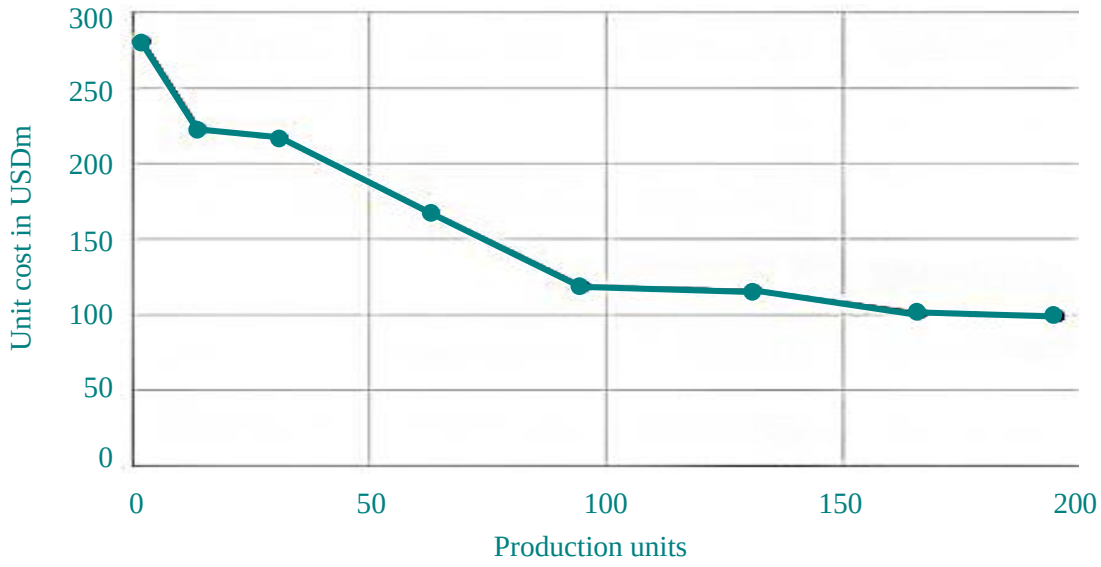

Figure 1: Learning cost curve for production batches of the F-35
Source: Arepally (2017).

comparable weapon systems with longer production runs could have been purchased.

The German government and the German arms industry have negotiated lists indicating which types of weapon systems should be reserved for production in Germany, those which ought to be procured from European sources, and which could be procured from anywhere. The last such list of "key technologies" was made public in 2021, when surface naval ships were added (see Table 1 above). Remarkably, the list includes both technologies that are widely seen as security sensitive, such as cryptography and IT communications hardware, and technologies that are not, such as armored vehicle production and shipbuilding. Interestingly, measured by exports to other countries, German producers are highly competitive in these two areas of arms production, indicating that the list may have been shaped by political lobbying power in addition to security concerns.

Even though exports of small and medium-sized submarines, surface naval ships, and tanks from Germany are sizeable, economies of scale obtained by German arms producers remain limited in these areas of arms production. They are much smaller in some other areas, particularly aerospace and electronics, where companies mainly have to rely on the German domestic market, which is small from a global perspective.[4] In many areas of military procurement, purchases from other countries are likely to be more cost efficient. The U.S. arms industry in particular has the potential to be more cost effective because of its technical proficiency, thanks to very high research and development expenditures and its generally longer production runs (due to the significant procurement spending for the U.S. armed forces and the United States' unparalleled levels of arms exports). Fixed costs, such as research and development expenditures and the cost of tooling production lines, can be distributed across a greater number of systems, resulting in lower unit costs. Furthermore, longer production runs imply cost savings through learning—this is particularly so for major weapon systems, which are typically produced in comparatively small numbers and so are more comparable to artisanal production than industrial production.[5] A typical example of a learning cost curve

4 Brzoska (2020).
5 Hartley (2008, 2013); Essig et al. (2016); Hogan (2020).

is shown in Figure 1 for the F-35 Lightning Multirole Fighter, produced in the United States. Arepally (2017) calculated a learning rate of 15.5 percent, meaning that a doubling of the number of systems produced reduces unit costs per aircraft by this amount. Learning costs in the range of 10 to 15 percent are typical of the production of major weapon systems in many Western countries.[6]

Pooling demand

The basis for economies of scale is a strong demand for a particular weapon system. Among allied countries, demand beyond the requirements of one country is often created by "pooling" procurement projects. This requires countries to agree on common specifications for weapon systems and the timing of weapon acquisitions. Pooling, for instance in NATO, has proven a difficult undertaking due to armed forces' opposition to compromising on specifications and timelines and disagreement among governments about production sites and shares. This lack of pooling has long been identified as a source of financial waste in NATO.[7] Potential pooling cost savings from pooling have been estimated in a number of studies. Of special interest has been increased pooling among European NATO members and EU member states. Estimates for this range from about 10 percent to 30 percent of procurement costs,[8] with the rates growing with the number of states and the number of their requirements.[9]

Co-production

In Western Europe, agreements on pooling demand for weapon systems often require parallel agreements on the details of production. A general practice is to go by the principle of *juste retour*, i.e. the principle that national shares in production ought to equal countries' shares in the funding of a joint procurement program. Such arrangements tend to lead to technically inefficient production. The companies chosen to participate in co-production projects are often not the producers the main contractors would have chosen had they been able to choose freely—with additional, non-optimal costs related to logistics and coordination among producers. In some cases, participation in co-production projects is primarily motivated by the goal of involving national producers (in order to generate employment or gain technical skills) rather than an interest in pooling. All this adds to the cost of weapon systems produced through co-production agreements compared to the cost of weapon systems produced through the use of a prime contractor.[10]

Co-production projects generally result in the provision of largely identical weapon systems for all partners. When the participating countries insist on specific requirements, however, this results in the production of widely different varieties of a common weapon platform. This further limits the savings that could have been obtained from pooling and exploiting economies of scale. An example is the Tiger attack helicopter, which was co-produced in widely different versions for the French and the German armed forces. Because of high costs and major time delays, in 2003 Germany finally cancelled its further participation in the program, which had been running for more than two decades.[11]

Cost overruns and time delays

A second symptom of inefficient procurement is cost overruns and time delays, i.e. departures from the costs and timelines originally agreed by procurement authorities and arms producers. These have been a regular feature of many large German procurement programs since the end of the Cold War.[12] A major source of cost overruns and

6 Hartley (2013); NATO (2015); Essig et al. (2016).
7 NATO (2015).
8 Küchle (2006); Wolf (2015).
9 Ballester (2013); Briani (2013); European Commission (2013, 2017).
10 Hartley (2008, 2016).
11 ESUT (2023).
12 Brzoska (2022).

time delays is overly demanding performance requirements imposed by armed forces, which are often stimulated (or at least tolerated) by arms producers. The willingness of arms producers to contract technological advances that they have yet to achieve is often based on a hope for technology gains funded by the procuring governments. Once such programs begin, governments are locked in and must generally agree to provide additional funds beyond the amounts initially required to cover the costs of trying to achieve promised benchmarks.

Another important source of cost overruns and time delays are changes to design and detail requirements made by armed forces during the procurement process. While in some cases these are small and easy to accommodate, in others they are major. As procurement programs often run over many years, such changes make sense as military technologies advance and the needs of armed forces change. However, this process often involves a catch 22: changes to design and detail lengthen procurement time, which in turn increases the likelihood of changes to design and detail.

Cost overruns and time delays are interrelated. Difficulties in meeting requirements and unplanned design changes will directly increase costs, and, indirectly, through the additional time it takes to produce the weapon system. At least in the German case, procurement contracts include inflation provisions, but the funds allocated to projects at the time of authorization only cover costs for the agreed procurement periods. Production beyond the agreed procurement timescale will be more expensive because of the longer inflationary period.[13]

Time delays are also likely to lead to additional costs beyond price inflation. Older weapon systems, which are often expensive to maintain, may need to be kept in service longer than planned, and stop-gap measures such as the interim procurement of alternative weapon systems may have to be adopted.[14]

Utilization rates

Once delivered to purchasing armed forces, weapon systems should be ready for use. When it comes to highly technologically advanced or overly demanding procurement programs, however, this is often not the case. Ideally, initial problems should be fixed in a timely manner. Weapon system utilization rates, defined as the share of fully operational weapon systems in the total number of weapon systems nominally held by the armed forces,[15] will rarely approach 100 percent, as systems often need to be in maintenance or are not fully operational because of a lack of trained personnel. However, low utilization rates are an indicator of bad procurement decisions and inefficiency with respect to spending procurement funds.

The German armed forces have had to cope with very low utilization rates when it comes to newly introduced weapon systems, such as various types of helicopters, but also ships and armored vehicles. Furthermore, there have been low utilization rates for weapons that have already been in service for some time, due to major technical problems or a lack of spare parts and trained personnel. The defense ministry and the German armed forces have launched several initiatives over the years to bring major weapon system utilization rates up to a considered acceptable level of 70 percent. These have been met with some success, but utilization rates for several weapon systems in the German armed forces have remained below this benchmark.[16]

Summary of symptoms and sources of inefficiency

Inefficiency in weapons procurement has a number of sources. Prominent among these in the context of Germany is a preference for involving German producers, either by procuring nationally or by insisting on *juste retour* in co-production projects. Political support for national producers is mostly driven by the regional economic interests of

13 Essig et al. (2016); (Wolf 2015).
14 Hartley (2020).
15 This is the definition used in this article. It corresponds to what is reported by the German Ministry of Defense in its reports (BMVg 2017a, 2019-2021a). Weapon systems procured by the armed forces but not currently in their possession because they are in maintenance with private companies are not considered.
16 BMVg (2021a).

parliamentarians but also stems from the perceived security benefits of maintaining a German arms industry. Lobbying by national arms producers majorly supports such perceptions.[17]

Another important source of inefficiency is the imposition of overly demanding requirements. Often, these aim at technological advancements near or beyond the capabilities of arms producers. While there is a case to be made for insisting on modern weapon systems, the additional costs of minor technological improvements often do not make operational sense. An insistence on weapon systems that are specifically tailored to an armed forces' preferences also limits the efficiencies that could otherwise be derived from the pooling of procurement.

Inefficiencies are also a feature of the way in which many co-production programs are organized. The German government is committed to increasing co-production in Europe but, along with its partners, has often been unable or unwilling to organize co-production efficiently. The weapon systems produced for the various partners in co-production programs often differ, sometimes substantially, and an insistence on distributing production shares according to shares in financing adds additional costs to production, beyond those resulting from the coordination of partners from various countries.

Data on German major weapons programs

Data on program cost, cost overruns, and time overruns

There is a long tradition of criticism of German major weapons procurement, and of procurement reforms, that mostly focuses on the bureaucracy surrounding procurement. In both the wider public and policy circles in Berlin, however, the general impression is that things got worse in the early 2000s, which saw projects with large cost overruns (such as the A400M transport plane) and costly weapon systems with major technical problems (such as the K-130 class corvettes).

When Ursula von der Leyen became Germany's first female Minister of Defense in 2013, she initiated another major attempt at procurement reform. Numerous outside business consultants were hired.[18] Lack of transparency in procurement processes was identified as a major source of inefficiency. The Defense Ministry decided to increase both the level of inhouse control over procurement processes and the level of publicly available information on procurement programs.

The Ministry of Defense began to publish biannual *Rüstungsberichte* in 2015.[19] In addition to a general discussion on the state of procurement and procurement reforms, these reports contain data on cost overruns and time delays in major weapon system procurement processes. Both the base data on weapon systems and the degree of information has changed over time, with less and less data made available to the public. Since 2018, the reports have been divided into two parts, with only the first part, containing general information and data on certain weapon systems, available to the general public.

The weapon systems included in the *Rüstungsberichte* differ among the biannual reports. Some projects are closed, and no further data is provided. New programs are included at the time they are appropriated by the German Bundestag. Furthermore, the scope of the reports has shifted, with later reports only covering very large programs, whereas earlier ones included a wider spectrum of weapon systems.

Changes in reporting and publication practices limit the usefulness of comparisons over time. Still, the available data suggest that both time delays and cost overruns have plagued procurement projects at similar rates from 2015 to

17 Brzoska (2019).
18 High expenditures for both business consultants and contract procedures led to major criticism, resulting in a special parliamentary investigation that found a good number of irregularities.
19 The reports can be found on the Website of the Ministry of Defense, www.bmvg.de/de/themen/ruestung/ruestungsmanagement/ruestungsbericht

Table 2: Aggregate data on German major weapon procurement programs, aggregated by production type

	Program costs, in EUR bn	*Program costs as a percentage of total*	*Additional costs as a percentage of original procurement costs*	*Average time delay over first parliamentary approval, in years*
Foreign direct purchases	2	3%	12%	-0.3
Simple co-production	15	23%	21%	8.2
Complex co-production	31	50%	26%	4.7
National production	15	24%	16%	3.1
Total	**62**	**100%**	**19%**	**4.6**

Note: Programs current in early 2022.
Source: Appendix A, author's own estimate based on information in BMVg 2019-2021.

at least 2022 (the latest report available at the time of writing). This period saw a mixture of programs that were on time and within planned costs and those that experienced significant time delays and cost overruns (such as the A400M).

The analysis that follows in the next section is based on the detailed data on original program costs (at the time of first parliamentary approval), as well as cost overruns and time delays in major weapon system procurement processes in early 2022 (see Appendix A for details). This base data has been aggregated into four categories of "production types" (see Table 2) and used for the estimation of inefficiencies in later sections—the rationale being based on the sources of inefficiency discussed earlier in this article. National procurement and production in Germany tend to result in small production runs, while purchases of complete weapon systems from producers outside of Germany, with or without procurement pooling, are generally made from large production runs.

Weapons procured from arrangements, involving both pooling and co-production, have been divided into two categories: complex and simple co-production. In complex co-production, the procured weapon systems differ significantly from partner to partner. While the basic designs are identical, this implies major additional design and production inputs to satisfy national requirements. The cost savings from procurement pooling are largely or even fully outweighed by the additional costs of production. In simple co-production, by contrast, the weapon systems procured by the partners are largely identical or feature only small national modifications. The categorization of co-productions was made by examining the characteristics of weapon systems in the inventories of participating partner countries.[20]

The data shows major differences with respect to shares in total procurement, time delays, and cost overruns among the four production types. Measured by current program costs (original program costs plus cost overruns by 2022), co-production projects with partners had the largest share among procurement programs—50 percent for complex co-production and 23 percent for simple co-production. The high share for complex co-production stems primarily from some joint programs for aircraft, including Eurofighter and Tiger helicopters.

Measured in relation to original program appropriations by the German Bundestag, complex co-production projects saw the greatest cost overruns among the four categories, while simple co-production projects had the longest

20 Brzoska (2022).

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Table 3: Major weapon system utilization rates in the German armed forces

	Air force	*Navy*	*Army*	*Average*
Average major weapon system utilization rates, 2017	60%	49%	51%	54%

Reported utilization rates by lifetime phase	*Introductory and growth phase*	*Ripeness phase*	*Saturation and degeneration phase*
Complex co-production	<40%	>70%	<50%
National production	70% / 79%	75% / 75%	<60% / 69%
Total	**85%**	**77%**	**65%**

Source: BMVg (2017a, 2019a-2021a)

time delays on average. Purely national procurement and production, with a share of 23 percent of the procured weapon systems included in the analysis, had lower cost overruns and time delays than co-production.[21] Purchases from foreign producers, which were the least important for German procurement (measured by contract value), had the fewest problems with cost overruns. On average, weapon systems were even delivered earlier than originally foreseen. These lower cost overruns and time delays can likely be explained by the fact that systems were already in production when the German parliament first authorized procurement.

Weapon system utilization rates

Another series of reports, *Berichte zu Rüstung und materieller Einsatzbereitschaft der Bundeswehr*, which were at least partly publicly available between 2017 and 2021, discuss and report on the use of major weapon systems in the German armed forces. Reporting has, however, been uneven and inconsistent over time.[22]

The earliest versions of the reports list and explain utilization rates for all major weapon systems (*Hauptwaffensysteme*). After 2017, however, the published reports no longer contain information by weapon system. Instead, information is aggregated according to the "lifetime phase" of the weapon system in question, distinguishing between an introductory and growth phase, a ripeness phase, and a saturation and degeneration phase. Furthermore, the scope of the weapon systems included in the reports has been expanded beyond major weapon systems. As no details on the inclusion and exclusion of weapon systems are provided, it is difficult to compare utilization rates over time.

Table 3 contains both information from the aggregation of the detailed data in the report for 2017 and data by lifetime phase contained in later reports. While reported average utilization rates have substantially improved, it is unclear how much of this is due to actual improvements and how much to the inclusion of a wider range of weapons than in the 2017 report. These improvements notwithstanding, a good number of weapon systems still fall short of the German armed forces' 70 percent goal. In late 2021, the average utilization rate for 71 weapon systems was 77 percent, with 33 below 70 percent, and 11 (mostly older weapon systems) below 50 percent.[23]

21 Weapon system types are not evenly distributed over production types (Appendix A, Table A1). National production mainly concerns shipbuilding, while in both co-production and foreign purchases aircraft programs dominate.
22 BMVG (2017a, 2019-2021a).
23 BMVg (2021a, p. 4).

Estimates of potential cost savings through more efficient procurement

Failure to profit from economies of scale

A first source of inefficiency considered here is going it alone in procurement and production when buying directly from foreign sources or where procurement pooling with allies was an option. The assumption made in the following section is that buying from foreign sources, or as a partner in pooling, allows buyers to profit from longer production runs (with its associated learning cost savings) compared with going it alone.

A standard formula for a simple learning cost function is:

$$C_n = C_1 n^b, \text{ with } b= (\ln(l/100)/\ln 2)$$

C_n is the cost of the nth weapon system, C_1 the cost of the first system, and l the learning rate.

The total cost of the production P of a batch of weapon systems, from the first to the nth weapon system, can be calculated (using Wright's formula) as:

$$P_n = C_1 n^{b+1}$$

since n times $n^b = n^{b+1}$.

Table 4: Model calculation, savings from larger procurement runs

Number of buyers	*1*	*2*	*3*
Number of systems per buyer	200	200	200
Total production run	200	400	600
Unit cost	10.0	8.5	7.7
Procurement cost per buyer of 200 units	2000	1700	1546
Savings for buyer 1 compared to being sole buyer	0%	-15%	-23%
Total	**62**	**100%**	**19%**

Note: Calculated with a learning rate of 15 percent.

There are clearly major differences between weapon systems. As indicated above in Section 2.2, learning costs are generally assumed to be quite high in defense procurement. This is illustrated in Table 4 for a very simple case with a learning rate of 15 percent. The doubling of units of production reduces the unit cost of weapon systems by 15 percent, and the tripling of production by 23 percent.

Estimating the potential savings that could be achieved by better exploiting economies of scale through foreign purchases or a larger degree of pooling is more difficult. To be reliable, such an estimate would require very detailed data on the requirements of both the German armed forces and potential partners for pooling, and the availability and prices of the weapon systems needed to fulfil these requirements.

Table 5 provides a very rough estimate based on two extreme sets of assumptions but using the actual data for German procurement reported in Table 2 and a learning cost rate of 15 percent. *Assumption (a)* is that larger production runs could only have been exploited in those cases where procurement and production were national. In this case, it is assumed that purchases from production runs twice the size of the national German procurement could have been made. This would have resulted in procurement costs that were 15 percent lower than the cost of procuring and producing nationally. *Assumption (b)* is that savings from learning costs were available but not exploited for all categories of procurement except foreign direct purchases. Furthermore, a doubling of production runs was assumed for both types of co-production, and a tripling of production runs for national procurement and production. The last row in Table 5 gives the range of potential savings for German procurement using these two extreme assumptions.

Table 5: Estimate of potential savings for German procurement projects through the better use of economies of scale

	Program costs, in EUR bn	*Percent savings with assumption (a)*	*Percent savings with assumption (b)*	*Range of savings, in EUR bn*
Foreign direct purchases	2	0	0	0
Simple co-production (largely identical weapon systems)	15	0	-15%	0 – 2.3
Complex co-production (weapon systems with substantial national differences)	31	0	-15%	0 – 4.7
National production	15	-15%	-23%	2.3 – 3.5
Total	**62**	**4%**	**17%**	**2.3 – 10.4**

Reducing the complexity of co-production

A second source of inefficiency is briefly discussed in section *Co-production* above. Due to its high share in German procurement, complex co-production is of major importance. An often-used assumption for co-production is that costs grow with the square root of the number of partners S.[24] The co-production cost of a batch of weapon systems (V_n) can then be calculated as:

$$V_n = P_n S^{1/2}$$

with P_n as the production costs of a single producer.

However, a distinction should be drawn between co-production in which more-or-less identical weapons are produced and co-production where the final products differ substantially. In the standard formula for co-production, the additional costs of co-production apply to all production costs, including the fixed costs of developing weapon systems, tooling, etc. This may be overly pessimistic with respect to the additional costs associated with co-producing weapon systems that are basically identical for all partners.

This is captured here insofar as the co-production factor is only applied to the variable costs of production C_V, but not the fixed costs C_F:

$$J_n = C_F + C_V S^{1/2}$$

Where the fixed costs are substantial, simple co-production can provide major cost savings compared to complex co-production. Unfortunately, data on the share of fixed costs in major German procurement programs is limited to data on research and development costs. These range between 20 and 40 percent of procurement program costs.

Again, a reliable estimate for the German case would require data on costs within various co-production programs that are not publicly available. Still, the potential range of savings through avoiding complex co-production projects in favor of co-producing largely identical weapon systems can be estimated. This is done in Table 6 by using two extreme alternatives, and by assuming that the number of partners was 2.5 and that fixed costs were 30 percent of

24 Hartley and Braddon (2014); Ford (2015).

Table 6: Estimate of potential savings for German procurement projects from less complex co-production

	Program costs, in EUR bn	*Percent savings with assumption (a)*	*Percent savings with assumption (b)*	*Range of savings, in EUR bn*
Complex co-production (weapon systems with substantial national differences)	2	0	0	0
Total	**62**	**12%**	**17%**	**7.6 – 11.4**

production costs. One alternative, *assumption (a)*, is that the actual procurement programs involved simple rather than complex co-production, avoiding the additional fixed costs associated with adapting systems to national specifications. The other alternative, *assumption (b)*, is that an identical number of weapon systems was produced without the cost increases typical of complex co-production—that is, the costs associated with largely different weapon systems and *juste retour*—thus avoiding both the additional costs associated with having more than one production partner and additional fixed costs related to national differences.

Estimating cost overruns and time delays

Further symptoms of inefficiency were identified in section *Cost overruns and time delays* above. Data from the German Defense Ministry on cost overruns and aggregated by weapon category in Table 2 are reported in column 1 of Table 7.

However, not all cost overruns and time delays can be attributed to technical inefficiency in weapons procurement. Some of the additional costs and time delays are due to requests for technical improvements coming from the armed forces within procurement processes and/or suggestions for such improvements that come from the industry and are accepted by procurement authorities. Very little quantitative information is available on the sources of cost escalation and program time delays. However, it can be assumed from the verbal reporting in the *Rüstungsberichte* that such improvements are a regular feature of procurement processes, which generally run over many years. It is assumed here that about 20 percent of reported cost overruns of the funds originally appropriated by the German Bundestag is due to such improvements, here called “innovation share”. Corresponding data is reported in column 2 of Table 7.

Cost overruns and time delays are interrelated,[25] however it makes sense to consider them separately. The estimates using data on cost overruns and time delays will be different but should indicate the range of inefficiency resulting from them.

A first estimate of additional costs from time delays AT ignores improvements in weapon systems over time. Here, it is calculated similar to a linear depreciation over the lifetime t_l of a weapon system, with t_d standing for time delay and P_o for original program costs:

$$AT = P_o (t_d / t_l)$$

Results using data by category for program costs and time delays reported in Table 2 are reported in column 3 of Table 7, using the additional simplifying assumption of an average lifetime of 40 years for all categories of weapon systems.

A second estimate for time overruns, reported in column 4 of Table 7, considers improvements during the procurement process. Such improvements reduce the inefficiency inherent in time delays.

25 See the above section Cost overruns and time delays.

Table 7: Estimates of cost overruns and time delays for German major weapons

	Cost overruns without innovation share, in EUR bn	*Cost overruns with 20 percent innovation share, in EUR bn*	*Costs of time delays without innovation share, in EUR bn*	*Cost of time delays with innovation share of 5 percent per year, in EUR bn*	*Range of estimates, in EUR bn*
Foreign direct purchases	0.2	0.2	0.0		0 – 0.2
Simple co-production	2.6	2.1	2.5	1.5	1.5 – 2.6
Complex co-production	6.4	5.1	2.9	2.2	2.2 – 6.4
National production	2.1	1.7	1.0	0.8	0.8 – 2.1
Total	**11.3**	**9.0**	**6.4**	**4.5**	**4.5 – 11.3**

Note: Data as of early 2022.
Source: Calculated from BMVg (2019-2021); programs listed in Appendix A.

It is assumed here that the innovation share X_t grows over time, as potential technical improvements become available during the procurement process:

$$AT= P_o (t_d)/40) (1-X_t* t_d)$$

For the numbers in column 4 of Table 7, it is assumed that X_t takes the value of 5 percent per year for all weapon categories, corresponding to the overall innovation share of 20 percent used for the calculation of cost overruns.

Estimating low utilization rates

A final source of inefficiency in procurement considered here is the low utilization rate recorded for many of the major weapons newly introduced into the German armed forces (reported on in the section *Weapon system utilization rates* above).

The costs from low utilization rates, CU, are here conceived of in terms of lost time—i.e. the period over which a weapon system could have been in use but was not—or, put differently, the cost of not having a functioning weapon system that has been paid for with procurement funds.

For rough estimation, the cost of low utilization rates is calculated as the difference between the actual utilization rate U_w and what is seen as an acceptable utilization rate U_a. As per the German Ministry of Defense, U_a is set at 70 per cent. The difference in utilization rates is multiplied by the value of the relevant weapon system in the German armed forces:

$$CU= (U_a - U_{w)} * V$$

V is estimated by using data on the number of weapon systems in the inventory of the German Bundeswehr with an estimated unit price, both based on data contained in the *Rüstungsberichte*. The price estimate takes into account the age of the individual systems (for details, see Appendix B).

Two calculations of utilization rates are reported in Table 8. Both are based on data from the official reports on

Table 8: Estimated cost of low major weapon system utilization rates

	Average utilization rates for weapon categories	*Estimated value of systems in Bundeswehr, in EUR bn*	*Value of non-usable units, in EUR bn*
Estimate 1: Based on data for 2017			
Army	*60*	*7.5*	*2.0*
Navy	*49*	*4.6*	*0.9*
Air force	*51*	*16.9*	*5.3*
Total/average	***54***	***29.0***	***8.1***
Estimate 2: 2017 data with 15 % improvement in utilization rate	0.2	0.2	0.0
Army	75	7.5	0.9
Navy	64	4.6	0.5
Air force	66	16.9	2.1
Total/average	**69**	**29.0**	**3.5**

Source: BMVg (2017a); Appendix B.

utilization rates published by the German Ministry of Defense.[26] Only systems with utilization rates below 70 percent are considered. Because the data are reported by armed service in the official reports, this is also done here for illustrative purposes. Actual calculations, however, were performed by individual weapon system covered in Appendix B.

The first estimate reported in Table 8 is based on the detailed data contained in the 2017 report on the availability of weapon systems.[27] The second is a rough estimate based on the assumption that utilization rates increased substantially in later years, as indicated in later, less detailed reports on utilization rates.[28] The improvement in utilization rates after 2017 is estimated at 15 percent. For the second estimate of the cost of low utilization, the detailed data for weapon systems reported in 2017 is recalculated with this improvement in utilization rates for all weapon systems with utilization below 70 percent.[29]

Summary

Table 9 summarizes the results of the four earlier rough estimates of inefficiencies, with low and high estimates reported in Tables 5 to 8.

All four inefficiencies are substantial. While it is tempting to add up the four estimates, there are obvious overlaps, particularly between complex co-production on the one hand and cost overruns and time delays on the other. However, even if we only consider one of these two categories, the total cost inefficiency estimated here ranges from more than EUR 10bn to almost EUR 30bn, corresponding to between 16 percent and 48 percent of procurement costs

26 BMVg (2017a, 2019a-2021a).
27 BMVg (2017a).
28 BMVg (2019a, 2021a); See also Table 3.
29 BMVg (2017a).

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Table 9: Summary of estimated procurement inefficiencies

	Low estimate, in EUR bn	*High estimate, in EUR bn*
Limited economies of scale (Table 5)	*2.3*	*10.4*
Unwarranted complex co-production (Table 6)	*7.6*	*11.4*
Cost overruns and time delays (Table 7)	*4.5*	*11.3*
Low major weapon system utilization rates (Table 8)	*3.5*	*8.1*

(totaling EUR 62bn) for the procurement programs included in the analysis.

The estimates allow for a comparison of the inefficiencies discussed in this article. A failure to fully exploit economies of scale through foreign purchases and the joint pooling of procurement with partners turns out to be a lesser source of inefficiency in German arms procurement than complex co-production, cost overruns and time delays, and low utilization rates. Clearly, these results are dependent on the various assumptions made for the estimates reported above, including concerning the additional costs of co-production and the possibility of making better use of economies of scale. To arrive at more reliable estimates, additional data on weapon systems procured by the German armed forces would need to be made publicly available. This article had to rely on plausible assumptions, some of which were based on information obtained in the broader literature on weapons procurement.

Seen in a broader light, the analysis suggests that difficulties associated with the complexity of both weapons production and the weapon systems procured by the German armed forces were the largest source of inefficiency for Germany (at least during the period until early 2022 covered here). Another important source was inefficiencies stemming from the organization of production, including Germany's preference for national production and its willingness to enter into complex forms of co-production. Major savings could have been achieved had decision-makers been willing to better exploit potential economies of scale through pooling procurement with partners or buying from producers with long production runs (rather than insisting on their own specifications). Additionally, large savings would have been achieved had they been satisfied with achievable levels of technological advancement rather than aiming far beyond the capabilities of national arms producers and partners in co-production projects.

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Appendix A: Base data for German major weapon procurement projects current in early 2022

Table A1: Base data for German major weapon procurement projects current in early 2022

	System type	*Procurement costs for Germany as of early 2022, in EUR m*	*Additional costs since parliamentary procurement decision, in EUR m*	*Time delay over parliamentary decision, in years*
Foreign purchases				
C-130J	Transport aircraft	1,025	82	-0.3
CH-53G	Helicopter	638	102	0
Sum/ Average		1,663	184	-0.2
Simple co-production				
A400M with DIRCM	Transport aircraft	9,039	1,627	13.5
NH90 TTH	Helicopter	4,153	1,329	11.2
NH90 NTH	Helicopter	1,100	55	0.0
AESA Radar	Radar	341	92	0
Sum/ Average		14,633	3,103	8.2
Complex co-production				
KH TIGER	Helicopter	4,143	953	6.7
Eurofighter with AESA	Fighter aircraft	26,938	7,812	2.8
Sum/ Average		31,081	8,765	4.7
National production				
F125	Frigate	2,190	1,117	5.8
K130 2. Los	Corvette	2,392	311	0.8
F126	Frigate	4,800	96	0.0
Puma	Armoured personnel carrier	4,975	1,393	5.8
SVFuA	Communication system	164	46	0
TanDEM-X	Satellite system	483	-116	0
Sum/ Average		15,005	2,847	3.1
Total sum/ average		**62,382**	**14,899**	**4.6**

Appendix B: Data for estimating the costs of low major weapon system utilization rates in the German Bundeswehr, 2017

Table B1: Costs of low major weapon system utilization rates in the German Bundeswehr, 2017

	System Type	*Utilization rate,in %*	*Number of weapon systems in Bundeswehr inventory*	*Estimated unit cost of weapon system, in EUR m*	*Estimated total value of system in Bundeswehr inventory, in EUR m*	*Estimated value of non-usable units in inventory, in EUR m*
Army systems						
Leopard 2	Main Battle Tank	60	176	15.0	2,640	377
Boxer	APC	65	167	3.0	501	36
Marder	Light Tank	66	319	1.0	319	18
Puma	Light Tank	43	112	6.0	672	259
Fuchs	APC	77	684	1.0	684	n.a.
Fennek	APC	77	180	1.6	288	n.a.
PzH 2000	Howitzer	56	75	1.6	120	24
MARS II	Rocket thrower	67	15	2.0	30	1
Tiger	Helicopter	31	39	57.0	2,223	1,239
Average/Sum		***60***			***7,477***	***1,954***
Navy Systems						
Klasse 122/123/124	Frigate	83	6	300	1,800	n.a.
Klasse 212A	Submarine	32	2	500	1,000	543
Sea Lynx	Helicopter	32	18	12	216	117
Klasse 130	Corvette	75	4	300	1,200	n.a.
P-3C Orion	Maritime Surveillance Aircraft	41	5	12	60	25
Sea King	Helicopter	31	16	22	352	196
Average/Sum		***49***			***4,628***	***881***
Air Force Systems						
Transall	Transport aircraft	68	25	20	500	14
A400M	Transport aircraft	38	8	175	1,400	640
MRCA Tornado	Fighter aircraft	41	26	100	2,600	1,077
CH-53	Helicopter	40	40	30	1,200	514
Eurofighter	Fighter aircraft	48	81	120	9,720	3,055
Patriot	Air defense system	70	10	150	1,500	0
Average/Sum		***51***			***16,920***	***5300***

Note: Sorted by military service, value of non-usable units calculated on the basis of an acceptable utilization rate of 70 percent