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On growing operating costs in the Armed Forces

A refinement of concepts and estimates of growth in real output unit costs (GROUC) in the Norwegian Armed Forces

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Kjetil Hatlebakk Hove
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Summary

The growth in unit costs, be it input or output, is often claimed to be higher in the Armed Forces than in the general economy. This growth poses a major challenge to long term defence planning if budgets or ambitions are not adjusted accordingly. This report aims to answer three questions:

What are possible reasons for higher operating costs growth in the Armed Forces than in the general economy?

We particularly discuss the following reasons:

- The Armed Forces uses a combination of input factors of production with a higher price growth than those of the general economy.
- Productivity growth can be lower in the Armed Forces than in the general economy, for example due to the need for a relatively large workforce to operate the advanced equipment, for which there is limited scope for productivity growth.
- Increasing average age of weapon systems leads to more frequent repairs.
- Increasing technological complexity results in more expensive spares and more specialized contractors. This reduces the size of the market and increases the risk.
- The number of units of each weapon system is reduced, while fixed costs cannot be reduced to the same extent.
- Markets, political regulations, incentives and a lack of ability to substitute between factors of input.
- History, institutions, culture and politics cement the current structure and do not allow for all the possible efficiency improvements.

What is the rate of cost growth in the Norwegian Armed Forces?

We estimate growth in real output unit costs (**GROUC**) as the change in cost per unit of activity (days of sailing, flight hours and exercise days). Our results indicate an annual **GROUC** of activity based costs of four to six per cent beyond **CPI**, far above what can be expected in cost reductions due to increased productivity.

What are the implications for long term planning?

If budgets are not increased, the performance of the Armed Forces (the force effect) inevitably has to be reduced, unless productivity increases at a faster rate than costs. If increasing costs are not properly accounted for, we will plan for a structure which is larger than we will be able to fund. The results will be larger and more painful cuts at a later date. There are, in general, three ways of dealing with growing operating costs domestically:

- Budgetary increases, so that activity and force effect can be maintained.
- Productivity gains, so that activity can be reduced while maintaining force effect.
- A reduction in force effect.

Sammendrag

Kostnadsveksten per enhet input eller output er ofte antatt å være høyere i forsvarssektoren enn i den øvrige økonomien. I denne rapporten diskuterer vi tre spørsmål:

Hvorfor er kostnadsveksten høyere i forsvarssektoren enn i den øvrige økonomien?

Vi ser spesielt på de følgende faktorene:

- Forsvarssektoren bruker en miks av innsatsfaktorer med høyere prisvekst enn den miksen av innsatsfaktorer som er i bruk i den øvrige økonomien.
- Produktivitetsveksten kan være lavere i forsvarssektoren enn i den øvrige økonomien, for eksempel fordi våpensystemene krever mer bruk av arbeidskraft, hvor det er mindre rom for produktivitetsvekst.
- Stigende gjennomsnittsalder på våpensystemene fører til hyppigere reparasjoner.
- Tiltagende teknologisk kompleksitet resulterer i dyrere reservedeler og mer spesialiserte leverandører. Dette reduserer antall tilgjengelige tilbydere og øker risikoen.
- Det blir færre enheter av hvert våpensystem, uten at faste kostnader kan reduseres tilsvarende.
- Markeder, politiske reguleringer, incentiver og manglende substitusjonsmuligheter.
- Historie, institusjoner, kultur og politikk sementerer dagens struktur og tillater ikke alle de mulige effektiviseringstiltakene.

Hvor høy er kostnadsveksten i forsvarssektoren?

Vi estimerer *growth in real output unit costs* (GROUC) som endringen i kostnaden per enhet aktivitet (seilingsdøgn, flytimer og øvingsdøgn). Resultatene indikerer en årlig kostnadsvekst for aktivitetsbaserte kostnader ut over generell prisvekst på fire til seks prosent, langt høyere enn hva som kan forventes av kostnadsreduksjon grunnet produktivitetsvekst.

Hva betyr kostnadsvekst for langtidsplanleggingen?

Dersom budsjettene ikke økes, må ytelsen til slutt reduseres, med mindre produktiviteten øker mer enn kostnadsveksten. Hvis ikke kostnadsveksten håndteres, vil vi planlegge med en struktur som ikke kan opprettholdes. Resultatet vil bli større og mer smertefulle kutt ved en senere anledning. Generelt kan vi si at det finnes tre innenriks løsninger for å håndtere kostnadsvekst:

- Økte budsjetter, slik at aktivitetsnivå og ytelse kan opprettholdes.
- Produktivitetsforbedringer, slik at aktiviteten kan reduseres mens ytelsen opprettholdes.
- Redusert ytelse.

Contents

Preface	7
1 Introduction	9
1.1 Contents of this report	9
1.2 Background	9
1.3 Audience	10
2 Why is operating cost growth important?	11
2.1 Some challenges	12
3 What is operating cost growth?	13
3.1 Evolution of costs of defence	13
3.1.1 Measurement unit	14
3.1.2 Base price index	14
3.2 Operating cost growth and investment cost escalation	16
3.3 Intra- and intergenerational operating cost growth	16
3.3.1 Intergenerational operating cost growth	16
3.3.2 Intragenerational operating cost growth	16
3.4 Input and output measures	18
3.4.1 Input and output prices in general	18
3.4.2 Input and output in defence	19
3.4.3 Input or output?	21
4 Theoretical foundations behind operating cost growth	23
4.1 Operating cost growth as a function of input factor mix	23
4.2 Operating cost growth as a function of productivity growth	24
4.3 Operating cost growth as a function of technological complexity: the importance of relative effect	24
4.3.1 Risk and uncertainty	25
4.3.2 The importance of relative effect	25
4.4 Operating cost growth as a function of age: wear and development cycles	26
4.4.1 Intragenerational age effects: wear	26
4.4.2 Intergenerational age effects: development cycles	26
4.5 Operating cost growth as a function of the number of units and activity levels	27
4.6 Operating cost growth as a function of markets: regulations, incentives and substitution	28
4.6.1 Regulations and incentives	28
4.6.2 Gold plating	30
4.6.3 Substitution	31
4.7 Operating cost growth as a function of history, institutions, culture and politics	33
5 Review of empirical studies	34

5.1	Studies on the various reasons behind operating cost growth	34
5.1.1	Input factor mix	34
5.1.2	Productivity	37
5.1.3	Technology	38
5.1.4	Ageing	38
5.1.5	Number of units	39
5.1.6	Gold plating	39
5.2	FFI studies using Norwegian data	40
6	Estimates of GROUC using activity as output	42
6.1	Theoretical approach	42
6.2	Data	44
6.2.1	Accounting data	44
6.2.2	Activity data	46
6.3	Results	47
6.3.1	GROUC based on calculated weights	47
6.3.2	Results based on estimated activity weights	48
6.3.3	GROUC in the Norwegian Armed Forces	53
6.4	Summary of the empirical analysis	53
7	Summary of results, implications and future work	57
7.1	Summary	57
7.2	Implications for long term defence planning	57
7.3	Countering operating cost growth	57
7.4	Future work	58
	Abbreviations	59
	Bibliography	61
	Appendix	
A	Estimation bias	68
B	Activity	69
C	What is the cost of a weapon?	72
C.1	What is the cost of a weapon?	72

Preface

This report was originally published in 2016 as *Defence specific inflation (DSI) of goods and services. A refinement of concepts and new estimates* (FFI-report 16/00175). A revised edition is warranted because we want to move away from the term "inflation", as this is often defined as the rises in prices in the general economy. Therefore, in this edition, we employ the general term operating cost growth, and the specific terms growth in real output unit costs (**GROUC**), growth in real input unit costs (**GRIUC**), growth in nominal output unit costs (**GNOUC**) and growth in nominal input unit costs (**GNIUC**), where we used the term DSI in the first report. The remaining changes in the report are a result of changes suggested by peer reviews of a paper written on the very same topic as this report (Hove and Lillekvelland 2018), as well as fixing a few typos.

The analyses of the report are also somewhat extended. In the previous edition of the report, we employed data for goods and services only. In this edition, we use data for all operating costs as the main sample and the goods and services data as a subsample for robustness checks. These analyses were conducted as a part of writing the paper based on the previous edition of the report.

Kjeller
8th December 2017

Kjetil Hatlebakk Hove
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1 Introduction

We face increasing difficulty in reconciling the tension between desires and scarce resources because our philosophy for using emerging technology has generated a cost structure that is growing at a much faster rate than our budget.

Franklin Spinney (1980, p. 9)

1.1 Contents of this report

Increasing operating costs is a continuous source of concern in long term defence planning. If costs increase while budgets remain constant, cuts in the number of weapon systems becomes inevitable unless productivity growth is sufficiently high. In this report, we aim to refine the concepts related to operating cost growth and explain various reasons as to why this phenomenon exists. We place particular emphasis on the term growth in real output unit costs (**GROUC**), which we employ in our empirical estimation. We make a distinction between intra- and intergenerational operating cost growth, where intragenerational operating cost growth is the cost increase within a generation of a weapon system, while the intergenerational operating cost growth is the increase between two generations. We also emphasize the difference between input and output operating cost growth. We then show how input factor mix, productivity changes, increased average age, fewer units produced, more advanced technology, markets and the historical context can contribute to operating cost growth.

Based on Norwegian defence accounts and activity data, we then estimate historical **GROUC**. We measure **GROUC** as the operating cost growth per unit of defence production, and we employ activity levels, such as the number of flight hours or sailing days, as a measure of units. We split costs into activity based and structural costs to estimate whether activity based costs increase dependent on time and activity level and whether structural costs increase with time.

This report is structured as follows: Chapter 2 provides a background as to why operating cost growth is important. Then, we proceed to define various operating cost growth terms more closely in Chapter 3, before we explain possible reasons as to why we experience operating cost growth in Chapter 4. In Chapter 5, we review the available literature on operating cost growth, based on the various reasons from Chapter 4. In Chapter 6, we provide a method, present data and results for estimating Norwegian **GROUC** from 1994 until 2013. Chapter 7 summarizes our report.

1.2 Background

We agree with a claim put forward by Hartley and Solomon (2016), that the topic of defence inflation largely has been neglected by defence and peace economists. With this report, we provide a comprehensive summary of available literature which we hope will spur future studies into the topic. Operating cost growth is important to understand for defence policy makers and defence bureaucrats because a high rate of operating cost growth must result in a reduction of the defence structure unless budgets increase or productivity increases faster than costs. The insights of this report provide an understanding as to why costs increase, which enable policy makers and bureaucrats to argue for increased budgets or to reduce cost by reducing the impacts of the underlying causes of

operating cost growth.

1.3 Audience

This report is aimed at defence economists, defence policy makers and defence bureaucrats. The primary audience is defence economists, which is why the report at times might seem a bit heavy to read. For example, some figures in Chapter 4 are very theoretical. These can be skipped without loss of understanding. Chapters 2 to 5 and 7 are aimed at all audiences, whereas for Chapter 6, the more technical Sections 6.1 to 6.3 are aimed at those seeking an understanding of the method, while Section 6.4 provides a summary for those interested only in the results.

2 Why is operating cost growth important?

The purpose of this report is to define operating cost growth, explain underlying causes, and to measure operating cost growth. But why is operating cost growth important? Figure 2.1 illustrates the challenges seen from the Norwegian perspective. The figure shows estimated operating and investment costs for the Norwegian Armed Forces over a 20 year period, as well as estimated future budgets. All costs are deflated by the annual budgetary technical price and wage compensation awarded by the Ministry of Finance. The annual budgetary technical price and wage compensation is supposed to cover general input price growth for the Armed Forces, though not increasing costs originating from, for example, improved performance of systems (Eide 2012). That is, price growth of fuel is supposed to be matched by budget increases, while more expensive spares caused by upgraded weapon systems are not. The lowermost area of Figure 2.1 shows the projected operating costs, indexed at 100 in 2015. Since not the entire increase in operating costs is matched by budgetary increases, the available funds for investments (the distance between the dark blue area and the green curve) decrease. At the current pace, if there were to be no reductions in operating costs or budget increases, there will be no room for any investments by the year 2042. This obviously poses a significant challenge for long term defence planning, and difficult decisions lie ahead.

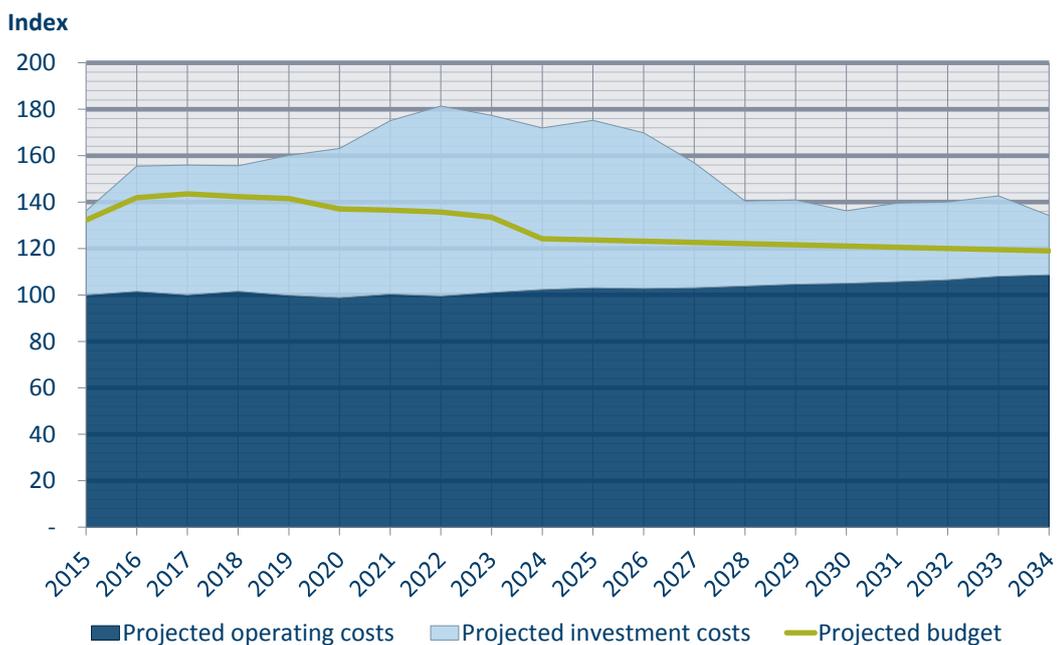


Figure 2.1 Projected costs and budget of the Norwegian Armed Forces 2015–2034, based on the cost proposal of the government for the current long term plan. The budget follows the plan from before the current long term plan (Ministry of Defence 2016) was proposed. Costs are deflated by the annual budgetary technical compensation and indexed at 100 in 2015. The annual budget is reduced by 0.5 per cent, as is the default annual budget reduction for all ministries. The reduction is meant to reflect efficiency gains. The temporary increase from 2016 until 2023 is due to the acquisition of new fighter aircraft.

2.1 Some challenges

In his 1980 report, Franklin "Chuck" Spinney (1980, p. 26) claims that there is a mismatch between short term and long term thinking in the Armed Forces. In the short term, operating costs are reduced in order to increase investments, whereas in the long run, investments shrink relative to operating costs. His claim is that reducing operating costs in order to increase investments reflects a tendency to sacrifice current weapon systems readiness levels in order to modernize for the future.

However, because operating costs increase, the price of even low readiness levels increase beyond what is viable in the long run. Modernization of weapons systems is being slowed and the number of units is reduced because

- The costs of replacing the systems are increasing
- The long term budget constraint has made it necessary to squeeze the growth in investments to accommodate the long term increase in operating costs.

He calls this pattern of growth *destructive* and a form of *organizational cancer*, where some parts of the organizations grow very fast and eat resources from the other parts. His argument is that this pattern will continue as long as operating costs grow at a faster rate than the budget. He warns of the dangers of following a strategy that depends on annual budget increases because this ignores the historic pattern of budget growth, which do not cover cost growth, and because it ignores the long term impact of growing economic uncertainty. In other words, the challenges outlined in conjunction with Figure 2.1 are not new. The insights from this chapter forms the background for this report.

Though there is not a great body of literature, operating cost growth is not an entirely unknown phenomenon. Several countries make use of defence "inflation" indices, including Canada, (Solomon 2003), the United States (Connor and Dryden 2013; Horowitz et al. 2012; Horowitz, Harmon and Levine 2016) and the United Kingdom (Hartley 2016b; Jones and Woodhill 2010). Norwegian studies, which we will return to in Section 5.2, have attempted to measure operating cost growth, but without constructing indices. In subsequent chapters, we discuss causes of operating cost growth and summarize previous literature.

3 What is operating cost growth?

3.1 Evolution of costs of defence

Figure 3.1 illustrates the concepts currently in use in Norwegian long term planning.

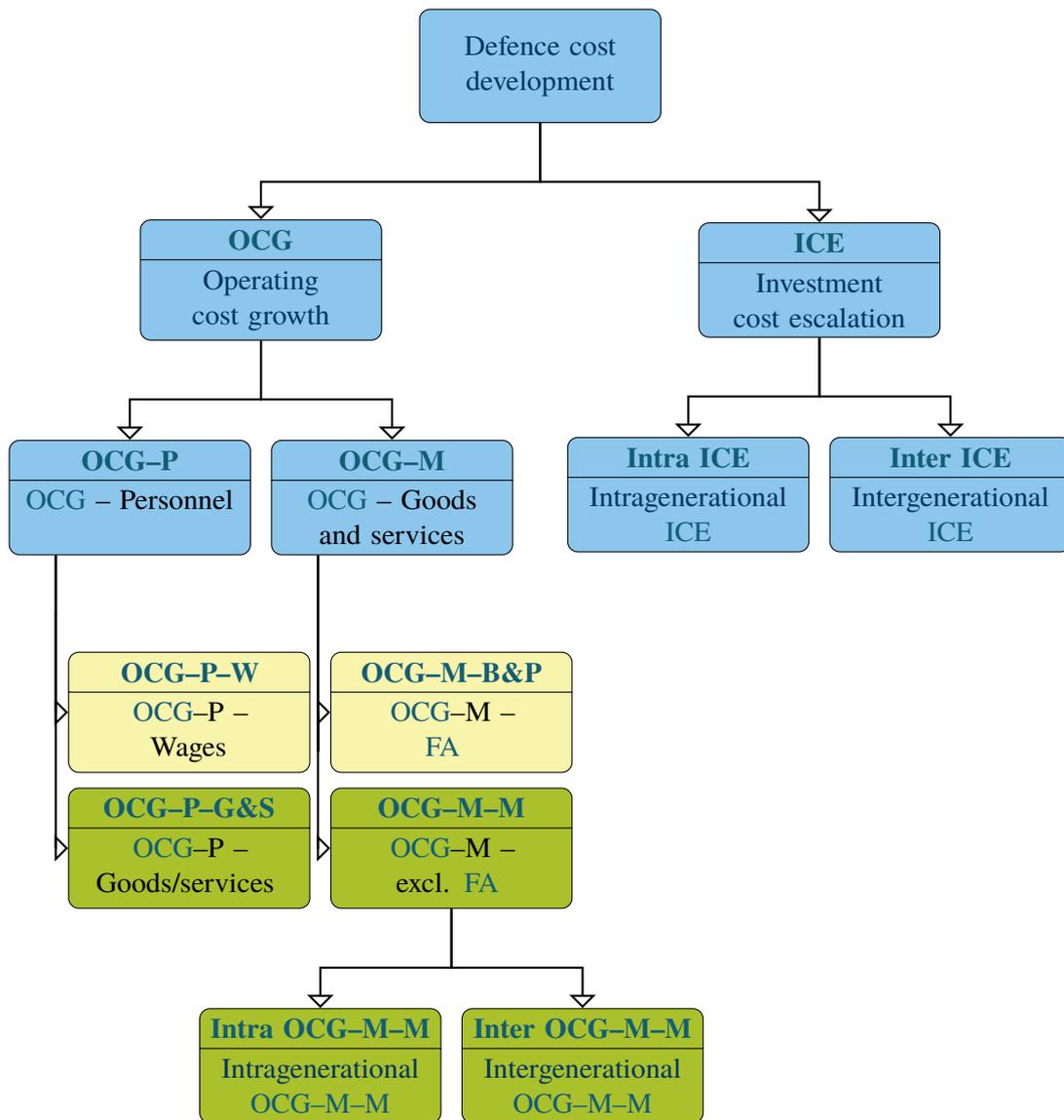


Figure 3.1 The various cost evolution concepts. Abbreviations: *OCG* = operating cost growth, *ICE* = investment cost escalation, *M* = goods and services, *P* = personnel, *FA* = facilities, *W* = wages. For a full list of abbreviations, see page 59.

Both escalation and growth mean the same here – the reason the term “escalation” is used is that in the international investment cost literature, “escalation” over time has come to mean growth both before and after adjusting for inflation. The Office of the Secretary of Defense (2017) uses escalation as a before-inflation term, but we stick with the literature convention here. Growth, on

the other hand, is a more general term.

The yellow and green parts of Figure 3.1 are of particular interest in this report. Combined, they constitute our empirical sample, whereas an empirical subsample is constructed of the green parts. A substantial literature has investigated the concepts of ICE and operating cost growth in defence. We discuss this further in Section 3.3. In previous FFI works, the ICE concept was discussed by Hove and Lillekvelland (2016). A more detailed review of the FFI studies related to operating cost growth are given in Section 5.2.

Operating cost growth can be measured in a variety of different ways. Here, we make a distinction between the measurement unit (input or output/outcome) and whether or not we express operating cost growth relative to a base price or cost index.

3.1.1 Measurement unit

The measurement unit depends on which measure we wish to obtain. We can distinguish between measures of output (what is produced) and input (what is used in the production). If we want to measure operating cost growth per unit of activity, i.e. an output measure, the measurement unit can be fighter aircraft hours, submarine sailing days, et cetera. If we want to measure operating cost growth per unit of weapons systems, i.e. an input measure, the measurement unit will be the number of fighter aircraft, the number of submarines, et cetera. In the empirical part of this report, we employ an activity based view, and measure operating cost growth per unit of activity. We discuss input and output measures further in Section 3.4

3.1.2 Base price index

Using a base price or cost index provides a real, or constant, operating cost growth index. If we measure the annual price increase of the goods and services bought by the Armed Forces, we measure nominal operating cost growth. If we measure operating cost growth relative to a base price or cost index, we find the real operating cost growth. In other words, if nominal operating cost growth is three per cent and general inflation is two per cent, real operating cost growth is one per cent. Table 3.1 shows the various resulting indices between whether we measure by input or output and whether or not we employ a base price index. The distinction is important, because the estimation results will vary depending on which combination of measurement unit and base price index we employ.

Furthermore, we find it useful to distinguish between economy-driven price growth and actor-driven cost growth. Economy-driven price growth is a result of for example increasing labour costs at suppliers or increased prices of nuts and bolts. The economy-driven price growth differs from price growth in the nationwide economy by the input factor mix. If the Armed Forces use a larger share of input goods with high price growth than is used in the nationwide economy, the economy-driven price growth will be higher than in the nationwide economy. Actor-driven cost growth can for example be a result of more expensive spares as we upgrade from F-16 to F-35. This growth is therefore a result of choices, though not always voluntary. A similar split is used for example by Arena et al. (2006, 2008) and Nordlund (2016).¹ Figure 3.2 illustrates the concepts for

¹Arena et al. (2006, 2008) use *customer driven* instead of *actor-driven*. The use of such a term on a general basis could indicate that the entire growth is due to the customer. We suggest the term *actor-driven* to indicate that, even though the customer decides to upgrade to a more advanced weapon system, this upgrade is a response to actions by other actors. This should in no way be interpreted to mean that customers have no influence over the level of cost growth. Nordlund (2016) uses a different terminology, where *Defence specific cost escalation* = *Defence specific inflation* +

		Base price or cost index	
		No	Yes
Measurement	Input	Current / growth in nominal input unit costs (GNIUC)	Constant / growth in real input unit costs (GRIUC)
	Output	Current-quality / growth in nominal output unit costs (GNOUC)	Constant-quality / growth in real output unit costs (GROUC)

Table 3.1 Types of cost indices and cost growth measures depending on measurement (input or output) and whether or not we employ a base price index in the calculations. The two terminologies are based on Horowitz, Harmon and Levine (2016) and Hove and Lillekvelland (2018).

output cost growth. The distinction between economy-driven price growth and actor-driven cost growth is important for example in Norway, where the budget is supposed to automatically increase by the economy-driven price growth each year, through an annual budgetary technical price and wage compensation. Any actor-driven cost growth has not been automatically compensated, though in 2017, a budget appropriation was introduced to cover parts of it (Hove 2017). Note that the distinction between economy-driven price growth and actor-driven cost growth is not always clear cut in practice.

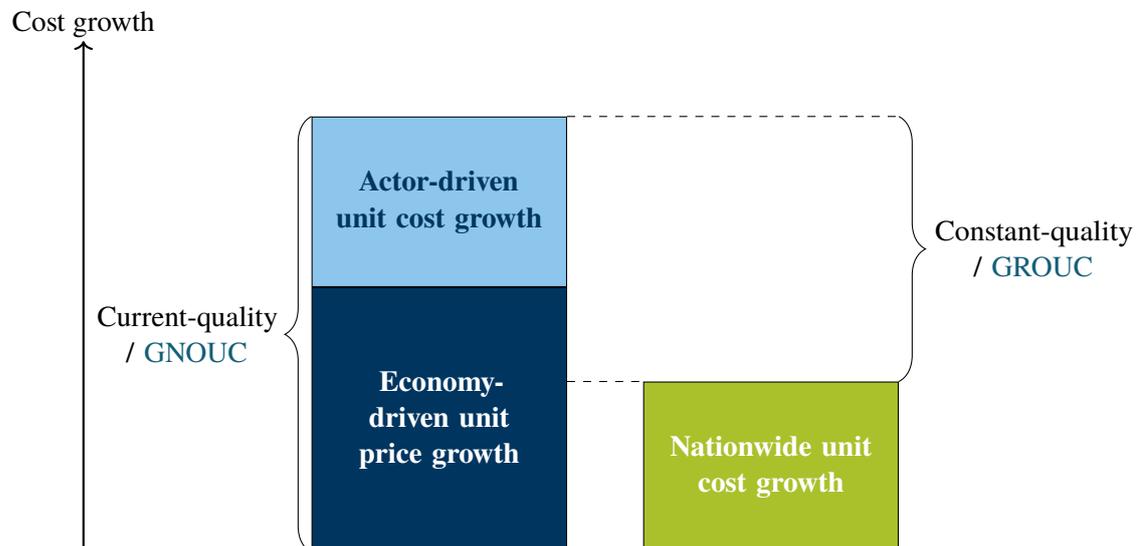


Figure 3.2 Output operating cost growth.

In the remainder of this chapter, we discuss the distinction between operating cost growth and ICE, between intra- and intergenerational operating cost growth, and between input and output operating cost growth. In Chapter 4, we suggest possible reasons behind operating cost growth.

Customer driven cost escalation.

3.2 Operating cost growth and investment cost escalation

Even though this report is concerned with operating cost growth, it is important to keep ICE in mind. Hartley (2016b) writes that a *distinction is needed between defence inflation and intergenerational cost increases or cost escalation which relate to rising real unit costs between successive generations of new equipment.*² Hartley and Solomon (2016) emphasize the importance of this distinction and of the importance of considering their mutual influence. Operating cost growth is related to ICE in the sense that they share common drivers. A driver that increases operating cost growth often also increases ICE, and vice versa. If titanium prices increase, replacement parts are more expensive to produce (operating cost growth), while parts of new aircraft are also getting more expensive to produce (ICE). If we switch to a more expensive composite material in new aircraft (ICE), future spares become more expensive as well (operating cost growth). In Section 3.3, we consider a conceptual separation between intra- and intergenerational operating cost growth, much in the same way we considered intra- and intergenerational ICE in Hove and Lillekvelland (2016).

3.3 Intra- and intergenerational operating cost growth

3.3.1 Intergenerational operating cost growth

In many cases, it is instructive to make a distinction between intra- and intergenerational operating cost growth. Figure 3.1 made this distinction for ICE, as did Hove and Lillekvelland (2016). A major part of goods and services purchases in defence consist of operation and maintenance (O&M) of weapon systems. Figure 3.3 shows costs per flight hour (FH) for various United States fighter and attack aircraft.³ The figure illustrates the clear correlation between investment and operating costs. This is not surprising, given increased complexity, fewer units in operation, and other reasons we will get back to in Chapters 4 and 5.

3.3.2 Intragenerational operating cost growth

Figure 3.4 illustrates selected Norwegian Air Force goods and services operating costs per flight hour over the twelve year period 2005–2016 in CPI-deflated Norwegian Kroner (NOK), as well as the average annual increase in costs per flight hour in parenthesis. The trend is similar across all weapon systems. Some possible reasons behind this growth can for example be a continued increase in capability (i.e. an 2016 F-16 is superior to an 2005 F-16), the results of ageing aircraft, the result of salary increases among suppliers of spares, or that the reduction in flight hours increases fixed costs per remaining flight hour. Chapter 4 deals with these, and other, possible causes of operating cost growth.

²Hartley (2016b) uses the term *intergenerational cost escalation* where we use the term *intergenerational investment cost escalation*.

³Data of operating costs are collected by Winslow Wheeler (Director of the Straus Military Reform Project at the Project On Government Oversight (POGO)) and were distributed by Time magazine (<http://timemilitary.files.wordpress.com/2013/04/afcap-data-for-2008-2012.xlsx>) and by POGO (<http://www.pogoarchives.org/labyrinth/08/03.xls>). Since the data originate from the same source, they should be comparable. F-4E costs are from 1996, F-117A from 2006 (among their last years of service). The rest of the costs are from 2012, though all costs are inflated to 2015 United States dollars (USD) using the Office of the Secretary of Defense (OSD) operation and support (O&S) index from the fiscal year (FY) 2015 National Defense Budget Estimates (Green Book). Investment costs are gathered from various open sources and are not necessarily fully comparable (see Appendix C for a discussion of what constitute an investment cost), but give an indication of investment cost levels.

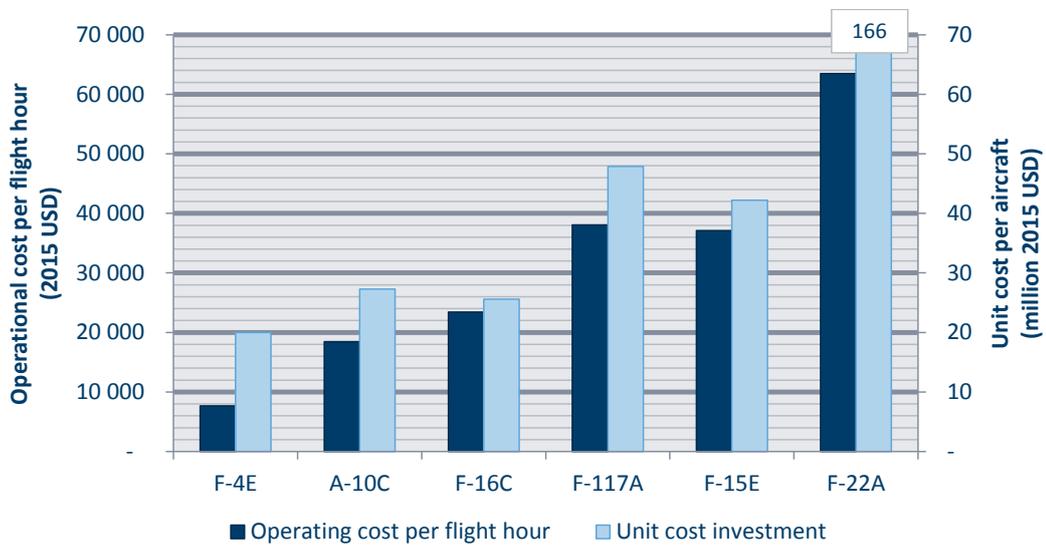


Figure 3.3 Operating and acquisition costs for selected US fighter and attack aircraft.

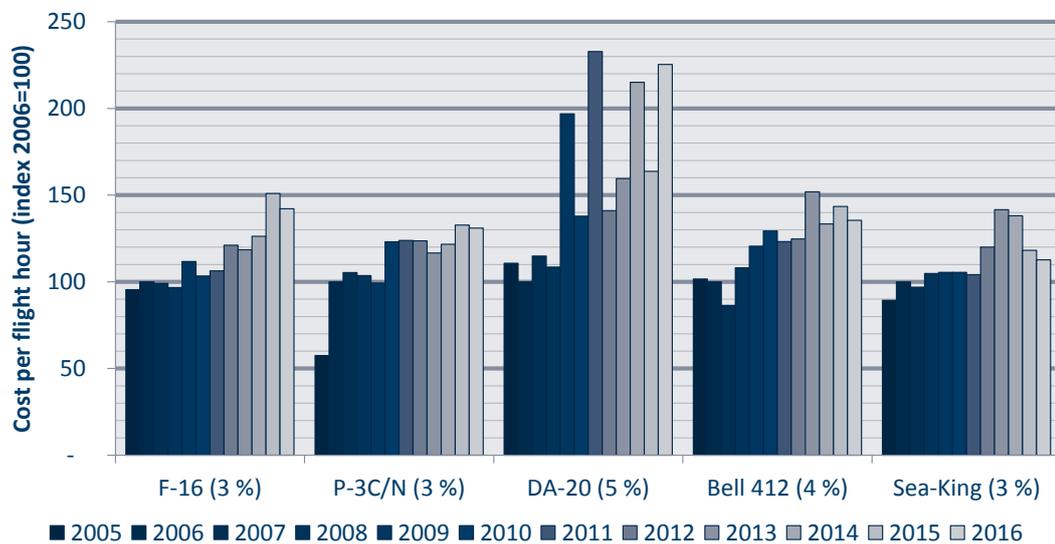


Figure 3.4 Costs per flight hour. Selected Norwegian Air Force systems. Average annual cost increase in parenthesis (excluding F-16 in 2015 and 2016, P-3C/N in 2005 and DA-20 in 2009, 2011, 2014 and 2016). The following observations are omitted: F-16 in 2015 and 2016 due to extraordinary repairs, P-3C/N in 2005 and DA-20 in 2009, 2011, 2014 and 2016 due to major maintenance. DA-20 vary a lot due to cycles of calendar-based maintenance.

Figure 3.5 illustrates a conceptual picture of OCG split into intra- and intergenerational parts. Similar figures are found in Jones and Woodhill (2010) and Nettet and Wessel (1995). The figure illustrates the intragenerational operating cost growth of F-16 from Figure 3.4, but also a jump from the current generation of F-16 fighters to the next generation of F-35 fighters. This increase is caused by factors typically associated with the causes of ICE, in particular technological complexity. Because the F-35 represents a technological jump, not a straightforward evolution, from the F-16, the increased costs arising as a result of this jump also leads to significantly more expensive spares, training, factory equipment, et cetera. During its lifetime, operating costs in Figure 3.5 rise from $P_{1982,F-16}$ to $P_{2020,F-16}$ (the curve AB) for the F-16 fighter. In 2020, operating costs start at $P_{2020,F-35}$ for the F-35. The slope of curve AB is the average rate of inflation for the F-16 (intragenerational operating cost growth). The shift from $P_{2020,F-16}$ to $P_{2020,F-35}$, BC , is the intergenerational operating cost growth from the F-16 to the F-35. The total operating cost growth trend at a generational change is given by AE .⁴

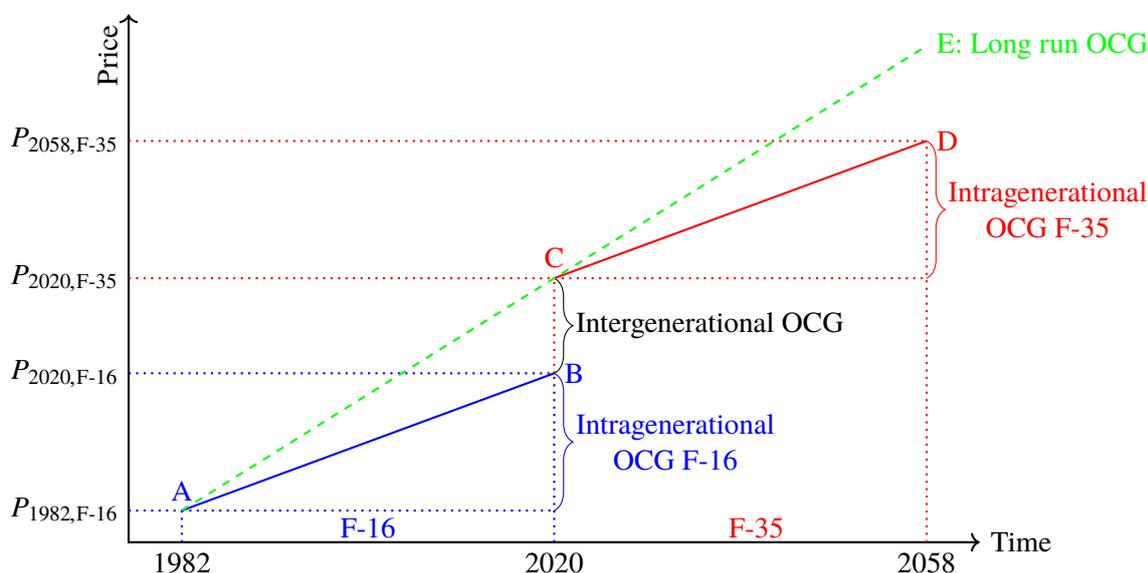


Figure 3.5 Intra- and intergenerational OCG. During its lifetime, operating costs rise from $P_{1982,F-16}$ to $P_{2020,F-16}$ (the blue curve AB) for the F-16. In 2020, operating costs start at $P_{2020,F-35}$ for the F-35. The slope of curve AB is the average rate of inflation for F-16 (intragenerational OCG). The shift from $P_{2020,F-16}$ to $P_{2020,F-35}$, BC , is the intergenerational OCG from the F-16 to the F-35. The total OCG trend at the time of a generational change is given by AE .

3.4 Input and output measures

3.4.1 Input and output prices in general

An important consideration when we discuss operating cost growth is whether we are measuring operating cost growth of input or output prices. Figure 3.6 illustrates the conceptual difference

⁴Within a generation, the slope of the AE falls somewhat. In 2020, once the F-35 is in use, the slope of AE will be equal to the slope of AC (as it is in the figure). In 2058, before we move on to the next generation fighter, the slope of AE will be equal to the slope of AD . Once the new generation is in use, the curve once again reverts to AE .

between input and output prices: The input operating cost growth is the operating cost growth of all the input factors of production. If the Air Force uses two factors of input in equal amounts, where one factor has a nominal price increase of 15 per cent, while the other has a nominal price increase of 5 per cent, the total input operating cost growth (**GNIUC**) is 10 per cent. However, the Air Force can also become more productive, for example through economies of scale or economies of scope. This would reduce output operating cost growth (**GNOUC**). Defence itself has no profit, but if the defence industry is a part of the operating cost growth measure, profits could be relevant.

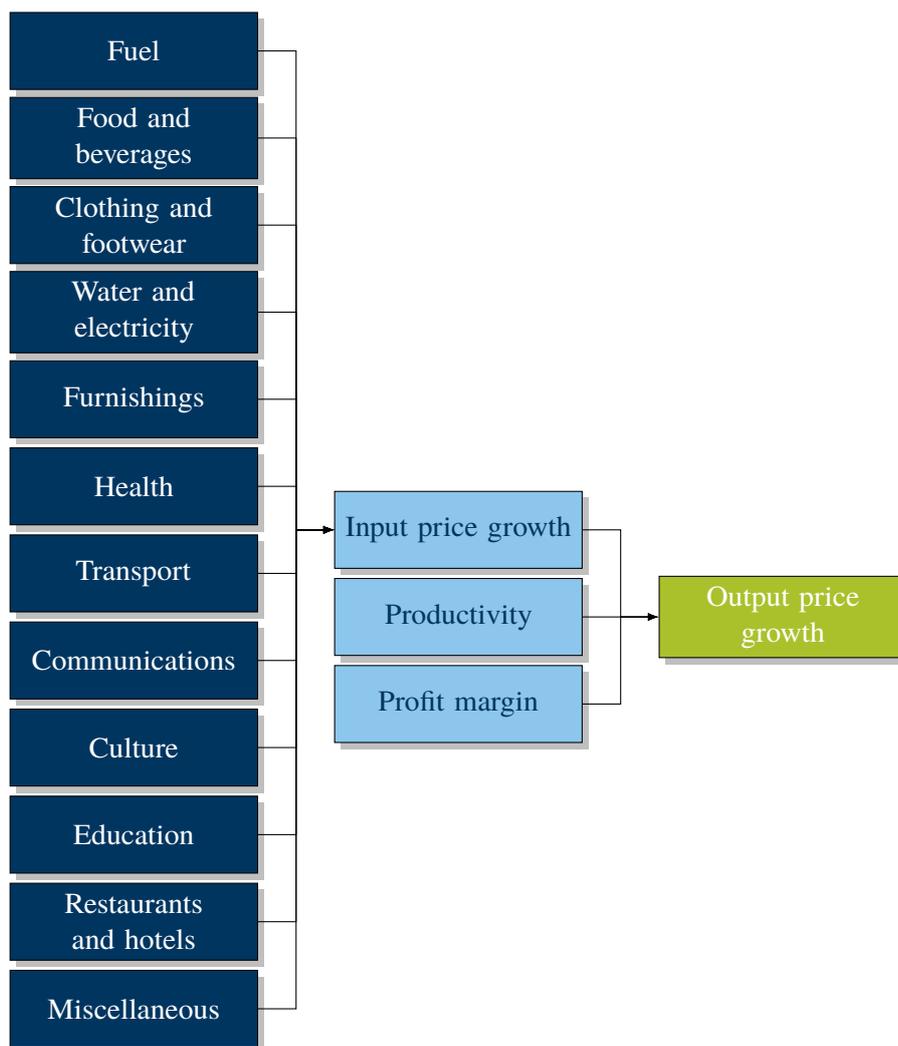


Figure 3.6 The general relationship between input and output price indices. Each box in the left hand column represent a price index. The indices are weighted together into the input price growth. Output prices equal input prices adjusted for productivity changes and profit margin.

3.4.2 Input and output in defence

The output of many government services are inherently difficult to measure. Health and education can to a certain degree be measured (see for example Kværner 2010, for a case study of health), but the effects of defence (peace and security) are in effect impossible to measure (Hartley 2010, 2011,

2016a; Hartley and Solomon 2015). Anagboso and Spence (2008, 2009) outline the relationship between input, output and outcomes as in Figure 3.7. The level of input is the number of fighter aircraft, the number of navy ships and so on. Direct output is the activities and the capabilities these inputs produce. If activity is reduced, the same level of output can be maintained if capabilities per flight hour or sailing day are increased. In Figure 3.6, this would be the productivity element. Activity, capability and input determine whether objectives can be met (while objectives influence which capabilities we produce). Together with external factors, fulfilment of objectives determine final outcome.

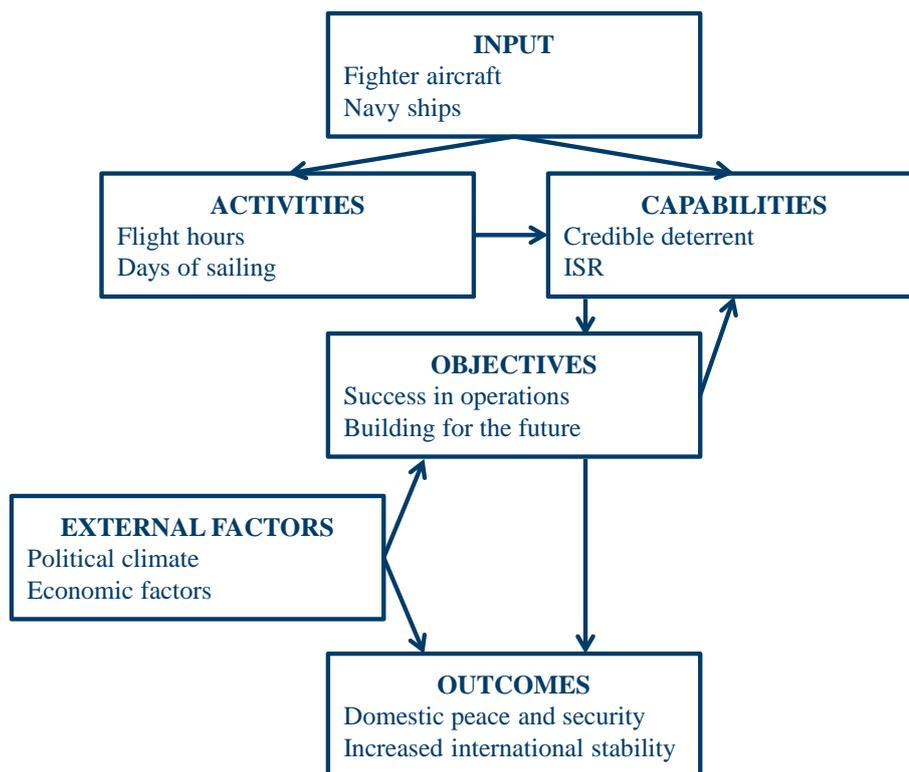


Figure 3.7 Relationship between inputs, output and outcomes. Activities, capabilities and objectives are output. Figure from Anagboso and Spence (2008, 2009).

It is not possible to measure outcome. However, it is possible to quantify some output measures. Anagboso and Spence (2008, 2009) discuss three possible output measures:

- **Activities**, which measure specific things the Armed Forces do. Murray (1992) and Murray et al. (1995) use training data as proxies for force quality. Activity will be a better measure the more training is related to force quality and is perhaps the most readily available measure (Verikios 1998). For example, ferrying an aircraft from one airport to another produces flight hours, but is a poor measure of force quality. Had the same number of flight hours been used for practising close air support at night, quality would be much higher.
- The **capabilities** of the Armed Forces. In other words, the ability of the Armed Forces to pursue a given course of action, such as precision bombing or special operations. Anagboso and Spence (2009) list the eight key UK capabilities: command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) and network enabled

capability (NEC), logistics, special forces, nuclear deterrent, strategic lift, maritime, land and air. Each of these has a subset of capabilities, such as mobility, firepower, protection and balance for land. In order to measure capability, they suggest quality adjusting equipment and manpower, thus creating a combined quality and quantity variable. Quality adjustments can include

- "Manning balances": Identify whether services have the appropriate amount of manpower based on current planning assumptions.
- "Manning pinch points": Identify where there is a deficit in personnel within specialised areas, for example fighter pilots.
- Identify whether guidelines which set out how long service personnel should spend away from their families and the time that units should have between operational deployments are adhered to.
- The percentage of staff that is medically fit for task.
- The extent to which the **objectives** of the Ministry of Defence (MoD) are met. Anagboso and Spence (2008) list the current UK strategic objectives and performance indicators:
 - Achieving success in the military tasks undertaken at home and abroad
 - Success in operations assessed against objectives for each operation or military task, including counter terrorism
 - Be ready to respond to the tasks that might arise
 - Delivery of force elements (Air Force squadron, Army brigade, Navy ship) at readiness
 - Manning balance
 - Build for the future
 - Procuring and supporting military equipment capability, through life
 - Procuring and supporting military non-equipment capability, through life
 - Sustainable development

Of course, there are several challenges when measuring objectives and capabilities, including difficulties to obtain an (unclassified) exhaustive list of capabilities, aggregation⁵, interdependence with allied capabilities and changing capability targets and objectives over time.

Because of limited data and few clear definitions, there are few studies on output based measures. The most easily obtainable measure is often activity data, such as flight hours, sailing days and exercise days. In our empirical study in Chapter 6, we measure GROUC employing activity data as the measure of output. Currently, we do not have sufficient data or definition to measure GROUC as a function of capabilities or objectives.

3.4.3 Input or output?

The choice between input and output cost growth should not only be based on the availability of output measures, but also of exactly what we want to measure. For example, Jones and Woodhill (2010) adopt an input based view on operating cost growth. They do this to separate between what they call "pure price movements" and "other sources of cost growth". If this is the aim, an input based approach is the correct choice. If the aim is to measure the growth in defence production, a good output measure would be the choice. In their definition of UK operating cost growth, Jones and Woodhill (2010, p. 10) say that for their purposes, allowing their measure to incorporate all

⁵In the tradition of Hicks (1940), cost weights can be used (for a more recent reference, see Diewert 2012). Though there is no one-to-one link between cost and importance, there should be a clear positive correlation.

aspects of cost growth is not particularly useful. Their interest lies in determining whether the MoD is adversely impacted by the the mix of people, goods and services the Armed Forces requires, i.e. by measuring GNIUC. Therefore, they adopt a definition of operating cost growth which separates out the pure price movement from other sources of cost growth has been adopted. Their definition is in other words input based, as they do not make quality or quantity adjustments.

Their definition ignores the relative effect (or *relative fighting power*, as they call it) of the Armed Forces. For example, Chalmers (2009) suggests that productivity growth in the MoD is similar to real wage growth and notes that if a mere 60 per cent of the claimed improvements in MoD efficiency are genuine, this would be enough to offset the costs of real wage growth. However, Jones and Woodhill note that Office for National Statistics (ONS) has estimated that public sector productivity, in the part where output can be directly measured, fell by an annual average of 0.3 % over a ten year period. Jones and Woodhill say that an output based measure recognising relative effect has its merits, but that it is not feasible in their study. We will discuss what Jones and Woodhill refer to as "relative fighting power" further in Section 4.3.2.

4 Theoretical foundations behind operating cost growth

In this chapter, we discuss possible contributors to operating cost growth. We will discuss the input factor mix, productivity, the age of the weapon systems, the number of units of a weapon system, technological complexity, uncertainty, regulations, incentives, substitution and history, institutions, culture and politics. As we shall see, many contributions are interrelated. Input factor mix and productivity are the two general causes of operating cost growth, whereas the rest of the causes mentioned in this chapter serve as further explanations as to why operating cost growth differs from nationwide cost growth. Note that if any of these explanations, for example an increase in age as in Section 4.4, only occur once, they do not necessarily contribute to long term operating cost growth – it is the continuous reinforcement of the factors over time which produce operating cost growth.

4.1 Operating cost growth as a function of input factor mix

Different input factors of production (real capital, labour, intermediate consumption) exhibit varying rates of price growth. In other words, input factor composition influences price growth. If the Armed Forces consume a large share of labour intensive intermediate input, we would expect higher price growth than for industries consuming goods and services where production is automatized.⁶ Figure 4.1 illustrates this. The economy in Figure 4.1 has two industries, defence and the general economy. Both consume seven types of goods, all with varying rates of price growth. Because defence consume more of the most expensive goods, price is higher than general inflation, for example the consumer price index (CPI). Normally, if prices of one good increases, an industry can to a certain extent substitute the good with cheaper goods. Substitution is further discussed in Section 4.6.3. The input factor mix influences both input and output growth (through input).

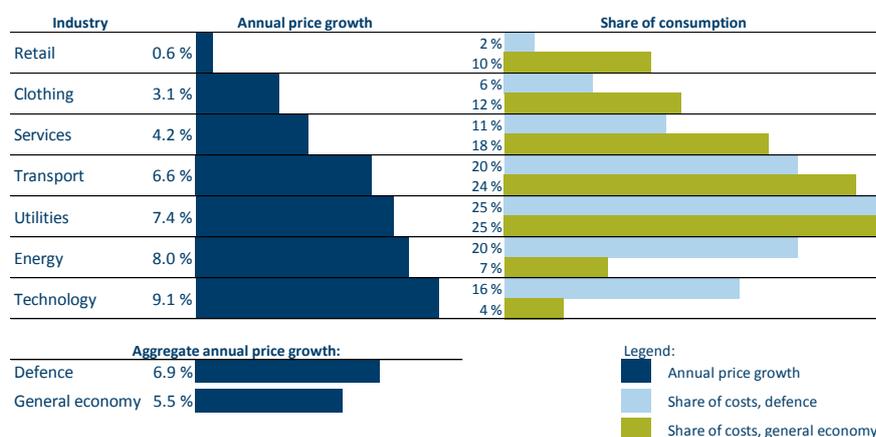


Figure 4.1 Example of input factor mix. In this economy, there are seven forms of input factors. Retail goods has the lowest annual price growth, oil and gas has the highest. Furthermore, defence (light blue bars) and the general economy (green bars) consume a varying share of these goods. By multiplying the annual price growth by each share and aggregating, we see that defence has a higher inflation than the general economy.

⁶Real wage growth is generally positive. For a depiction of Norwegian real wage growth, see NOU 2013:13 (2013, p.14, Figure 2.1, lower left pane).

4.2 Operating cost growth as a function of productivity growth

With increasing productivity, more output can be produced per unit of input. If input prices rise by 10 per cent, while the equipment is 2 per cent more productive, output prices increase by approximately 8 per cent.⁷ Productivity in the public sector is difficult to measure, in particular in the case of the provision of collective services, such as defence (Simpson 2009). Neither is there any unique measure of productivity. OECD (2001) lists a number of objectives for productivity measurement, including the measure of technological progress (see Section 4.3) and efficiency improvements. The first objective is perhaps most interesting in an intergenerational context, whereas the latter is most interesting in an intragenerational perspective. Nordlund (2016) also emphasize the effect of "Baumol's cost disease" (Baumol 2012; Baumol and Bowen 1966), where the labour intense public sector cannot increase productivity to the extent the private sector can.

4.3 Operating cost growth as a function of technological complexity: the importance of relative effect

Figure 4.2 (based on data from Deo, Starnes Jr. and Holzwardt 2001) illustrates the changing share of materials in various fighter aircraft. The share of composites and titanium – more expensive materials – increases. This not only implies increased investment costs, but also increased operating costs (because the cost of spares and qualified personnel also increase).

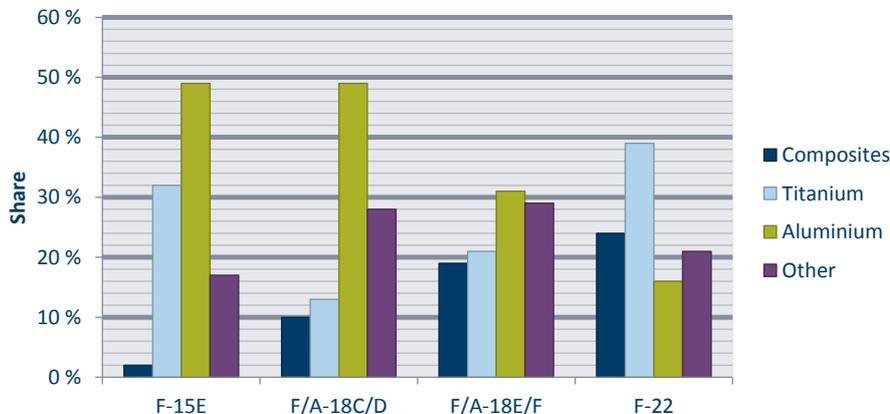


Figure 4.2 Share of composites, titanium, aluminium and other types of material in various fighter aircraft. Data from Deo, Starnes Jr. and Holzwardt (2001).

Not only does complexity of the materials themselves (substituting steel for titanium) increase – modern weapon systems are more complex in the sense that they depend on third party systems and on each other. Modern weapon systems are not isolated systems, but part of an array of systems – a system of systems. For example, fighter aircraft are much closer linked to each other and to headquarters than previous generations. They require specialized tools, infrastructure and software that are custom made. This should increase capabilities, but also increases complexity and costs.

⁷ $\frac{1.10}{1.02} - 1 \approx 7,84\%$.

Specialization increases for each successive generation of a weapon system, as does the cost of operating the system. As Spinney (1980, p. 9) notes, this is not a new problem:

We face increasing difficulty in reconciling the tension between desires and scarce resources because our philosophy for using emerging technology has generated a cost structure that is growing at a much faster rate than our budget.

Spinney (1980, pp. 8–14) further notes that increasing complexity is a cost in itself because it decreases predictability of future costs and increases rigidity in a branch where *survival of the fittest makes flexibility a paramount virtue*. He identifies three ways in which increasing complexity magnifies the cost of adjusting to change:

- By increasing investment, operating, and support costs.
- By increasing the uncertainty surrounding our cost structure – particularly for our operating and support costs.
- By stretching out the time horizon for the cost consequences of current decisions (see Section 4.4.2).

On the reason behind increasing complexity, he notes that when uncertainty with regards to the future is combined with seemingly endless technological opportunities, it is easy to demand great specifications of a weapon system. In other words, Spinney emphasizes that there is an element of choice to operating cost growth – we have chosen to invest in technology intensive equipment. This increases complexity, costs and uncertainty.

4.3.1 Risk and uncertainty

Risk (not knowing what will happen next, but knowing the probability distribution of it) and uncertainty (not knowing what will happen next, and not knowing the probability distribution of it) also play a part in operating cost growth. As weapon systems become more complex, the producers increase their dependence on specialized suppliers and specialized manpower. Singh (1997) argues that the risk of failure increases with more complex technologies.⁸ We imagine this could lead to increased prices through a number of causes, for example higher risk premiums or higher prices to be able to pay more specialized manpower.

4.3.2 The importance of relative effect

This section has so far discussed the importance of technological complexity for operating cost growth, without giving a proper reason for why the Armed Forces chooses to increase costs in this manner. In Hove and Lillekvelland (2016), we placed great emphasis on the concept of relative effect (similar terms are relative force effect and effectiveness, as used by Jones and Woodhill 2010; Kirkpatrick 1995). In short, we argue as follows: Military equipment has little or no intrinsic value – it has a value only when compared to equipment of adversaries. Many consider an increase in effect per unit to be offset by a similar increase in the effect per unit of equipment of potential enemies (Kirkpatrick 1995, 1997, 2004; Kirkpatrick and Pugh 1983; Pugh 1986, 1993). As Pugh (1986, p. 140) writes, equipment “is good or bad only in relation to what possessed by a potential (or actual) adversary. The benefits of improved armament are largely those of devaluing existing equipment, especially that of the adversary”. While the absolute performance of a new generation

⁸According to Singh, alliances partly moderate such risks. This could perhaps be a reason behind some of the many mergers in the defence manufacturing industry over the last 20 years.

of a weapon system might increase, the effectiveness relative to the weapons of the adversary might be unchanged. Investing in unchanged performance would thus lead to reduced relative effect. That is why we, as further elaborated in Hove and Lillekvelland (2016), see defence investments pushing towards the technology frontier, with all the implications that has for cost increases. While Kirkpatrick (1997) argued that relative effect causes ICE, Chalmers (2009) argues that if ICE exists, the increase in prices will affect the adversary as well, and therefore will have an ambiguous effect on relative effect of the equipment. There is no doubt, however, that the absolute price increases. Of course, prices cannot rise as long as there is no willingness to pay, and has to be seen in relation to this. Willingness to pay for a five per cent increase in quality can be far more than five per cent, because the effectiveness of the new system relative to that of the adversary increases by more than five per cent.

4.4 Operating cost growth as a function of age: wear and development cycles

4.4.1 Intragenerational age effects: wear

Consider the following statement: "Unit costs increase with age." Figure 4.3 illustrates the so called bathtub curve (see for example Xie and Lai 1996), where maintenance costs (or the system failure rate) are dependent on age. Cost development is illustrated along three curves:

- *Early*, or infant mortality, failures are failures that occur due to material defects, design errors and assembly errors. Most of these can be sorted out early on, while some continue to affect reliability throughout product lifetime.
- *Constant*, or random, failures occur any time during product lifetime.
- *Wear* failures occur as products near the end of their life span. Both heavy use and time itself (through corrosion, cosmic radiation, moisture, etc.) increase the failure rate.

The sum of these, *Total*, gives three phases of life: a young system, where costs are decreasing, a mature system, where costs exhibit a stable path, and an ageing phase, where operating cost growth increases.⁹ In other words, maintaining each successive generation of a weapon system for a longer time will contribute to operating cost growth. Increase in the average age of weapon systems has for a long time been a known issue.

4.4.2 Intergenerational age effects: development cycles

As age increases with each successive system, so does the time the input factor mix is fixed. During development of a new product, important changes are made with regards to future costs. While the costs of change are initially small and the freedom of choice is great, costs of change increase and freedom of choice is reduced as development progresses. Figure 4.4 illustrates the concept. The optimal input factor mix can change dramatically over a 30 year life cycle period. In another example, fuel efficiency will be of greater concern if oil price doubles, but the use of fuel per flight hour cannot be changed until a new generation is developed. A prolonged lifespan can therefore increase operating cost growth. Age affects both input (through input factor mix) and output (through productivity – increasing as a system matures, decreasing when it ages) operating cost growth. During development of new weapon systems, technological complexity generally increases. In Section 4.3, we discussed this in further detail.

⁹That is, the second derivative is positive.

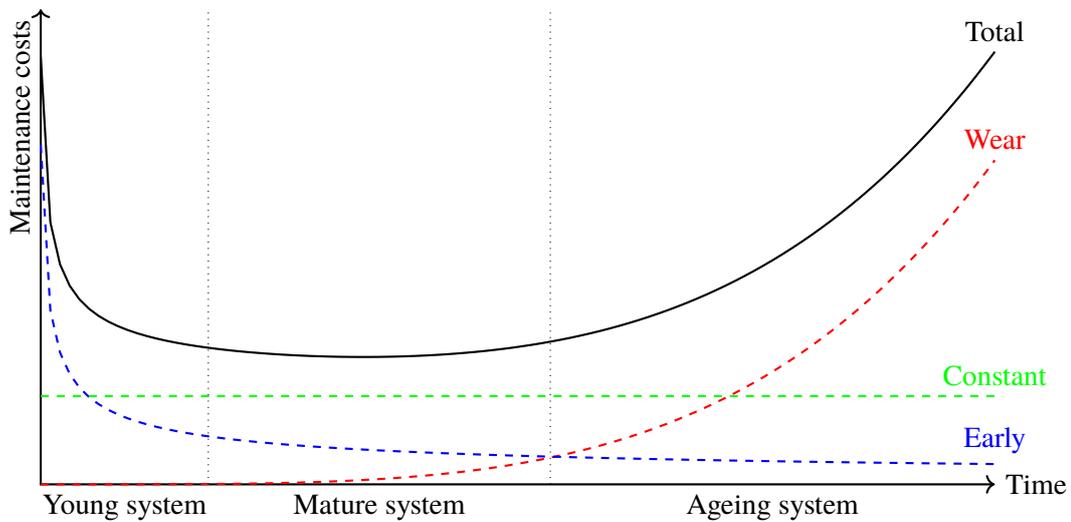


Figure 4.3 The bathtub curve of maintenance costs. Costs decrease as early design and production flaws are corrected, but rise as wear takes its toll.

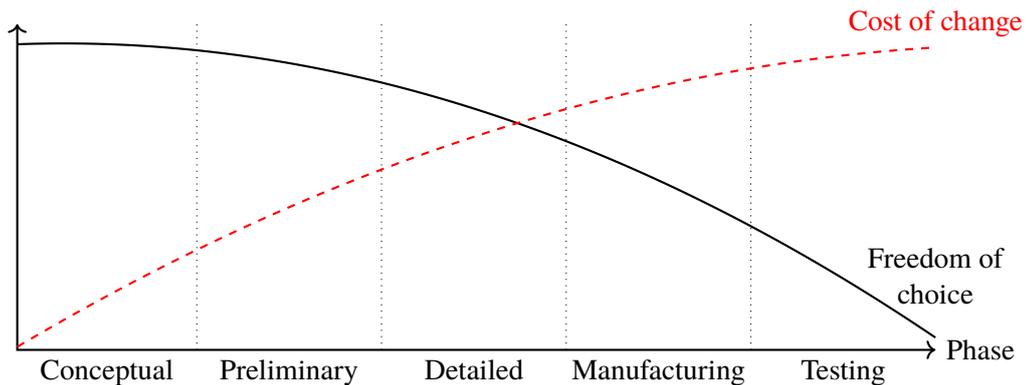


Figure 4.4 New product design: Freedom of choice versus cost of change. Freedom of choice is reduced, while cost of change increases as development progresses. Figure based on <http://enfinio.com/new-product-development/>

4.5 Operating cost growth as a function of the number of units and activity levels

As a general trend, the numbers of units per weapon system are falling (see for example Ruehrmund Jr. and Bowie 2010, for USAF data), as are activity levels. This also has implications for operating cost growth. Consider Figure 4.5, where the variable, fixed and total costs of a weapon system are illustrated. If we own few units of a system, the cost of operating each unit will be very high, since fixed costs, such as facilities (FA) and a certain level of support functions, support staff etc. must be present regardless of the number of units. In this example, better utilization of support facilities between four and eight units lowers the slope of the variable cost curve. When we have more than

eight units, pressure increases on available support facilities and the slope increases again.¹⁰

Figure 4.6 illustrates this point further by plotting the average cost curves, which fall by the number of units. In other words, if we reduce the numbers of items in one generation from seven to six, and in the next generation from six to five, this will increase operating cost growth as long as it is measured in the number of units. The same reasoning holds for a reduction in activity levels in an output context.

4.6 Operating cost growth as a function of markets: regulations, incentives and substitution

4.6.1 Regulations and incentives

The defence industry is a highly regulated industry. A limited number of suppliers, export restrictions, offset agreements, classified materials, restrictive legislation and similar free market restrictions can contribute to operating cost growth. Consider an economy where we have two sectors, *Civil* and *Armed*, both buying some electronic device with similar effect at the same cost. Ten years later, the electronic device must be replaced by a new device with a new level of effect. *Civil* will buy in a market where there is heavy competition and (relatively) free trade. Suppliers compete with one another, worldwide, to produce the best devices in the most efficient way. They continually cut costs (for example by substituting labour for machines) in order to remain competitive in the face of competition. *Armed*, however, will buy in a market where they are told by the government to buy from the single national provider. This national provider cannot export the device to other countries because the technology is classified. In this case, it seems a tempting conclusion that *Armed* will face a cost growth higher than that of *Civil*, since the national provider has not been exposed to the tough international competitive market and has therefore not been incentivized to cut costs or introduce efficiency measures to the same extent. Furthermore, the national provider draws no benefits from the international division of labour, further widening the gap.

The real world is not always as straight forward as the above example, though. An important issue in a non-competitive market is who has market power. If *Armed* is the single buyer (monopsony), and there are several suppliers, the government can use this power to push down prices. On the other hand, since government has such an important influence, several public choice considerations arise (Hartley 2016b). Considerations include vote-maximising politicians, budget-maximising bureaucrats and a military industrial complex. US president Dwight D. Eisenhower coined the phrase military industrial complex in his famous 1960 speech, where he said that "we must guard against the acquisition of unwarranted influence, whether sought or unsought, by the military industrial complex. The potential for the disastrous rise of misplaced power exists and will persist."^{11, 12} In other words, a collusion between politicians, bureaucrats and the industry can lead to sub-optimal choices and increasing costs.

If we have a single customer and a single buyer, we have a bilateral monopoly. Prices could in theory be lower than in a free trade market with many suppliers and many buyers. Figure 4.7

¹⁰In this example, the fixed costs are constant for any number of units. However, they probably increase in discrete numbers as we pass certain thresholds. For example, we need an entirely new building once we have more than six units. However, this distinction is not necessary to state our point, thus we leave it out.

¹¹<http://coursesa.matrix.msu.edu/~hst306/documents/indust.html>.

¹²Spinney (1980) uses the term *military industrial congressional complex* and Hartley (2016b) the phrase *military-industrial-political complex*.

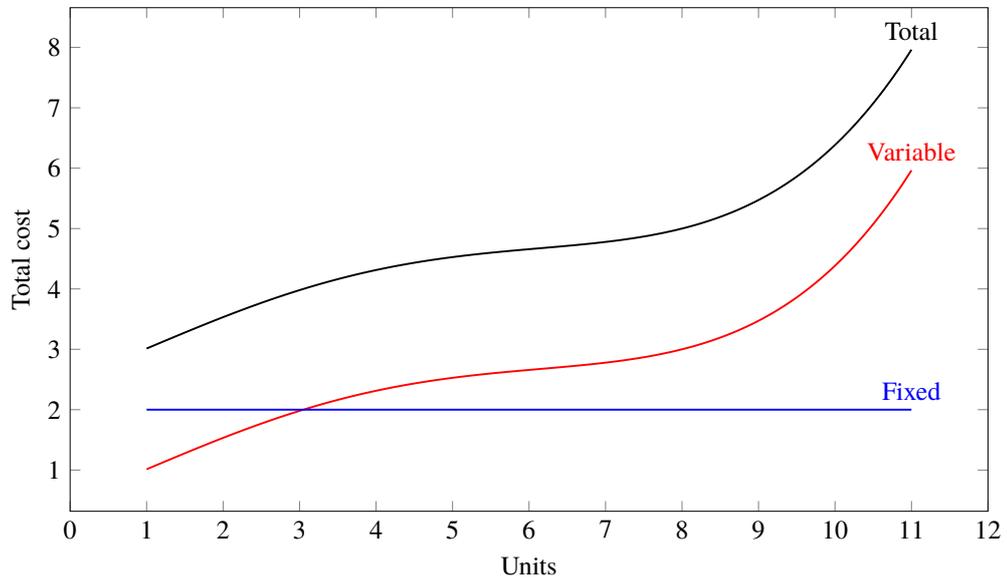


Figure 4.5 Variable, total and fixed cost curves.

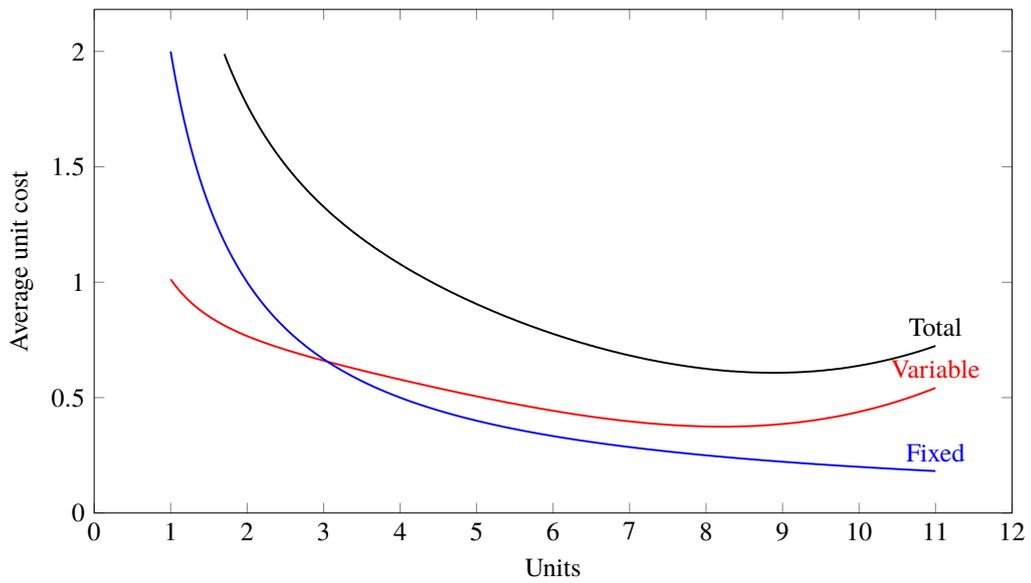


Figure 4.6 Average variable, total and fixed unit cost curves.

illustrates this. However, in the long run, if the relative power between suppliers and buyers remain unchanged, we would expect price growth because of declining productivity relative to the rest of the economy.

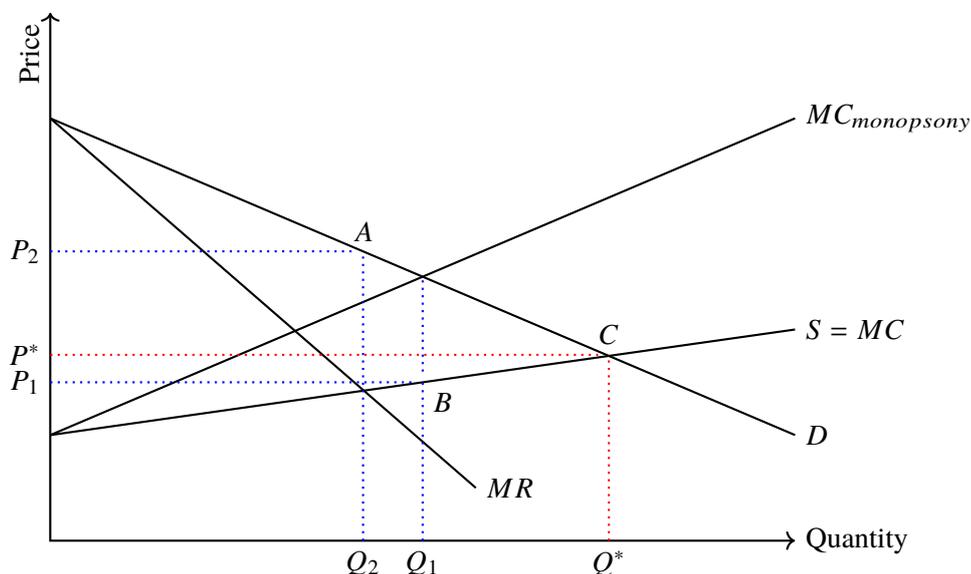


Figure 4.7 Example of a bilateral monopoly in the defence market. In a perfectly competitive market, optimal price P^* and quantity Q^* are set at the intersect between supply S and demand D . In a monopoly, price P_2 and quantity Q_2 are determined where supply is equal to marginal revenue MR . In a monopsony, price P_1 and quantity Q_1 are determined where the marginal cost to the consumer $MC_{monopsony}$ is equal to demand. In a situation where we have both monopoly and monopsony effects, prices will be in the range of $[P_1, P_2]$ and quantity in the range of $[Q_1, Q_2]$, i.e. between points A and B .

Solomon (2003, p. 23) sums up many of these points:

Imperfections in some segments of the market place provide the potential for greater price fluctuations than prevail elsewhere in the economy. For example, 'military' commodities are often available from a limited number of suppliers (an oligopoly) or nonmarket forces otherwise dictate a non-competitive selection of suppliers. Some of the distinctive factors of military goods are: (i) A unique relationship between buyer and seller (monopsony-oligopoly); (ii) Government restrictions regarding domestic content and national security requirements; (iii) Rent seeking behaviour by defence industries and others using military spending as an economic policy instrument (keeping expensive bases and weapon systems to promote regions and industrial sectors); (iv) Decreasing returns to scale in technology may contribute to an inflation rate different from the general economy.

4.6.2 Gold plating

The concept of gold plating is particularly known from software engineering (McConnell 1996), but it also applies to the Armed Forces. Phillips (1991) defines gold plating as "weapons whose capabilities are not cost-effective". McConnell (1996, pp. 46–49) distinguishes between requirements and developer gold plating:

Requirements gold-plating: Some projects have more requirements than they need right from the beginning. Performance is stated as a requirement more often than it needs to be, and that can unnecessarily lengthen a software schedule. Users tend to be less interested in complex features than marketing and development are, and complex features add disproportionately to a development schedule. [...]

Developer gold-plating: Developers are fascinated by new technology and are sometimes anxious to try out new features of their language or environment or to create their own implementation of a slick feature they saw in another product—whether or not it’s required in their product. The effort required to design, implement, test, document, and support features that are not required lengthens the schedule.

Because of the market and incentive effects, it is easy to see that gold plating can be a problem in acquisitions, and therefore also for operating cost growth, through more expensive spares, rapid repairs and so on. In order to be an operating cost growth issue, the problem of gold plating has to intensify over time. Requirement gold plating is also related to what we call nonfunctional demand. Leibenstein (1950) makes a distinction between functional and nonfunctional demand. By functional demand, he means the “part of demand for a commodity which is due to the qualities inherent in the commodity itself.” Nonfunctional demand is the part of demand which is not due to the quality of the product itself, but for example is due to external effects on utility of purchasing exactly that good.

4.6.3 Substitution

If the price of one of two input factor increases, producers can to a certain extent turn to substitutes in order to minimize cost increases. The elasticity of substitution, to which extent one input factor can be substituted for another, determines the total cost growth. The more we can substitute, the less the total cost growth will be. Say we use the same amount of two input factors in the production of a good and both experience a cost growth of four and eight per cent, respectively. If there is no scope for substitution, the aggregate cost growth will be six per cent. If there is scope for substitution, the aggregate cost growth will be somewhere between four and six per cent, depending on the extent to which the input factors can be substituted. Because of political regulations and market factors, the scope of substitution is often smaller than in the rest of the economy. Figure 4.8 illustrates an example of this, where total costs increases because of government regulation.

Connor and Dryden (2013, p. 18) argue that defence cost growth will be above general inflation because there is less scope for substitution in the Armed Forces:

Unlike the typical American consumer, DoD cannot, under most circumstances, reap the benefits of an open, competitive market; there is no “store brand” of the parts needed on the Bradley and the Abrams that can be substituted when suppliers raise their prices. Because of readiness requirements, DoD cannot buy fewer parts just because prices go up. Many of the suppliers of these parts are monopolies because of the intellectual property wrapped up in the items.

4.7 Operating cost growth as a function of history, institutions, culture and politics

Finally, history, institutions, culture and politics has a, often entwined, say for current operating costs. For example, the effects of the cold war can still be seen, some 25 years after the fall of the Soviet Union. A system of many, distributed, bases is financially inefficient. Furthermore, the current location of bases is not necessarily optimal from a military point of view. There is also a significant lag from history. In Norway, it took ten years from the end of the cold war until defence structures were significantly altered (Johnson, Hove and Lillekvelland 2017).

Many institutions often favour status quo. For example, unions would often prefer not to move to a new base in a different part of the country, even though it would mean increased military effect or increased financial efficiency. This is rational on the hands of the unions, but can increase operating costs. A culture within the Armed Forces lacking in transparency can also contribute to operating cost growth, in that efficiency measures are not undertaken because nobody knows where they should be undertaken.

Politics influence operating cost growth through several channels. Defence is often used as a regional policy tool, promoting employment and business in remote areas. If transportation costs (which makes up a greater portion of total expenditure when defence is used for regional policy), labour costs (to attract employees or replace those who leave) as well as other types of cost rise faster than the base price index, political choices has a significance on operating costs. Furthermore, politicians often favour domestic industries over international industries. This can, through reducing competition and the exploiting of comparative advantages, increase operating cost growth.

5 Review of empirical studies

5.1 Studies on the various reasons behind operating cost growth

In this section, we summarize international and Norwegian studies on operating cost growth and the related measures. We categorize the results as we did in Chapter 4, but stress that the various categories overlap. Results mentioned under the heading input factor mix thus does not imply that there are no markets or reductions in the number of units involved.

5.1.1 Input factor mix

Jones and Woodhill (2010) establish a method for calculating what they call defence inflation in the United Kingdom (UK). For non-personnel expenditure, spending on 40 000 contracts constitute around 90 per cent of near cash expenditure (of which 400 contracts constitute 75 per cent).¹³ The authors measure price growth within contracts, i.e. not including births and deaths of contracts. Thus, they measure an intragenerational price growth, ignoring the intergenerational effect (see Figure 3.5). Still, they estimate a higher growth in defence contracts in the period 2005–2009 than for the retail price index excluding mortgages (RPIX). Hartley (2016b) compares the measure of defence inflation to the gross domestic product (GDP) deflator and finds that there is a great difference. Figure 5.1 summarizes the aggregate UK "defence inflation" index over the last ten years. We see that defence inflation has risen by 40 per cent more than the GDP deflator, but along similar lines as the RPIX. This underlines the importance of choosing a suitable base price index.

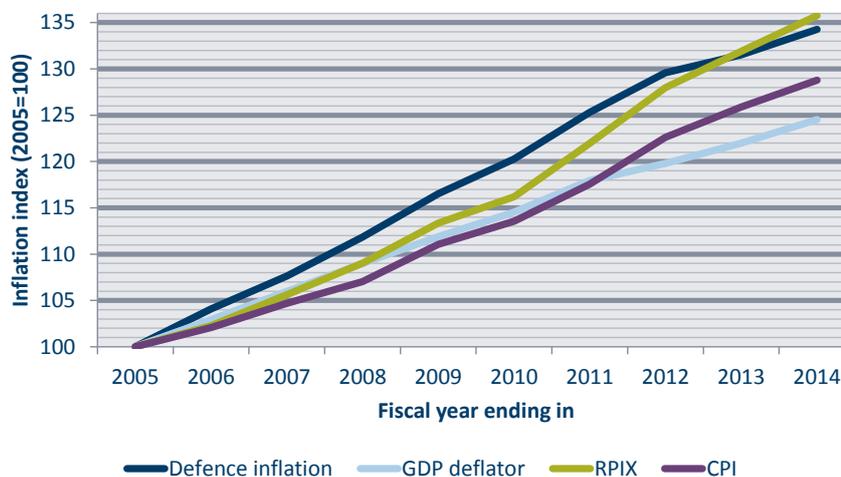


Figure 5.1 UK "defence inflation" 2005–2014. Sources: Defence inflation: Hartley (2016b), citing MoD (2014, 2015). CPI and RPIX: Office for National Statistics (2016a,b). GDP deflator: HM Treasury (2016).

¹³"Near cash" is mainly a British term. A definition is as follows: "Resource expenditure that has a related cash implication, even though the timing of the cash payment may be slightly different. For example, expenditure on gas or electricity supply is incurred as the fuel is used, though the cash payment might be made in arrears on a quarterly basis. Other examples of near-cash expenditure are: pay, rental." Taken from <http://www.gov.scot/Topics/Government/Finance/spfm/glossary>.

Figure 5.2 illustrates the Norwegian CPI and the price of intermediate consumption for defence from national accounts data for 1970 (left) and 1991 (right).¹⁴ Overall, from 1970, there are no indications of excess price growth. From 1991, however, prices have risen nearly twice as fast in defence as CPI has risen.

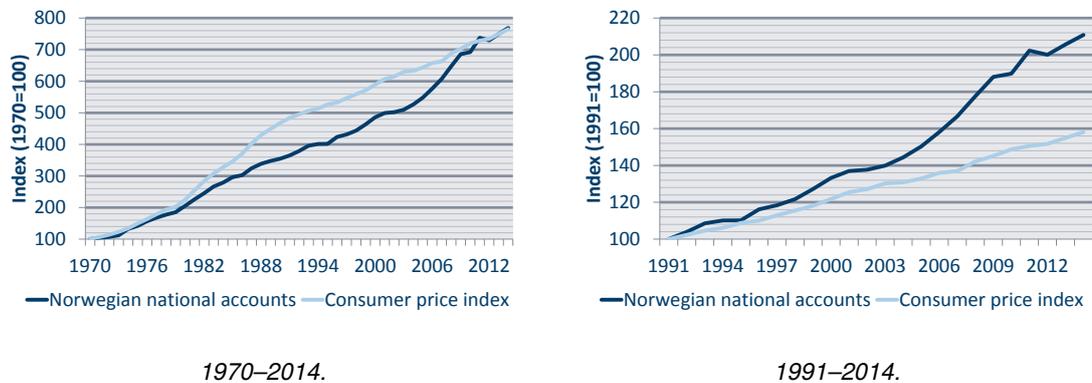


Figure 5.2 Price indices of intermediate consumption from Norwegian national accounts and the consumer price index 1970–2014. Figures from Hove (2015).

Figure 5.3 illustrates shares of intermediate consumption (goods and services) for the national account industries Defence, Public administration, Mainland Norway excluding Public administration and Manufacturing (columns) bought from 10 groups of industries, as well as the average annual cost escalation of production for that group of industries. In Figure 5.3, for example, Defence spend almost 27 per cent of their intermediate consumption expenditure on "Other services", where the average growth in price of production is 2.8 per cent. There is a tendency for Defence to spend relatively more than the private sector industries on expensive groups.

Solomon (2003, p. 23) also mentions the input factor mix as a source of Canadian defence inflation. He notes that "machinery and equipment" constitute 8 per cent of GDP, but 20 per cent for the Armed Forces. On the other hand, "food and clothing" constitute 24.6 per cent of GDP, but only 1.2 per cent for the Armed Forces. Holcner and Neubauer (2015) notes that Canadian and US defence inflation is, in general, higher than CPI. That input prices rise at different rates is further illustrated by Figure 5.4, based on Bureau of Economic Analysis (BEA) data (BEA 2015). The coloured curves show the development of the price of intermediate goods and services, as well as two of its fourteen sub indices.¹⁵ We see that while electronics prices have declined continuously since 1990, petroleum products have seen a massive increase in prices. The total price trend does not seem to deviate much from the CPI¹⁶, though.

¹⁴Price growth of intermediate consumption can be outlined as follows: Assume an industry j consume a share of its intermediate consumption, $\alpha_{j,i}$, from a group of goods and services, i (in sum $\sum_{i=1}^I \alpha_{j,i} = 1$). By multiplying the weights with various price indices (consumer price indices, retail price indices, production price indices, import price indices, et cetera), p_i , final price levels are obtained. Price indices are equal across industries, thus $p_{j,i} = p_{k,i} = p_i, \forall j, k$.

¹⁵The method for obtaining the indices is documented in BEA (2014). The 14 indices are i) Aircraft, ii) Missiles, iii) Ships, iv) Vehicles, v) Electronics, vi) Other durable goods, vii) Petroleum products, viii) Ammunition, ix) Other nondurable goods, x) Installation support, xi) Weapons support, xii) Personnel support, xiii) Transportation of material and xiv) Travel of persons.

¹⁶Consumer Price Index – All Urban Consumers. <http://www.bls.gov/cpi/data.htm>.

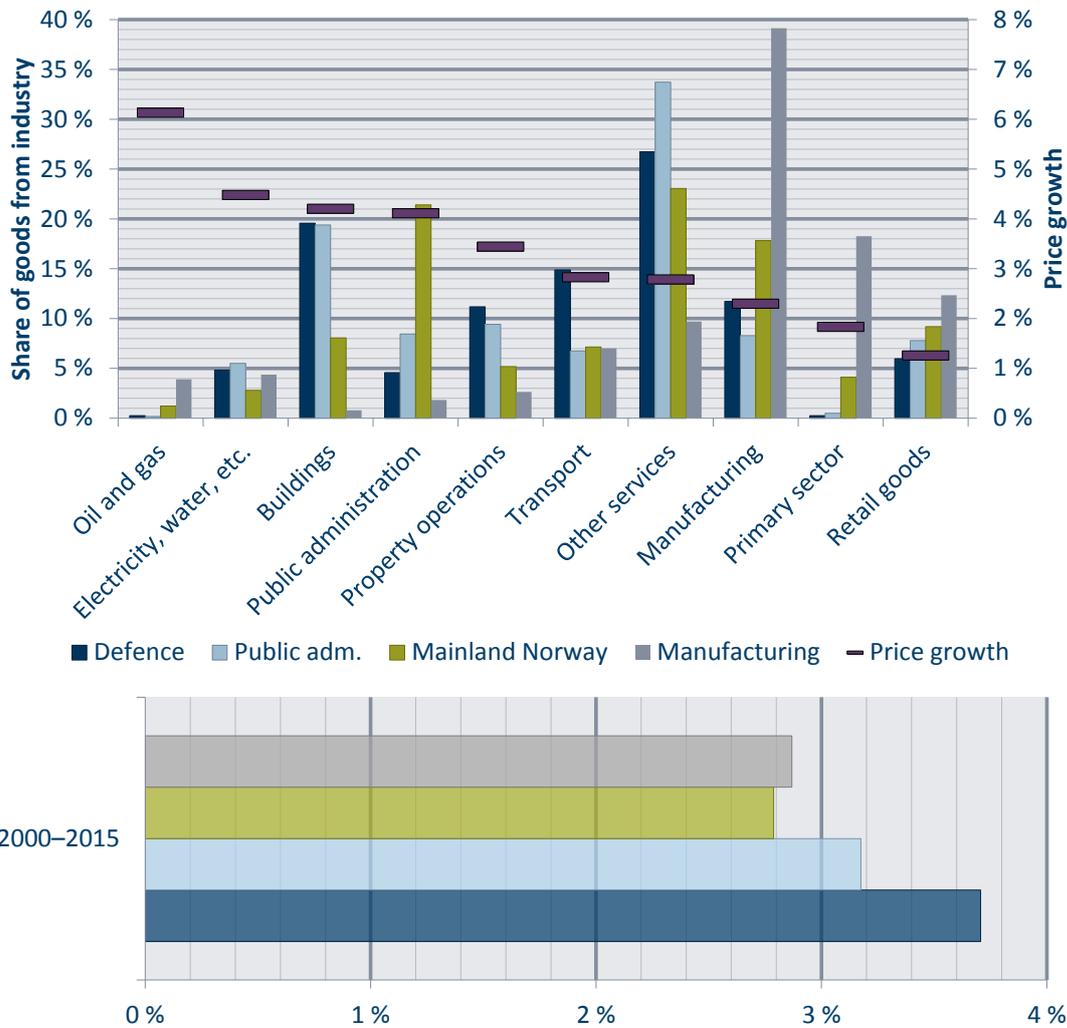


Figure 5.3 Top part of figure: Share of intermediate consumption (left axis) originating from various industries for defence (dark blue columns), public administration (light blue columns), mainland Norway exclusive of public administration (green columns) and manufacturing (grey columns) 2010–2012. Average price growth of production for the various industries shown by purple bars (right axis). Lower part of figure: average price growth intermediate consumption 2000–2015. Source: Statistics Norway and own calculations.

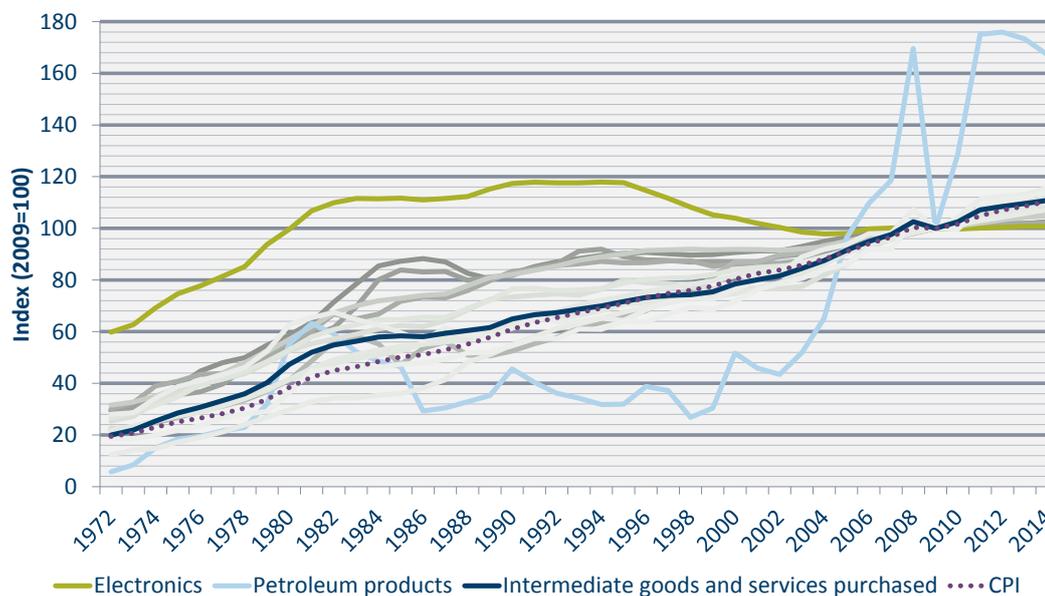


Figure 5.4 Price indices for national defence components by type. Electronics and petroleum products are highlighted, as is the total price index for intermediate consumption. The other twelve sub indices are shown in greyscale. Indexed at 100 in 2009. Data from BEA (2015). Consumer Price Index – All Urban Consumers is shown for comparison.

5.1.2 Productivity

When it comes to productivity, not much has been done in terms of studying efficiency improvements. Fløttum et al. (2012) writes that in Norwegian national accounts, 1960s and 1980s studies based on wage statistics indicated a productivity growth of 0.5 per cent in Norwegian public services, except for defence, where there was zero productivity growth. Røgeberg, Skoglund and Todsén (2004) carried out research based on so-called quality-adjusted labour cost indices.¹⁷ In the period 2000–2002, they found an annual productivity growth of 0.6 per cent for central government administration and 0.8 per cent for defence. Note that these are measures of labour productivity, not overall productivity, which is harder to measure.

Since 2009, the Norwegian Armed Forces has had an obligation to improve cost efficiency by 0.5 per cent annually. Åmot (2014, 2015) finds many examples of efficiency gains, though not necessarily as a direct result of the 0.5 per cent obligation. Though difficult to measure, we would expect some efficiency gains in the Armed Forces. Since the Armed Forces are labour intensive (Borge et al. 2017; Hove 2015), we expect a somewhat lower productivity growth than in the general economy. Also, Borge et al. (2017) find indications of Baumol’s cost disease in the Norwegian Armed Forces.

¹⁷Quality-adjusted labour cost is a measure of labour input into production which takes into account different skill levels of different types of workers.

5.1.3 Technology

Few studies are done on the exact link between technological complexity and operating cost growth. However, there are some indirect studies, mainly showing that operating costs increase between generations or over time. Droff (2013) shows how the costs of the fighter aircraft *Rafale* is three times greater than that of the older *Mirage 2000*. Also, Figure 3.3 illustrated the increase in operating costs between generations of fighter aircraft in the US Air Force. Such comparisons do not show a direct link between technology and operating costs, only indications.

Spinney (1998) says that increasing technological complexity shifts the maintenance burden towards a greater degree of depot level maintenance (away from the operating base).¹⁸ He then illustrates how D-level maintenance costs increase as systems grow more complex. This not only increases costs, it also increases dependence on supply systems and a geographically distributed infrastructure, which underlines our mention of risk in Section 4.3.1. In other words, though there are not detailed studies on the exact effects of increased complexity on operating costs, there are compelling indications of the link. Because of the lack of detailed studies, it is hard to separate between the effects of ageing and technological complexity.

5.1.4 Ageing

There are several studies on the effects of ageing. Keating, Boito and Woods (2015) find that maintenance costs in the US Air force grows at roughly five per cent beyond economy-wide inflation annually (cited in Keating and Arena 2016). Dixon (2006) find maintenance cost increases at an annual rate of 3.5 per cent for civilian aircraft six to 12 years old, but nearly unchanged rates for aircraft 12 to 25 years old. Hawkes and White (2008) use data for US Air Force aircraft up to 44 years of age. The find indications of a bathtub curve. Costs increase more for very young aircraft and for aircraft of 30 years and older.

A study by CBO (2001) also addresses the issue of ageing in particular. The study cannot positively identify evidence for an effect of ageing on operating cost growth at an aggregate level, but stresses that the topic is complex, conclusions are difficult to reach and that they study aggregate cost, not cost growth per weapons system, as for example in the study by Hawkes and White (2008). They also note that "the average ages of ships, aircraft, and armored vehicles will rise in the future, in some cases to unprecedented levels. That trend could eventually lead to much higher O&M costs for equipment, which could in turn lead to higher total O&M spending" (CBO 2001, p. 21). CBO provides anecdotal evidence that the 40 year old KC-135 Stratotankers experienced increasing O&M costs due to age, whereas the CH-46 Sea Knight and the UH-60 Black Hawk went through upgrade programmes which reduced O&M costs. Furthermore, they quote several studies who identify a connection between age and increased O&S costs. Francis and Shaw (2000), Hildebrandt and Sze (1990), Johnson (1993), Levy (1991), Pyles (2003) and Stoll and Davis (1993) all identify maintenance and/or cost increases with increasing age.

CBO (2001) suggest four ways of countering the effects of ageing:

- To allow the costs to increase with age and pay the cost. The risk is lower operational readiness, due to lack of spare parts, lack of available units and budgetary constraints.
- To perform service life extension programmes (SLEPs), which would incur some investment costs, but hopefully push operating cost increases further into the future. The risk is that investment costs are substantial and that O&S might increase anyway.

¹⁸In a three-level maintenance system, we have organizational, intermediate and depot level (O-, I-, and D-level) maintenance. O-level is typically at the base, whereas D-level is highly specialized and located at a shared location.

- To buy more of the current generation, i.e. substitute ageing F-16 with new F-16s. The risk is that the relative effect of the system is reduced as adversaries increase their capabilities.
- To buy a new generation of a weapon system, i.e. substitute ageing F-16 with new F-35s. The risk is that operating costs increase by even more than the effect of ageing would have.

5.1.5 Number of units

There are very few works on the direct effects of reducing the number of units. Krey and Presterud (2012) conducted a study of activity based and structural costs in the Norwegian Armed Forces. Structural costs are not dependent upon activity in the short run. They considered the effects of removing one or two units of the P-3 Orion multimission maritime aircraft (MMA), the DA-20 electronic warfare (EW) aircraft and mine countermeasure (MCM) ships. The number of flight hours and days of sailing for each unit were kept constant, so that if units were reduced by one third, so was activity. Since Norway has only a few units of each of these weapon systems, they found significant unit cost increases of further reductions. The results are shown in Figure 5.5. Note that structural costs as a share of total costs increase as fewer units are in operation.

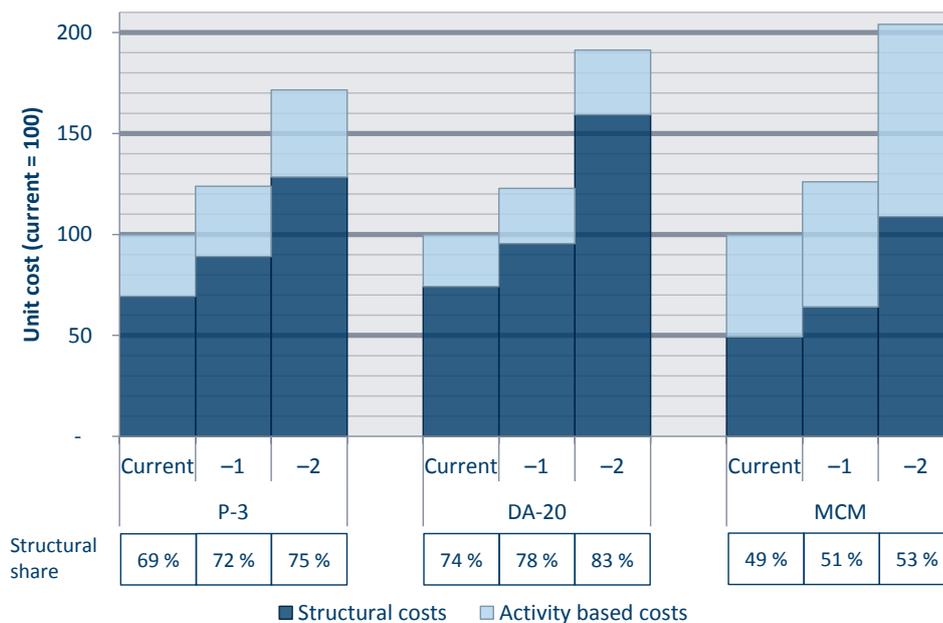


Figure 5.5 Unit operating cost for the current number of P-3 MMA, DA-20 EW aircraft and MCM ships, and for a reduction of 1 or 2 units. Indexed at 100 for current number of units. Based on Krey and Presterud (2012). Structural shares of costs shown as per cent of total unit cost.

5.1.6 Gold plating

Many studies have touched upon the concept of gold plating, albeit not all of them directly. As gold plating is mainly related to investments, but with consequences for operations, we keep this section short. Bolten et al. (2008) studied the causes of cost growth in United States (US) weapon system acquisitions and found that decisions were to blame for the majority of cost growth. Decisions

include changes in requirements, quantity or schedule. A study by Presterud and Øhrn (2015) found a suboptimal incentive structure in the acquisition process of the Norwegian Armed Forces. One of their conclusions is that the different branches try to "maximize their share of the investment funds by using their expert power to acquire equipment with unnecessarily high specifications (gold plating)."

5.2 FFI studies using Norwegian data

This chapter builds upon a large body of Norwegian Defence Research Establishment (FFI) literature aimed at estimating total operating cost growth of goods and services. With the exception of Kjernsbæk, Vamraak and Bruun (2005), all the reports aim to measure or estimate the input based operating cost growth, **GRIUC**. Gulichsen (2003) was the first report written independently on operating cost growth, though the phenomenon was mentioned in previous works (for example Nettet and Wessel 1995). Gulichsen (2003) empirically estimates a **GRIUC** factor for personnel of 3.8 per cent and a **GRIUC** factor for goods and services of 2.1 per cent. The report recommends a **GRIUC** factor for personnel to be used in long term planning to be set at 2.45 per cent and the **GRIUC** factor for goods and services is to be set at 0.75 per cent.

While Gulichsen divides total wage costs by man-years to obtain the average cost per unit of personnel, there is no such adjustment made for goods and services. Thus, goods and services **GRIUC** is not strictly **GRIUC**, as it is not measured per unit. Goods and services **GRIUC** is notoriously difficult to measure, as one unit of goods and services can be anything between woolly socks and missiles – it is more difficult to quantify, has varying levels of aggregation and is more heterogeneous than personnel. In 2005, Kjernsbæk, Vamraak and Bruun (2005) suggested an updated and output based method, using activity levels – flight hours for the Air Force, sailing hours for the Navy, sailing distance for the Coast Guard and exercise days for the Army – as a measure of units. The updated method of Kjernsbæk, Vamraak and Bruun shows that historical **GROUC** was about 3.75 per year above inflation in the period 1994–2002. These numbers were, not surprising, considering the activity level adjustment, higher than previously estimated figures by Gulichsen. In Chapter 6, we conduct our empirical analysis in a similar way as Kjernsbæk, Vamraak and Bruun (2005) did.

Johansen and Berg-Knutsen (2006) also provide an empirical study, estimating personnel **GRIUC**¹⁹ at 2.7 (base salary), 3.7 (base salary plus added pay) and 4.1 (base salary plus added pay and personnel driven goods and services (P-G&S)) per cent. Combined with a conscript **GRIUC** of 5.1 per cent, the overall personnel **GRIUC** is estimated at 4.5 per cent. For goods and services, they built on the work of Kjernsbæk, Vamraak and Bruun (2005), producing a **GROUC** estimate of 2.4 per cent. However, Johansen and Berg-Knutsen (2006) also attempted going one step further, not only measuring historical operating cost growth, but also providing arguments concerning future operating cost growth. Figure 5.6 outlines the prospected future operating cost growth of Johansen and Berg-Knutsen (2006). Johansen and Berg-Knutsen use annual defence accounts to categorize previous expenditures into three categories causing operating cost growth:

- Costs sharing the same drivers as the costs in the general economy, which they approximate by **CPI**.
- Costs being driven by more advanced technology, which they approximate by **ICE**.
- Costs that mainly consist of labour input, such as consultancy services, which they approximate

¹⁹The measure is equal to **GROUC** if we assume that the production per man year is constant over time.

by wage growth.

Johansen and Berg-Knutzen found shares of 37, 40 and 23 per cent respectively. As Johansen and Berg-Knutzen define operating cost growth as being growth beyond CPI, the contribution of CPI on GRIUC is naturally 0 per cent. The concept of ICE is thoroughly discussed in Hove and Lillekvelland (2016). Amongst other things, the quest of obtaining the most technologically advanced equipment drives unit costs upwards. More expensive equipment not only costs a lot to acquire, it also costs more to maintain than more simple equipment. Johansen and Berg-Knutzen use 3 per cent growth beyond CPI as their ICE estimate. Finally, costs that mainly consist of labour input is assumed to rise by the rate of real wage growth. This is intuitive, given that real wage growth is approximately the same across industries. Increased productivity can offset the effects of this price growth, but as we measure GRIUC (i.e. per unit of input), this is not relevant in our case. In a steady state situation, Johansen and Berg-Knutzen argue that the activity level and defence structure does not contribute to operating cost growth. In sum, a future GRIUC of 1.6 per cent is expected. This is the method currently in use in Norwegian long term planning, though with periodic revision of the numbers.

Gulichsen, Johansen and Pedersen (2011) contributed to the understanding of operating cost growth by emphasizing the operating cost growth of personnel related goods and services (confer Figure 3.1). The authors claim there is a increase in the volume of goods and services per man year. For example, every employee now has a computer, and an increasing share also has a tablet computer. This is a volume increase affecting the overall cost growth of personnel.

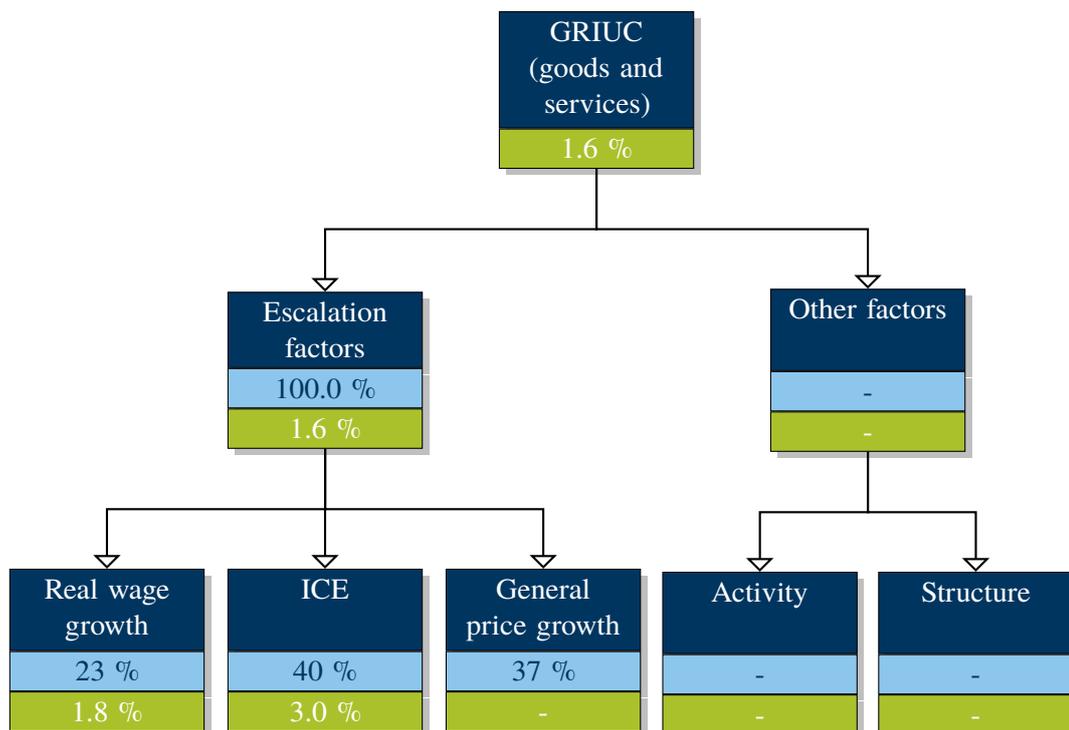


Figure 5.6 Underlying drivers behind GRIUC of goods and services, including shares and annual growth (Johansen and Berg-Knutzen 2006).

6 Estimates of GROUC using activity as output

In previous chapters, we described why GROUC exists and outlined existing research on GROUC and related measures. In this chapter, we estimate historical GROUC, adjusting costs for changes in activity. In the context of Section 3.4, this is an adjustment for changes in output. This means that we cannot draw conclusions on changes in prices of inputs based on our estimates. The difference between changes in prices on input goods and output goods in the Armed Forces is caused by changes in productivity (see Section 3.4.1). Thus, our estimates show the expected increase in costs given that activity is held constant.

Unfortunately, our dataset does not allow for distinguishing between intra- and intergenerational GROUC. Our estimate should be viewed as a long-term average output GROUC. As Figure 3.5 illustrated, the total GROUC trend does not need to follow the intragenerational GROUC trend, and will therefore not necessarily be precise when used on short time horizons. Neither are we able to pinpoint which of the seven causes behind cost growth is the strongest, or how much each contribute. This would require a better data set.

Section 6.1 describes the theoretical argument for our empirical approach, Section 6.2 describes the data we use, and the way we have treated the data, while Section 6.3 describes and discusses the results. Section 6.4 summarizes the empirical analyses and the results. Section 6.1 to Section 6.3 can be a bit technical, therefore we advise those primarily interested in the results to proceed to Section 6.4.

6.1 Theoretical approach

As mentioned earlier in this report, there is no formally agreed way of estimating GROUC on inputs. One of the main reasons for this is varying data availability. Chapter 5 gave a brief overview of previous approaches. Unfortunately, measuring the amount of input required to operate one unit of a weapon system is not possible with the current Norwegian Armed Forces accounting system. The amount of input required to operate one unit is, however, likely to be strongly correlated with the amount of output produced by that unit. In our analysis, we employ activity, for example number of flight hours or days spent sailing, as the unit of measurement.

Assume that the amount of input, $G_{t,i}$, needed to operate unit i at time t is:

$$\bar{G}_{t,i} = \bar{Y}(a_{t,i}, e_{t,i}) \quad (6.1)$$

where Y is a correspondence between need for inputs and activity, $a_{t,i}$, and productivity, $e_{t,i}$, meaning that the amount of inputs needed to operate unit i depends on the activity and the productivity of the unit. In this context, productivity only affects the amount of inputs needed to operate one unit.

The costs of operating unit i at time t , will be the vector of inputs needed to operate unit i , times the vector of prices P_t . P_t contains all prices, and not just the prices needed to produce unit i . The operating cost of unit i can be written as:

$$C_{t,i} = \bar{P}_t^T \bar{G}_{t,i} = \bar{P}_t^T \bar{Y}(a_{t,i}, e_{t,i}) \quad (6.2)$$

which is simply the sum of need for each type of input times the price of that input.

The change in unit operating cost can be found by taking the total derivative of (6.2):

$$dC_{t,i} = \bar{Y}^T(a_{t,i}, e_{t,i})d\bar{P}_t + \bar{P}_t^T \bar{Y}'_1(a_{t,i}, e_{t,i})da_{t,i} + \bar{P}_t^T \bar{Y}'_2(a_{t,i}, e_{t,i})de_{t,i} \quad (6.3)$$

The first part of (6.3), $\bar{Y}^T(a_{t,i}, e_{t,i})d\bar{P}_t$, says that the operating cost of unit i can change as a result of changing prices of input. For example, if the price of fuel increases, so will the price of operating unit i (given that the element for fuel in $G_{t,i}$ is positive).

The second part of (6.3), $\bar{P}_t^T \bar{Y}'_1(a_{t,i}, e_{t,i})da_{t,i}$, says that the operating cost of unit i depends on the activity level of unit i . Since we can assume that the need for input increases as activity increases, $\bar{Y}'_1(a_{t,i}, e_{t,i}) > 0$, it follows that the cost will increase as activity increases. For long term planning purposes, activity is usually assumed constant over time or explicitly given.

The third part of (6.3), $\bar{P}_t^T \bar{Y}'_2(a_{t,i}, e_{t,i})de_{t,i}$, says that the cost of operating unit i also depends on the productivity level in the operation. Since the need for input decrease as productivity increases, $\bar{Y}'_2(a_{t,i}, e_{t,i}) < 0$, productivity improvements can contribute to reducing the consequences of increasing prices. An example could be that more fuel efficient vehicles reduces the need for fuel, given constant activity. In the following, we assume there is no productivity growth. As a consequence, our estimate will be biased downwards if productivity is increasing.

Assume that (6.1) takes the simple form

$$\bar{Y}(a_{t,i}, e_{t,i}) = \bar{V}_i a_{t,i} + \bar{S}_i \quad (6.4)$$

where \bar{V}_i is the amount of each input required to produce one unit of activity, and \bar{S}_i is the amount of each input required that is independent on activity. (6.4) means that the required amount of input required to operate system i (by assumption) is linearly dependent on activity. Activity is the only reason for changed needs of input, ignoring changes in productivity. Further assume that $\bar{P}_t \bar{V}_i = p_t v_i$, $\bar{P}_t \bar{S}_i = p'_t s_i$, implying that all prices follow the same trend. Using these assumptions, we can rewrite our problem as follows:

$$C_{t,i} = p_t v_i a_{t,i} + p'_t s_i \quad (6.5)$$

We make a distinction between activity-based costs and structural costs. Activity-based costs are similar to variable costs and structural costs are similar to fixed costs. The terms were introduced into Norwegian long-term planning by Krey and Presterud (2012). We continue to use them here as they are more descriptive of what we study (costs driven by activity). First consider total structural costs:

$$T_{t,s} = p'_t \sum_{\forall i} s_i \quad (6.6)$$

By assuming that all prices grow at the same constant rate, r' , the change in total structural costs can be written:

$$\frac{T_{t,s}}{T_{t-1,s}} = \frac{p'_t \sum_{\forall i} s_i}{p'_{t-1} \sum_{\forall i} s_i} = r' \quad (6.7)$$

Total activity-based cost can be rewritten similarly as structural costs:

$$T_{t,a} = p_t \sum_{\forall i} v_i a_{t,i} \quad (6.8)$$

$$\frac{T_{t,a}}{T_{t-1,a}} = \frac{p_t \sum_{\forall i} v_i a_{t,i}}{p_{t-1} \sum_{\forall i} v_i a_{t-1,i}} = r \frac{\sum_{\forall i} v_i a_{t,i}}{\sum_{\forall i} v_i a_{t-1,i}} \quad (6.9)$$

Which means that activity-based costs change at a constant rate, r , times the change in total activity weighted by the volume of input required to produce each type of activity. There are two possible routes to estimate the average growth in activity-based operating costs. The first is to use accounting

data to calculate v_i for each weapon system. This is similar to what was done by Kjernsbæk, Vamraak and Bruun (2005) (in fact so similar that we chose to use their weights). The second route is to estimate v_i using the maximum likelihood method²⁰. In Section 6.3, the results from both methods are presented.

6.2 Data

Our dataset consists of two parts. The first part is accounting data from the Norwegian Armed Forces accounting system. The second is activity data covering major weapon systems. This data originates from a few different sources: Statistics Norway (SSB), government white papers and Norwegian Armed Forces internal statistics. Table 6.1 shows descriptive statistics of the dataset.

Statistic	N	Mean	St. Dev.	Min	Max	Unit
Structural costs	20	20,510,019	1,057,449	18,627,598	21,980,516	1000 2015-NOK
Activity related costs	20	6,578,564	1,017,613	4,705,482	7,863,053	1000 2015-NOK
Structural costs (subsample)	20	1,063,725	209,293	756,306	1,461,366	1000 2015-NOK
Activity related costs (subsample)	20	3,423,715	731,523	2,193,466	4,609,080	1000 2015-NOK
EW plane	20	1,094	301	594	1,687	Hours of flight
Frigate	20	7,062	1,420	4,542	9,557	Days of sailing
Helicopter	20	10,041	1,164	8,721	13,096	Hours of flight
Army exercise	20	120,806	29,222	65,348	181,401	Days of exercise
Fighter aircraft	20	10,498	2,042	7,846	15,839	Hours of flight
Coast Guard	20	4,758	1,064	3,487	7,372	Days of sailing
MPA	20	2,328	405	1,752	3,463	Hours of flight
Logistics vessel	20	7,211	2,379	3,720	11,129	Days of sailing
MCM	20	10,378	3,128	5,578	15,392	Days of sailing
FAC	20	4,660	2,912	0	12,972	Days of sailing
Transport aircraft	20	2,448	1,299	500	4,893	Hours of flight
Trainer aircraft	18	1,411	612	626	3,036	Hours of flight
Submarine	20	9,173	2,641	5,160	12,874	Days of sailing

Table 6.1 Descriptive statistics.

6.2.1 Accounting data

Our accounting data is gathered from the Norwegian Armed Forces internal accounting system. We use data from 1994 to 2013. For the main sample, all operating costs are included. For the subsample, we have only included goods and services costs (i.e. not including pay and buildings and property expenses) from parts of the organization that has operational activity or are strongly related to parts of the organization that has operational activity. This includes the Army, the Navy, the Air Force, the Coast Guard, and the Norwegian Defence Logistics Organization (FLO).²¹ In

²⁰The maximum likelihood method is an estimation method that allow for nonlinear relationships.

²¹Costs related to international operations are also included, since international contributions is a large part of the activity in some years.

total this includes a little more than half the Armed Forces' goods and service expenses and 17 per cent of the costs in the main sample. All costs are in 2015 NOK.

Separating activity-based costs and structural costs is a challenging task. Due to the changes in the accounting system, it is in some cases unclear which costs should be considered structural and which should be considered activity-based. One of the major challenges is the introduction of internal trade of services in the Armed Forces. Under this system, costs can be filed multiple times. This is most common for maintenance, where FLO incurs the initial cost of maintenance, which it bills the branches. In other words, it is accounted twice as an expenditure and once as an income. Only the initial maintenance cost is included in our dataset.

Costs like fuel and ammunition can easily be assigned as activity-based. We have chosen to assign all maintenance costs as activity-based costs. Some maintenance is dependent on activity, condition-based maintenance, while other maintenance is independent on activity, calendar-based maintenance. Unfortunately, the Norwegian Armed Forces accounts do not allow for such a distinction. Facilities are assigned as structural costs, as is base salary. Variable pay is assigned as activity-based for the branches, but as structural for the rest of the Armed Forces. The total expenditure in each category can be seen in Figure 6.1 (entire sample) and Figure 6.2 (subsample). Structural costs are relatively stable in real terms throughout the period, while real activity-based costs are increasing. As equipment related to operational activity, and hence activity-based costs, tend to be relatively technologically advanced, this result should not be a surprise. This is also in line with previous findings (Kvalvik and Johansen 2008).

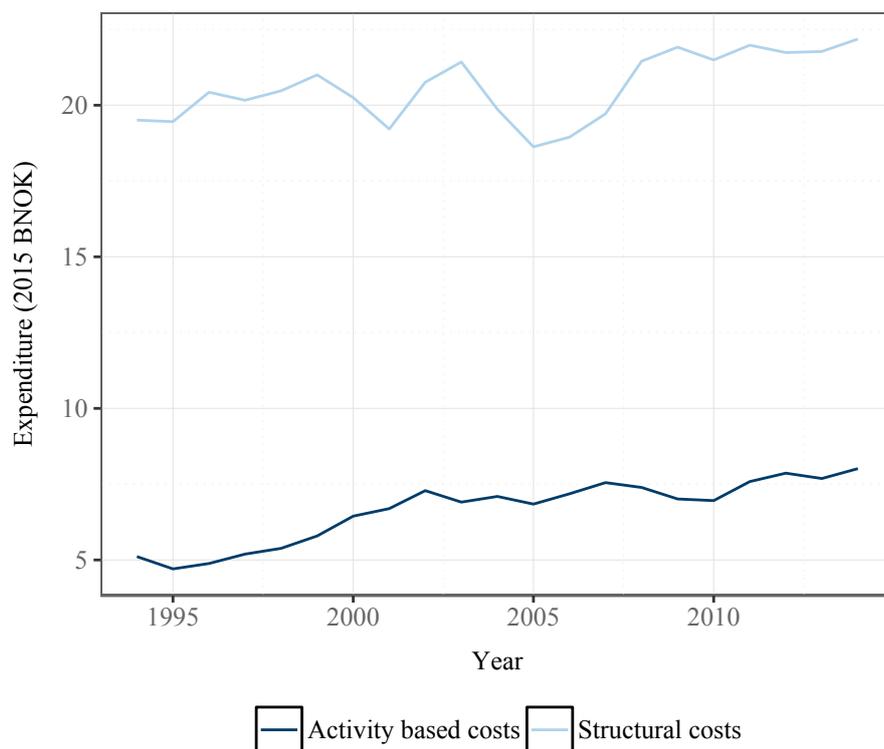


Figure 6.1 Cost categories. The entire Armed Forces is included.

One important critique of the division into activity-based and structural costs is that during a 20 year time period, structural costs could also be dependent on trends in activity level. For example,

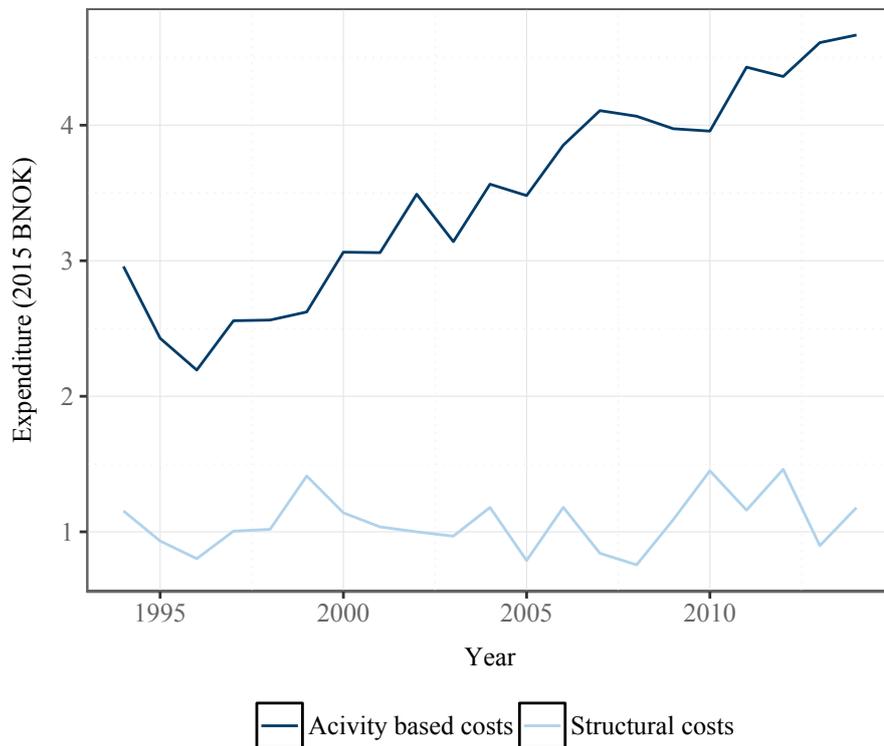


Figure 6.2 Cost categories. Only goods and services costs for branches with operational activity.

reductions in number of units or consistent reduction of activity, will probably also influence structural costs.

6.2.2 Activity data

The data for activity is gathered from Statistics Norway (SSB) and the Norwegian Armed Forces internal statistics. Detailed activity for each weapon system can be seen in Appendix B. We collected data for flight hours for the Air Force, sailing days for the Navy and the Coast Guard and exercise days for the Army.

Aggregate weighted activity ($\sum v_i a_{t,i}$ in (6.8)) is calculated by weighting the different types of activity by their cost. For example, if a flight hour of a fighter aircraft is three times as expensive as that of a transport aircraft, a fighter aircraft flight hour carries three times the weight. Cost per unit of activity was calculated by Kjærnsbæk, Vamraak and Bruun (2005), using 2002 data. As 2002 is near the middle of the dataset, we use the same weights as Kjærnsbæk, Vamraak and Bruun (2005). Finally, the aggregate activity for each branch is weighted together by the total activity-based costs for each branch, found in Section 6.2.1. Thus, if the Army costs twice as much as the Air Force, Army activity counts twice as much. The activity weights can be found in Table 6.9. The aggregate activity can be seen in Figure 6.3.

The aggregate activity has declined quite substantially over the period. From 2005 to 2006 the activity increased by 32 % due to a major increase in activity in the fast attack craft (FAC) branch. A similar decline is found from 2007 to 2008 as the 14 old *Hauk* class FACs were replaced by 6 new *Skjold* class corvettes. Initially, the *Skjold* class had little activity, but from 2010 the activity

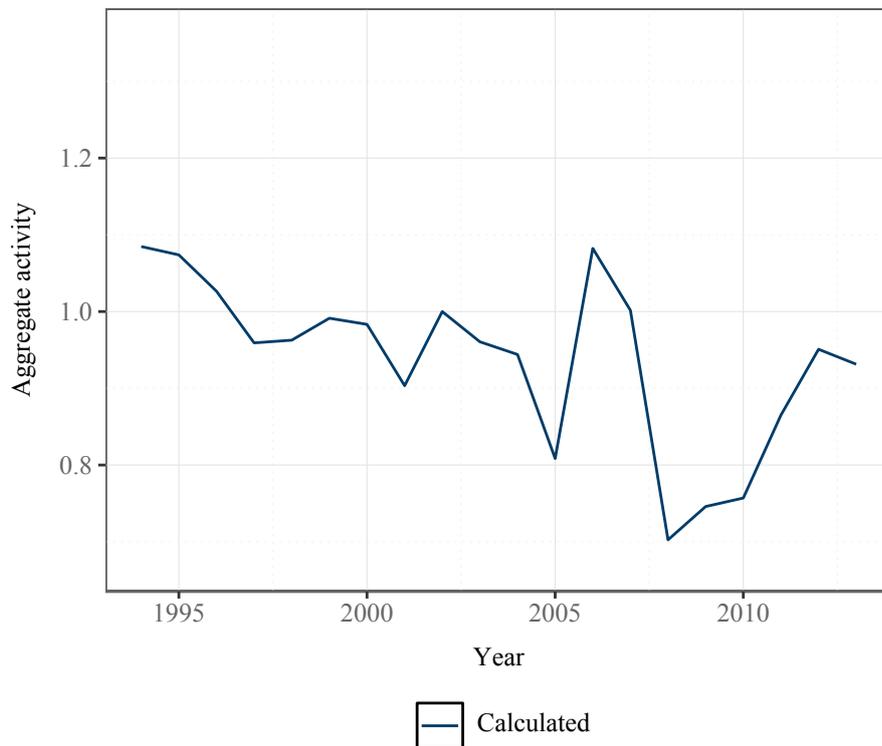


Figure 6.3 Weighted total activity.

increased rapidly.

As the **FAC** branch serve as an example of, the contribution from one unit of activity might have changed during the period. A unit of activity in 2013 might be far superior to a unit of activity in 1994, for example as a result of replacing the Hauk class with the Skjold class. This means that the decline in activity might be outweighed by performance improvements. This is in line with the argument of Anagboso and Spence (2008, 2009), discussed in Section 3.4.2. On the other hand, a potential adversary might also experience performance improvements which outweigh our performance improvement. This is a topic thoroughly discussed in the related topic of **ICE** (see for example Hove and Lillekvelland 2016).

From the data it seems that costs have increased while activity has decreased. Section 6.3 shows the average annual **GROUC**, given constant activity levels.

6.3 Results

6.3.1 GROUC based on calculated weights

As stated in Section 6.1, the average **GROUC** can be calculated using (6.9) and the weighted activity found in Section 6.2.2. The results are reported in Table 6.2 (entire sample) and Table 6.3 (subsample).

Column **GROUC** is the mean **GROUC**, sd is the standard deviation of the mean, and the p-value is for a T-test of the mean equaling zero. None of the results are different from zero on any

	GROUC	sd	p-value
GROUC on activity based costs	0.038	0.029	0.20
GROUC on structural costs	0.007	0.010	0.51

Table 6.2 Estimates of GROUC. GROUC for activity based costs calculated based on calculated activity weights for the entire sample.

	GROUC	sd	p-value
GROUC on activity based costs	0.043	0.033	0.22
GROUC on structural costs	0.022	0.062	0.74

Table 6.3 Estimates of GROUC. GROUC for activity based costs calculated based on calculated activity weights for the subsample.

conventional significance level, meaning that we cannot conclude with certainty that the GROUC rate is positive. As the data set is quite small, this is not surprising. The average activity based GROUC is quite high, about 4 percentage points above CPI, while GROUC on structural costs are somewhat lower, about 1–2 percentage points above CPI. As there is one GROUC estimate for structural costs and one GROUC estimate for activity based costs, it is not straight forward to compare the results to previous results. Kjærnsbæk, Vamraak and Bruun (2005) found an total GROUC of about 3 per cent, while Johansen and Berg-Knutsen (2006) found an total GROUC on 2,4 per cent. This is between the average GROUC on structural costs and activity based costs, indicating that the results are quite similar. As the method and data used by Kjærnsbæk, Vamraak and Bruun (2005) and the data and method used in this report is similar, this is not unexpected.

One of the major weaknesses with using the calculated activity weights is that the weights are only based on one year. This means that the results could be quite different if weights from another year are used. In Section 6.3.2, this problem is circumvented by estimating the weights.

6.3.2 Results based on estimated activity weights

The alternative to using calculated activity weights, is to estimate (6.9) using the maximum likelihood method.²² As there are an infinite number of solutions to the minimization problem, the weight of fighter aircraft is forced to 1.²³ The results from the regression are reported in Table 6.4 (entire sample) and Table 6.5 (subsample).

The coefficients on activity can be viewed as contribution to aggregate activity relative to the contribution from fighter aircraft, since the coefficient on fighter aircraft is set to one. As the coefficients can be rescaled, only the relative size of the coefficients matter. In contrast to our expectations, some of the activity weights turn out to be less than zero. This implies that increasing activity for these systems reduces costs. One explanation could be that periods with low activity are due to extensive maintenance, hence activity can be negatively related to costs. Another explanation could be that the activity measures are correlated, which indeed turn out to be the case (see Table B.1). The cause of the correlation could be budget changes (positive correlation) and/or

²²We used (6.9) in log form in our estimation.

²³ From (6.9), if $v_i = \gamma h_i$, where $\gamma \neq 0$, then $r \frac{\sum v_i v_i a_{t,i}}{\sum v_i v_i a_{t-1,i}} = r \frac{\sum v_i \gamma h_i a_{t,i}}{\sum v_i \gamma h_i a_{t-1,i}} = r \frac{\sum v_i h_i a_{t,i}}{\sum v_i h_i a_{t-1,i}}$, meaning that there exists an infinite number of possible solutions, and that the weights can be rescaled without affecting the result.

	Estimate	Std. Error	z value	Pr(z)
GROUC	0.042	0.018	2.326	0.020
EW plane	3.413	5.364	0.636	0.525
Frigate	0.252	0.501	0.503	0.615
Helicopter	0.636	1.479	0.430	0.667
Days of exercise	0.007	0.062	0.111	0.911
Coast guard	0.798	1.059	0.753	0.451
MPA	3.952	4.856	0.814	0.416
Logistics vessel	1.383	1.415	0.977	0.328
MCM	0.616	0.613	1.006	0.314
FAC	0.034	0.200	0.170	0.865
Transport aircraft	-2.049	1.774	-1.155	0.248
Submarine	-0.797	1.113	-0.716	0.474

Log-likelihood: -57.5285

AIC: -31.5285

Table 6.4 Estimates of **GROUC** based on estimated activity and estimated activity weights for each weapon system. Entire sample.

	Estimate	Std. Error	z value	Pr(z)
GROUC	0.064	0.022	2.912	0.004
EW plane	-3.019	3.066	-0.985	0.325
Frigate	0.486	0.504	0.963	0.335
Helicopter	0.343	0.921	0.372	0.710
Days of exercise	-0.022	0.031	-0.694	0.487
Coast guard	-0.471	0.550	-0.856	0.392
MPA	3.180	2.966	1.072	0.284
Logistics vessel	0.508	0.597	0.850	0.395
MCM	-0.414	0.546	-0.757	0.449
FAC	0.208	0.146	1.431	0.152
Transport aircraft	-0.180	0.773	-0.233	0.816
Submarine	0.745	0.790	0.943	0.346

Log-likelihood: -48.229

AIC: -22.229

Table 6.5 Estimates of **GROUC** based on estimated activity and estimated activity weights for each weapon system. Subsample.

changed prioritization between weapon systems (negative correlation).

One approach to reduce the correlation problem is to remove some of the covariates. In this report, covariates are removed using the best subset approach.²⁴ Models using all possible combinations of the covariates are estimated and compared using AIC. In total 8 191 different models were estimated and compared. The selected model is reported in Table 6.6 (entire sample) and Table 6.7 (subsample).

	Estimate	Std. Error	z value	Pr(z)
GROUC	0.059	0.015	3.976	0.000
MPA	5.966	3.175	1.879	0.060
Logistics vessel	0.838	0.398	2.104	0.035
Log-likelihood: -50.29928				
AIC: -42.29928				

Table 6.6 Model selected using AIC. Entire sample.

	Estimate	Std. Error	z value	Pr(z)
GROUC	0.055	0.018	3.062	0.002
Frigate	0.830	0.686	1.211	0.226
MPA	6.980	6.040	1.156	0.248
Logistics vessel	1.456	0.976	1.491	0.136
Log-likelihood: -43.33836				
AIC: -33.33836				

Table 6.7 Model selected using AIC. Subsample.

Although there are a lot fewer parameters in Table 6.6 and Table 6.7, the **GROUC** estimate remains significantly positive. This model includes frigate and logistics vessel activity from the Navy and MPA and fighter aircraft activity from the Air Force. The activity measures for the Army are omitted. This could be due to Army activity being less quantifiable than activity in the other branches, and hence correlating less with costs.

Since the maximum likelihood method relies on an initial guess, the models have been tested for sensitivity of that initial guess. In particular to ensure the restricted coefficient, here the coefficient on fighter aircraft activity, does not affect the result. We have also tested for autocorrelation in the residuals, which does not turn out to be an issue. Figure 6.4 (entire sample) and Figure 6.5 (subsample) illustrates the various activity measures.

Table 6.8 (entire sample) and Table 6.9 (subsample) compares the calculated weights from Section 6.3.1 and the estimated weights of this section. Although the activity weights are quite different, the aggregated activity levels are quite similar. *Calculated* is aggregated activity using the calculated weights, while *estimated* and *subset* is the aggregated activity using maximum likelihood estimation of the full dataset and the best subset of data respectively All series are scaled such that aggregate activity is equal to 1 in 2002. The most visible difference is the difference in the years after 2005 due to **FAC** activity being weighed less when estimated than when calculated.

The **GROUC** rate on activity-based costs in the different approaches varies from about 4 to

²⁴For an explanation of best subset and Akaike information criterion (AIC), see for example Hastie, Tibshirani and Friedman (2009).

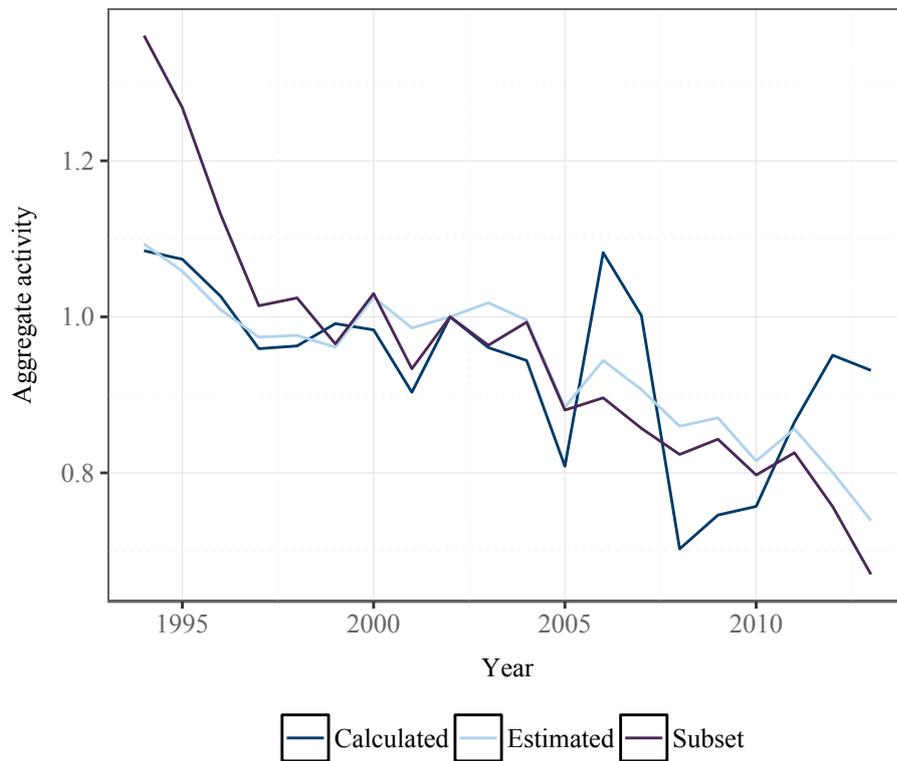


Figure 6.4 Aggregate activity using three different aggregation results. Entire sample.

	Calculated	Estimated	Subset
EW plane	5.324	3.414	
Frigate	1.131	0.252	
Helicopter	0.537	0.637	
Days of exercise	0.166	0.007	
Fighter aircraft	1.000	1.000	1.000
Coast guard	1.689	0.798	
MPA	5.351	3.953	5.966
Logistics vessel	0.225	1.383	0.838
MCM	0.186	0.617	
FAC	2.195	0.034	
Transport aircraft	3.366	-2.049	
Submarine	0.112	-0.796	

Table 6.8 Estimated and calculated weights. Rescaled such that fighter aircraft equals 1. Entire sample.

6 per cent. This is high compared to the most recent estimates at FFI, but similar, although not directly comparable, to the estimates found by Kjærnsbæk, Vamraak and Bruun (2005).

Although results that are similar to the ones we find exist, we suspect that we overestimate GROUC on activity-based costs. In other words, we expect GROUC to be somewhat lower than six per cent. This overestimation is likely to occur because of imperfect separation of activity-based

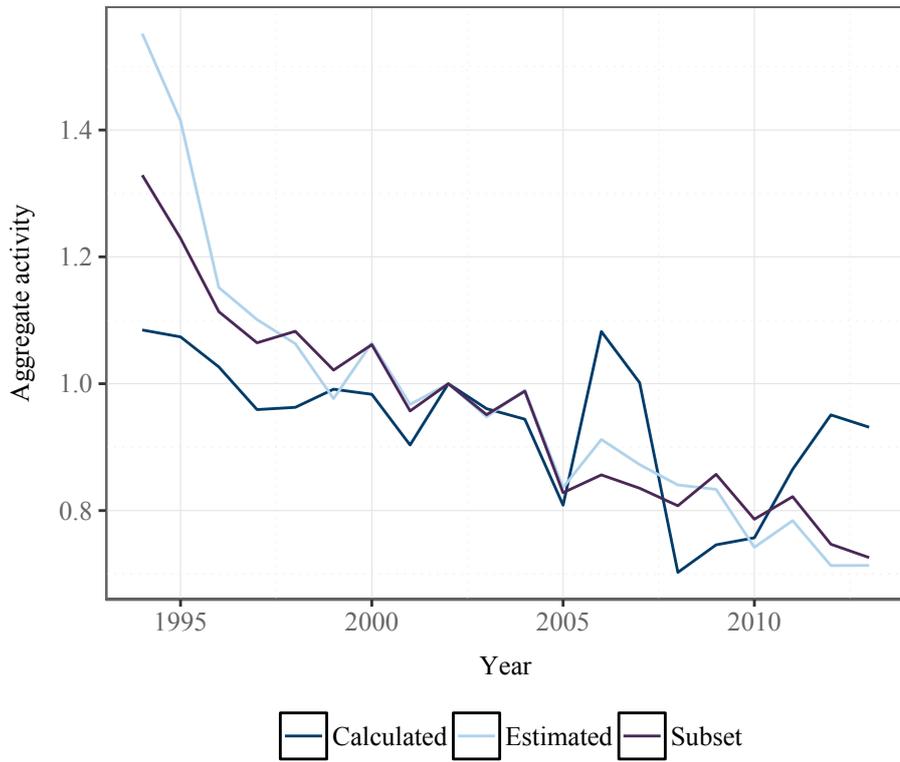


Figure 6.5 Aggregate activity using three different aggregation results. Subsample.

	Calculated	Estimated	Subset
EW plane	5.324	-3.019	
Frigate	1.131	0.486	0.830
Helicopter	0.537	0.344	
Days of exercise	0.166	-0.022	
Fighter aircraft	1.000	1.000	1.000
Coast guard	1.689	-0.471	
MPA	5.351	3.184	6.980
Logistics vessel	0.225	0.509	1.456
MCM	0.186	-0.414	
FAC	2.195	0.209	
Transport aircraft	3.366	-0.180	
Submarine	0.112	0.744	

Table 6.9 Estimated and calculated weights. Rescaled such that fighter aircraft equals 1. Subsample.

costs and structural costs. As the increase in costs is amplified by the decline in activity, the consequence of including some costs that are weakly dependent (or independent) of activity in the activity-based costs is that costs seem to increase more than they actually do. In particular maintenance costs could, at least partially, be argued to be weakly dependent on activity (see Section 4.5). In the similar case, where we include activity-based costs in the structural costs, we would underestimate GROUC on structural costs. A further discussion and formal explanation of

this subject can be found in Appendix A.

In the subsample, substitution between goods and services and personnel might lead to further bias in our estimates. If the Armed Forces substitute from personnel to goods and services, cost related to goods and services will grow faster than what is explained solely by **GROUC**, since the reduction in personnel costs is omitted from the dataset. This will lead to further overestimation of **GROUC**. Whether this is the case is however unclear. The number of personnel has been reduced, in particular in the period 2000 to 2005 (Johnson, Hove and Lillekvelland 2017), but it is unclear if some of these reductions are related to increase in consumption of goods and services.

More data, including lags to account for delays between activity changes and cost changes would have been useful for a more precise analysis. Separating activity-based on generations of a weapon system, rather than just weapon systems, could further improve precision. Unfortunately, the current amount and quality of data available does not allow for such analyses.

6.3.3 **GROUC in the Norwegian Armed Forces**

As different parts of the organization have different shares of activity-based costs, there should also be a difference in expected **GROUC**. Parts of the organization with high share of activity-based costs are expected to have higher total **GROUC** than parts of the organization with less activity-based costs. On the next two pages, Figure 6.6 (entire sample) and Figure 6.8 (subsample) shows the share of activity-based costs for each of the branches in the Norwegian Armed Forces (excluding the investment organization). The costs in **FLO** have been distributed among the other branches based on the amount of services received by each branch. As expected, the branches, the Coast Guard, and international operations rank quite high, while staffs, and administrative tasks rank quite low.

The consequence of **GROUC** not only depends on the share of activity-based costs, but also on the size of the branch. The consequence of a high **GROUC** is small if the initial monetary size is small, while the consequence of even a small **GROUC** rate on a large monetary size might be huge. For example, an annual **GROUC** rate of one per cent results in a 22 per cent increase in costs over 20 years.

Figure 6.7 (entire sample) and Figure 6.9 (subsample) shows the size and estimated **GROUC** of each branch in the Norwegian Armed Forces. The further up and to the right a branch is, the greater the consequence of **GROUC**. The curved lines show combinations of expenses and **GROUC** that in total produce the same cost increase. The three on the top of the list are the branches, the Air Force, the Navy and the Army. A bit further down we find the strategic headquarters, search and rescue, and the Coast Guard. The Coast Guard has the highest **GROUC** rate, but the size of expenses in the Coast Guard is too low for the **GROUC** from the Coast Guard to make a significant impact.

6.4 **Summary of the empirical analysis**

In this chapter the **GROUC** rate has been estimated using two different approaches. **GROUC** on structural costs are estimated to be close to non-existent, while **GROUC** on activity based costs vary from about four per cent to about six per cent, depending on estimation strategy. The difference between **GROUC** on structural costs and activity based costs is not surprising, since the costs related to activity often are associated with more advanced systems than the costs unrelated to activity. This in turn implies that different parts of the Norwegian Armed Forces face different **GROUC** rates.

For all our results there is some uncertainty about the precision of the estimates. This is probably due to the data quality and the limited number of observations. In addition to the uncertain

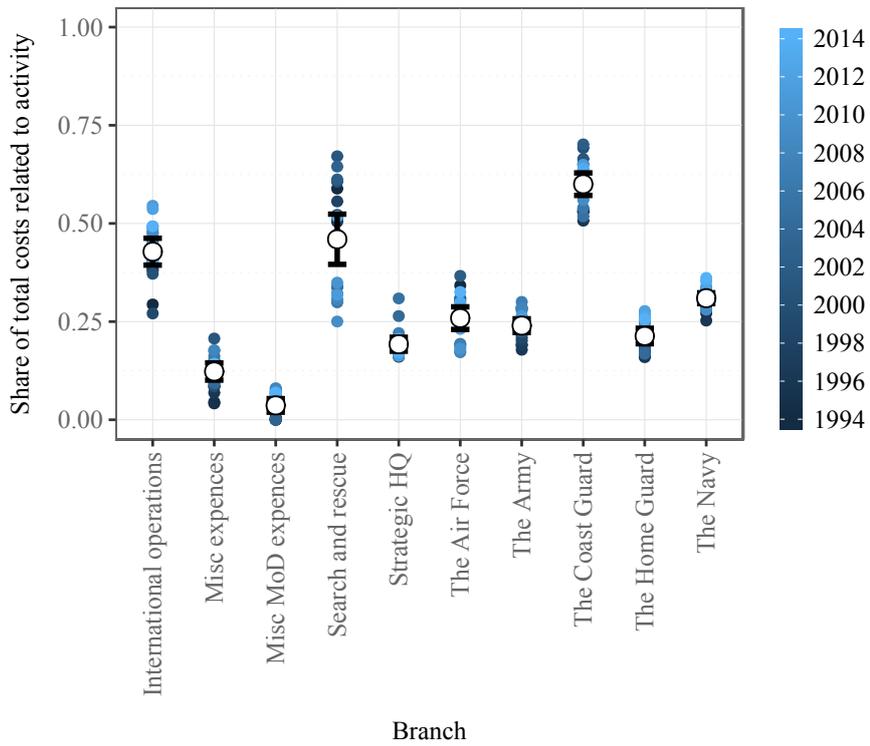


Figure 6.6 The figure shows activity shares in each branch with mean and 95 % confidence interval of mean. Entire sample.

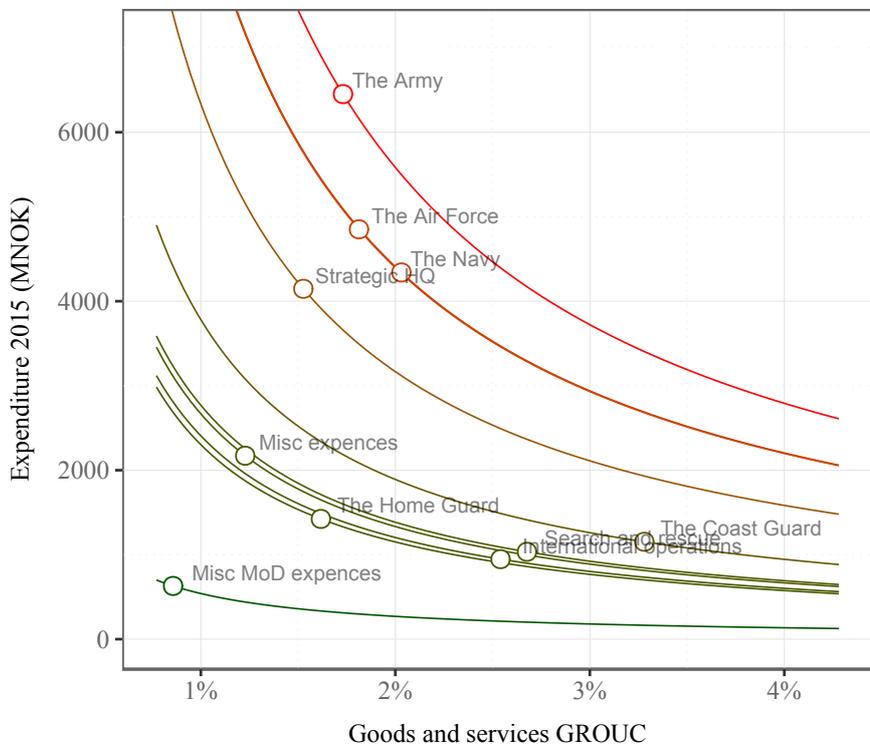


Figure 6.7 Impact from GROUC in each branch. Entire sample.

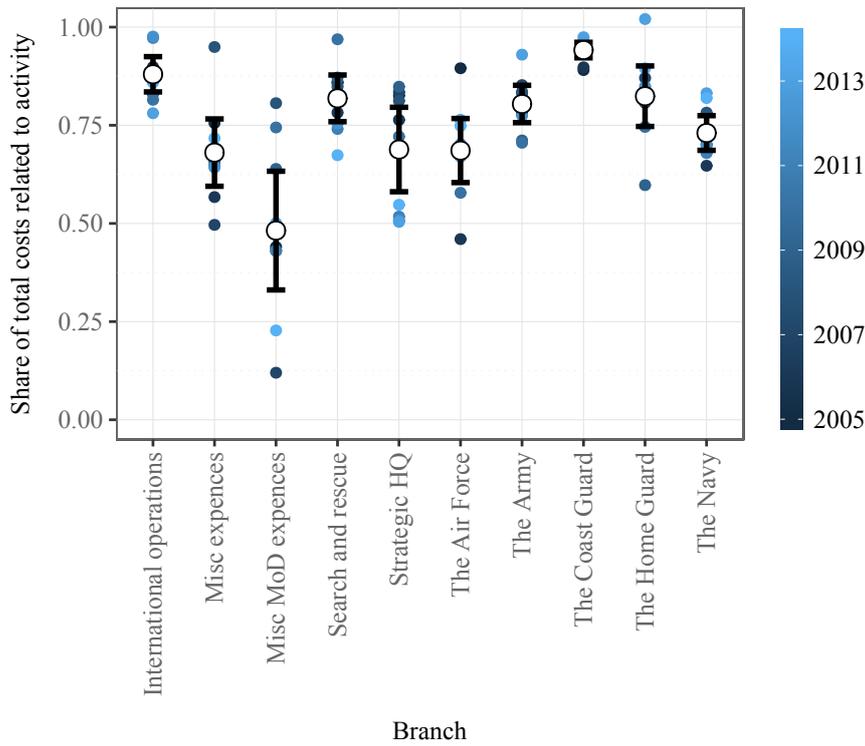


Figure 6.8 The figure shows activity shares in each branch with mean and 95 % confidence interval of mean. Subsample.

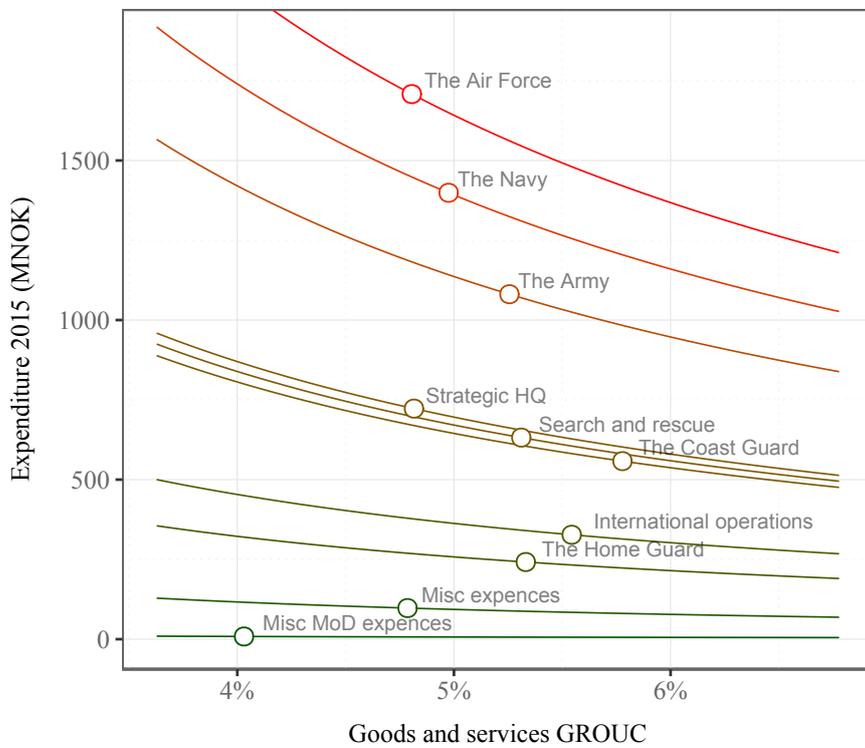


Figure 6.9 Impact from GROUC in each branch. Subsample.

estimates, we suspect that the GROUC rates we find might be higher than the true rates, because we cannot estimate productivity increases. This makes it difficult to conclude with one single GROUC estimate. Further, our estimation assumes a common GROUC rate for all weapon systems, which most likely is not the case. Even if our estimates have some uncertainty and weaknesses, we consider them to be useful. Historically, we can conclude that the costs of operating the materiel of the Norwegian Armed Forces have grown considerably.

It should be noted that the GROUC rates found in this report only provide a historic picture. Whether the GROUC rates can be expected to be the same for the future years depends on multiple factors.

7 Summary of results, implications and future work

7.1 Summary

In this report, we have explained the concept of growth in real output unit costs (**GROUC**) as being the part of defence output operating cost growth that exceeds nationwide unit cost growth. Similar terms are growth in real input unit costs (**GRIUC**), growth in nominal output unit costs (**GNOUC**) and growth in nominal input unit costs (**GNIUC**). We have shown how it can be useful to distinguish between intra- and intergenerational operating cost growth, and between input and output measures. We have illustrated how the input factor mix, productivity, age, the level of technology, the number of units, markets, history and politics can influence the rate of operating cost growth.

Various Norwegian and international studies have estimated operating cost growth, using a variety of methods. In this report, we have attempted to measure **GROUC** of goods and services as an output based measure, using activity levels as the output measure. We used flight hours for the Air Force, sailing days for the Coast Guard and the Navy and the number of exercise days for the Army as measures of the activity levels. Activity levels were then aggregated using cost weights. We then separated Norwegian defence account data from 1994 until 2013 into activity based and structural costs. Activity based costs show an upwards trend, whereas structural costs remain relatively constant. As activity falls, this exacerbates **GROUC**. We estimate a **GROUC** of structural costs of about one to two percent and an output **GROUC** of activity based costs of four to six per cent. Because of an imperfect separation between activity based and structural costs and the fact that we cannot capture productivity growth, we suspect an overestimation of the activity based **GROUC**. However, the estimated **GROUC** is so large we do not doubt that it is positive.

7.2 Implications for long term defence planning

If operating cost growth is higher than defence budget growth, this obviously poses a significant challenge for long term defence planning. The results of this study underline the importance of considering operating cost growth in long term defence planning. After 20 years, an annual operating cost growth rate of three per cent will result in an 80 per cent cost increase. If operating cost growth is not properly accounted for, we will plan for a structure which is larger than we are able to fund. The result will be larger and more painful cuts at a later date. There are, in general, three ways of domestically dealing with operating cost growth:

- Budgetary increases, so that activity and force effect can be maintained.
- Productivity gains, so that activity can be reduced while maintaining force effect.
- A reduction in force effect.

Attempting to postpone intergenerational cost increases by increasing the average age of weapon systems or reducing the number of units can be tempting, but can still fuel operating cost growth through other channels.

7.3 Countering operating cost growth

Detailing measures of how to counter operating cost growth has not been a major part of this report. Therefore, we just outline a couple of possible measures to counter operating cost growth:

- A continuous emphasis on costs. Are the most expensive capabilities really needed? How can

the cooperation between industry and the Armed Forces be organized to optimize incentives? How can the Armed Forces be structured to improve incentives to reduce operating cost growth?

- Restructuring the Armed Forces. If projected costs of current and future capabilities rise beyond projected budgets, the current organization must be revised. This can be solved for example through international cooperation or a shift in emphasis of certain defence objectives.
- Increased use of international standards and international cooperation. An emphasis of fewer standards would help reduce costs. For example, costs would be lower if five countries buy the same helicopter, than if five countries buy the same helicopter, but with five separate modifications. Since all specifications of all countries cannot be included, countries would have to give up some of their requirements. This would reduce the benefit of the helicopter for each country. The question is if the reduced benefit is outweighed by the reduced cost.
- A stronger link between investment cost and operating costs. If the link between (and the responsibility for the financing of) investment costs and operating costs is made clearer, incentives to procure gold plated investments would fall.
- There is a choice between investing in few, but technologically advanced units, and many, less technologically advanced units of a weapon system. Sometimes, many, less technologically advanced units could perhaps be more cost effective than few, but technologically advanced units.

7.4 Future work

GROUC is a complicated phenomenon with a wide range of challenging issues for future studies to address. We identify four future types of work:

- Measure, and compare, input and output operating cost growth.
- Conduct more detailed studies of the causes of operating cost growth. In this report, we present a very aggregate analysis. We cannot quantify which of the factors from Chapter 4 have the strongest influence on operating cost growth. Smaller, case based, studies can shed further light on this issue. Such studies can also result in operating cost growth factors for individual weapon systems, for use in long term planning.
- Improve branch analysis. It is not currently possible to conduct analyses for separate branches. Data for the last part of the period can be used, but early data cannot. Thus, in a few years time, we encourage a revisit of our data for extended analyses.
- Develop output indicators for use in national accounts. Currently, national accounts are based on the input-output method, where input equals output. Adjusting for quality could prove a step forward in the quality of national accounts.

Abbreviations

AIC	Akaike information criterion
APUC	Average procurement unit cost
BEA	Bureau of Economic Analysis
C4ISR	Command, control, communications, computers, intelligence, surveillance and reconnaissance
CPI	Consumer price index
DAP	Defense Acquisition Portal
DAU	Defense Acquisition University
EW	Electronic warfare
FA	Facilities
FAC	Fast attack craft
FAC	Flyaway cost
FFI	Norwegian Defence Research Establishment
FH	Flight hour
FLO	Norwegian Defence Logistics Organization
FY	Fiscal year
GDP	Gross domestic product
GROUC	Growth in real output unit costs
GRIUC	Growth in real input unit costs
GNOUC	Growth in nominal output unit costs
GNIUC	Growth in nominal input unit costs
Green Book	National Defense Budget Estimates
ICE	Investment cost escalation
Intra OCG–M–M	Intragenerational OCG–M–M
Inter OCG–M–M	Intergenerational OCG–M–M
Intra ICE	Intragenerational ICE
Inter ICE	Intergenerational ICE
LCC	Life cycle cost
M	Goods and services
MCM	Mine countermeasure
MILCON	Military construction
MMA	Multimission maritime aircraft
MoD	Ministry of Defence

NEC	Network enabled capability
NOK	Norwegian Kroner
OCG	Operating cost growth
OCG-M	Operating cost growth – Goods and services
OCG-M-M	Operating cost growth – Goods and services – exclusive of FA
OCG-M-B&P	Operating cost growth – Goods and services – FA
OCG-P	Operating cost growth – Personnel
OCG-P-W	Operating cost growth – Personnel – Wages
OCG-P-G&S	Operating cost growth – Personnel driven goods and services
O&M	Operation and maintenance
ONS	Office for National Statistics
OSD	Office of the Secretary of Defense
O&S	Operation and support
P	Personnel
P-G&S	Personnel driven goods and services
PAUC	Program acquisition unit cost
POGO	Project On Government Oversight
R&D	Research and development
RDT&E	Research, development, test and evaluation
RPIX	Retail price index excluding mortgages
SLEP	Service life extension programme
SSB	Statistics Norway
URF	Unit recurring flyaway
UK	United Kingdom
US	United States
USAF	United States Air Force
USD	United States dollars
W	Wages

Bibliography

- Anagboso, Mavis and Alison Spence (2008). *Scoping Paper on Possible Improvements to Measurement of Defence in the UK National Accounts*. Newport: Office for National Statistics. URL: <http://www.statistics.gov.uk/cci/article.%20asp?id=2070>.
- Anagboso, Mavis and Alison Spence (2009). 'Measuring defence'. In: *Economic and Labour Market Review* 3.1, pp. 44–52. ISSN: 1751-8326. DOI: 10.1057/elmr.2009.8. URL: <http://www.palgrave-journals.com/elmr/journal/v3/n1/abs/elmr20098a.html> (visited on 19/12/2015).
- Arena, Mark V., Irv Blickstein, Obaid Younossi and Clifford A. Grammich (2006). *Why Has the Cost of Navy Ships Risen? A Macroscopic Examination of the Trends in US Naval Ship costs over the Past Several Decades*. Monograph 484. Santa Monica, CA: Rand Corporation. URL: <http://www.rand.org/pubs/monographs/MG484.html> (visited on 29/08/2014).
- Arena, Mark V., Obaid Younossi, Kevin Brancato, Irv Blickstein and Clifford A. Grammich (2008). *Why Has the Cost of Fixed-Wing Aircraft Risen? A Macroscopic Examination of the Trends in US Military Aircraft Costs over the Past Several Decades*. Monograph 696. Santa Monica, CA: Rand Corporation. URL: <http://www.rand.org/pubs/monographs/MG696.html> (visited on 29/08/2014).
- Baumol, William J. (2012). *The cost disease: Why computers get cheaper and health care doesn't*. New Haven: Yale university press.
- Baumol, William J. and William G. Bowen (1966). *Performing Arts. The Economic Dilemma: A Study of Problems Common to Theatre, Opera, Music and Dance*. New York: The Twentieth Century Fund.
- BEA (2014). *Concepts and Methods of the U.S. National Income and Product Accounts*. URL: <https://www.bea.gov/national/pdf/NIPAChapters1-9.pdf>.
- BEA (2015). *Section 3 – Government Current Receipts and Expenditures*. URL: http://www.bea.gov/National/nipaweb/SS_Data/Section3All_xls.xls (visited on 06/01/2016).
- Bolten, Joseph George, Leonard Leonard Robert S., Mark V. Arena, Obaid Younossi and Jerry M. Sollinger (2008). *Sources of Weapon System Cost Growth: Analysis of 35 Major Defense Acquisition Programs*. Monograph 670. Rand Corporation. URL: <http://www.rand.org/pubs/monographs/MG670.html> (visited on 29/08/2014).
- Borge, Lars-Erik, Kjetil Hove, Tobias Lillekvelland and Per Tovmo (2017). *The Baumol Effect in Defence and Public Administration*. NTNU Working Paper. NTNU/FFI.
- Chalmers, Malcolm (2009). 'The Myth of Defence Inflation'. In: *RUSI Defence Systems* 12.1 (June), pp. 12–22.
- Congressional Budget Office (2001). *The Effects of Aging on the Costs of Operating and Maintaining Military Equipment*. Congress of the United States.
- Connor, Kathryn and James Dryden (2013). *New Approaches to Defense Inflation and Discounting*. RR237. RAND Corporation. URL: http://www.rand.org/pubs/research_reports/RR237.html (visited on 30/05/2015).

-
-
- Deo, Ravi B., James H. Starnes Jr. and Richard C. Holzwart (2001). *Low-Cost Composite Materials and Structures for Aircraft Applications*. Paper presented at the RTO AVT Specialists' Meeting on "Low Cost Composite Structures", held in Loen, Norway, 7-11 May 2001, and published in RTO-MP-069(II).
- Diewert, W. Erwin (2012). 'The Measurement of Productivity in the Nonmarket Sector'. In: *Journal of Productivity Analysis* 37.3, pp. 217–229. ISSN: 0895-562X. JSTOR: 43549888.
- Dixon, Matthew C. (2006). *The Maintenance Costs of Aging Aircraft*. Monograph. Santa Monica, CA: RAND Corporation. URL: <http://www.rand.org/pubs/monographs/MG486.html> (visited on 15/11/2015).
- Droff, Josselin (2013). 'Technological change and disruptive trends in the support of defense systems in France'. In: *Journal of Innovation Economics & Management* 12.2, pp. 79–102. URL: http://www.cairn.info/resume.php?ID_ARTICLE=JIE_012_0079.
- Eide, Espen Barth (2012). 'Forsvarsomstilling med svært gode resultater [Defence restructuring with very good results]'. In: *Norsk Militært tidsskrift* 2012.3.
- Fløttum, Erling Joar, Tore Halvorsen, Liv Hobbestad Simpson and Tor Skoglund (2012). *History of National Accounts in Norway*. Social and Economic Studies 113. Oslo: Statistics Norway.
- Francis, Peter J. and Geoffrey B. Shaw (2000). *Effect of Aircraft Age on Maintenance Costs*. CAB D0000289.A2. Alexandria, Va: Center for Naval Analyses.
- Gulichsen, Steinar (2003). *Driftskostnadsvekst i Forsvaret [Operating Cost Escalation in the Norwegian Armed Forces]*. FFI-rapport 2002/02999. Kjeller: Norwegian Defence Research Establishment (FFI).
- Gulichsen, Steinar, Per Kristian Johansen and Karl Rolf Pedersen (2011). *Realkostnadsvekst i offentlig sektor – teoretisk fundament og konsekvenser for Forsvarets langtidsplanlegging [Real cost increases in the public sector – theoretical foundation and consequences for Norwegian Armed Forces long term planning]*. FFI-rapport 2010/01630. Kjeller: Norwegian Defence Research Establishment (FFI).
- Gulichsen, Steinar and Karl Rolf Pedersen (2012). *Forsvarets langsiktige realkostnadsvekst – betydningen av mulighet til substitusjon [Long term real cost growth in the Norwegian Armed Forces – the significance of substitution]*. FFI-rapport 2011/02404. Kjeller: Norwegian Defence Research Establishment (FFI).
- Hartley, Keith (2010). 'The Case for Defence'. In: *Defence and Peace Economics* 21.5, pp. 409–426. ISSN: 1024-2694. DOI: [10.1080/10242694.2010.511024](https://doi.org/10.1080/10242694.2010.511024). (Visited on 16/12/2015).
- Hartley, Keith (2011). *Defence Output Measures. An Economics perspective*. DRDC CORA CR 2011-178. Defence R&D Canada – Centre for Operational Research and Analysis.
- Hartley, Keith (2012). *White Elephants. The Political Economy of Multi-National Defence Projects*. ISBN: 978-2-87555-010-1. New Direction – The Foundation for European Reform. URL: <http://newdirectionfoundation.org/elephants.pdf>.
- Hartley, Keith (2016a). 'UK Defence Inflation and Cost Escalation'. In: *Defence and Peace Economics* 27.2. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1093757](https://doi.org/10.1080/10242694.2015.1093757). (Visited on 16/12/2015).

-
- Hartley, Keith (2016b). 'UK defence inflation and cost escalation'. In: *Defence and Peace Economics* 2 (27). ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1093757](https://doi.org/10.1080/10242694.2015.1093757). (Visited on 16/12/2015).
- Hartley, Keith and Binyam Solomon (2015). 'Measuring Defense Output: An Economics Perspective'. In: *Military Cost-Benefit Analysis: Theory and Practice*. Ed. by Francois Melese, Anke Richter and Binyam Solomon. London: Routledge, pp. 36–73. ISBN: 978-1-138-85042-2.
- Hartley, Keith and Binyam Solomon (2016). 'Special issue: defence inflation'. In: *Defence and Peace Economics* 27.2. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1123464](https://doi.org/10.1080/10242694.2015.1123464). (Visited on 12/01/2016).
- Hastie, Trevor, Robert Tibshirani and J. H. Friedman (2009). *The elements of statistical learning: data mining, inference, and prediction*. 2nd ed. Springer series in statistics. New York, NY: Springer. 745 pp. ISBN: 978-0-387-84857-0.
- Hawkes, Eric M. and Edward D. White (2008). 'Empirical Evidence Relating Aircraft Age and Operating and Support Cost Growth'. In: *Journal of Cost Analysis and Parametrics* 1.2, pp. 31–43. URL: <http://www.tandfonline.com/doi/abs/10.1080/1941658X.2008.10462215>.
- Hicks, John R. (1940). 'The Valuation of the Social Income'. In: *Economica* 7.26, pp. 105–124. ISSN: 0013-0427. DOI: [10.2307/2548691](https://doi.org/10.2307/2548691). JSTOR: 2548691.
- Hildebrandt, Gregory G. and Man-bing Sze (1990). *An Estimation of USAF Aircraft Operating and Support Cost Relations*. N3062. RAND Corporation. URL: <http://www.rand.org/pubs/notes/N3062.html> (visited on 09/06/2015).
- HM Treasury (2016). *GDP deflators at market prices, and money GDP: March 2016*. URL: <https://www.gov.uk/government/statistics/gdp-deflators-at-market-prices-and-money-gdp-march-2016> (visited on 23/03/2016).
- Holcner, Vladan and Jiří Neubauer (2015). 'Modelling expected defense specific inflation'. In: *AIP Conference Proceedings*. Proceedings of the International Conference on Numerical Analysis and Applied Mathematics 2014 (ICNAAM-2014). Vol. 1648. AIP Publishing, pp. 720010–1–720010–4. DOI: [10.1063/1.4912947](https://doi.org/10.1063/1.4912947). URL: <http://scitation.aip.org/content/aip/proceeding/aipcp/10.1063/1.4912947> (visited on 07/01/2016).
- Horowitz, Stanley A., Alexander O. Gallo, Daniel B. Levine, Robert J. Shue and Robert W. Thomas (2012). *The Use of Inflation Indexes in the Department of Defense*. IDA Paper P-4707. Alexandria, VA: Institute for Defense Analyses (IDA).
- Horowitz, Stanley A., Bruce R. Harmon and Daniel B. Levine (2016). 'Inflation adjustments for defense acquisition'. In: *Defence and Peace Economics* 27.2, pp. 231–257. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1093758](https://doi.org/10.1080/10242694.2015.1093758).
- Hove, Kjetil (2015). *Forsvaret i nasjonalregnskapet – bruk av tall i analyser ved FFI [The Norwegian Armed Forces in Norwegian national accounts – use of numbers in Norwegian Defence Research Establishment analyses]*. FFI-notat 2015/00576. Kjeller: Norwegian Defence Research Establishment (FFI).
- Hove, Kjetil Hatlebakk (2017). *Effektforbedring materiell: Definisjoner og innretning Hva den nye avsetningen i forsvarsbudsjettet er ment å brukes til, og hvordan den kan innrettes i praksis*. FFI-rapport 17/00891. Kjeller: Forsvarets forskningsinstitutt.

-
-
- Hove, Kjetil Hatlebakk and Tobias Lillekvelland (2018). 'On Growing Operating Costs of the Armed Forces'. In: *Defence and Peace Economics* (forthcoming).
- Hove, Kjetil and Tobias Lillekvelland (2015). *Defence investment cost escalation – a refinement of concepts and revised estimates*. FFI-rapport 2014/02318. Kjeller: Norwegian Defence Research Establishment (FFI).
- Hove, Kjetil and Tobias Lillekvelland (2016). 'Investment cost escalation – an overview of the literature and revised estimates'. In: *Defence and Peace Economics* 27.2, pp. 208–230. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1093754](https://doi.org/10.1080/10242694.2015.1093754).
- Johansen, Per Kristian and Espen Berg-Knutsen (2006). *Enhetskostnadsvekst i Forsvaret [Cost escalation in the Norwegian Armed Forces]*. FFI-rapport 2006/00900. Kjeller: Norwegian Defence Research Establishment (FFI).
- Johnson, Alexander Urnes, Kjetil Hove and Tobias Lillekvelland (2017). 'Country Survey: Military Expenditure and Defence Policy in Norway 1970–2013'. In: *Defence and Peace Economics* 28.6, pp. 669–685. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1101896](https://doi.org/10.1080/10242694.2015.1101896).
- Johnson, John A. (1993). *Age Impacts on Operating and Support Costs: Navy Aircraft Age Analysis Methodology*. Pautuxent River, Md: Naval Aviation and Maintenance Office (NAMO).
- Jones, D. L. and D. L. Woodhill (2010). *Estimating Defence Inflation*. Defence Statistics Bulletin 10. Defence Analytical Services and Advice. URL: <http://webarchive.nationalarchives.gov.uk/20140116142443/http://www.dasa.mod.uk/publications/finance-and-economics/archive/defence-statistics-bulletins/defence-statistics-bulletin-number-10-estimating-defence-inflation-30-march-2010.pdf>.
- Keating, Edward G. and Mark V. Arena (2016). 'Defense inflation: what has happened, why has it happened, and what can be done about it?' In: *Defence and Peace Economics* 27.2, pp. 176–183. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1093760](https://doi.org/10.1080/10242694.2015.1093760).
- Keating, Edward G., Michael Boito and Dulani Woods (2015). *Estimating the Costs of Continued T-38C Training Aircraft Operation versus Replacement by a T-X Training Aircraft*. RR-710-AF. Santa Monica, CA: RAND Corporation.
- Kirkpatrick, David L. I. (1995). 'The rising unit cost of defence equipment – The reasons and the results'. In: *Defence and Peace Economics* 6.4, pp. 263–288. ISSN: 1024-2694.
- Kirkpatrick, David L. I. (1997). 'The affordability of defence equipment'. In: *The RUSI Journal* 142.3, pp. 58–80. ISSN: 0307-1847. DOI: [10.1080/03071849708446151](https://doi.org/10.1080/03071849708446151).
- Kirkpatrick, David L. I. (2004). 'Trends in the Costs of Weapon Systems and the Consequences'. In: *Defence and Peace Economics* 15.3, pp. 259–273. ISSN: 1024-2694.
- Kirkpatrick, David L. I. and Philip G. Pugh (1983). 'Towards the Starship Enterprise – are the current trends in defence unit costs inexorable?' In: *The Journal of Cost Analysis* 2.1, pp. 59–80. ISSN: 0882-3871.
- Kjernsbæk, Hans Martin, Tore Vamraak and Tor Erling Bruun (2005). *Materiellrelatert driftskostnadsvekst i Forsvaret [Increased operating costs of goods and services of the Norwegian Armed Forces]*. FFI-rapport 2005/00358. Kjeller: Norwegian Defence Research Establishment (FFI).

-
-
- Krey, Solveig Marie and Ane Ofstad Presterud (2012). *Fleksibiliteten i Forsvarets kostnadsstruktur – analyse basert på KOSTMOD [Cost flexibility in the Norwegian Armed Forces – an analysis based on KOSTMOD]*. FFI-rapport 2011/01541. Kjeller: Norwegian Defence Research Establishment (FFI).
- Kvalvik, Sverre Ruud and Per Kristian Johansen (2008). *Enhetskostnadsvekst på forsvarsinvesteringer (EKV-I) [Investment cost escalation (ICE)]*. FFI-rapport 2008/01129. Kjeller: Norwegian Defence Research Establishment (FFI).
- Kværner, Jens Sørli (2010). *Realkostnadsvekst i offentlig sektor – casestudie av helsesektoren [Real cost growth in the public sector – a case study of the health sector]*. FFI-notat 2010/02403. Kjeller: Norwegian Defence Research Establishment (FFI).
- Leibenstein, H. (1950). 'Bandwagon, Snob, and Veblen Effects in the Theory of Consumers' Demand'. In: *The Quarterly Journal of Economics* 64.2, pp. 183–207. ISSN: 0033-5533, 1531-4650. DOI: [10.2307/1882692](https://doi.org/10.2307/1882692). URL: <http://qje.oxfordjournals.org/content/64/2/183> (visited on 22/10/2014).
- Levy, Robert (1991). 'ASPA and the Effect of Deferred Depot Maintenance on Airframe Rework Cost'. In: *Center for Naval Analyses Report*.
- McConnell, Steve (1996). *Rapid Development: Taming Wild Software Schedules*. 1st ed. Redmond, Wash: Microsoft Press. 680 pp. ISBN: 978-1-55615-900-8.
- Ministry of Defence (2016). *Prop. 151 S (2015–2016). Kampkraft og bærekraft. Langtidsplan for forsvarssektoren [Capable and sustainable. Long term plan for the Armed Forces]*. shorthand: Prop. 151 S (2015–2016). Oslo: Forsvarsdepartementet. URL: <https://www.regjeringen.no/contentassets/a712fb233b2542af8df07e2628b3386d/no/pdfs/prp201520160151000dddpdfs.pdf> (visited on 15/03/2017).
- MoD (2014). *Defence Inflation Estimates 2012/13*. London: Ministry of Defence.
- MoD (2015). *Defence Inflation Estimates 2013/14*. London: Ministry of Defence.
- Murray, Richard (1992). 'Measuring public-sector output: The Swedish report'. In: *Output Measurement in the Service Sectors*. Ed. by Zvi Griliches. University of Chicago Press, pp. 517–542. URL: <http://www.nber.org/chapters/c7244.pdf> (visited on 19/12/2015).
- Murray, Richard, Anders Holmberg, Krister L:son Lagersvärd and Bernt Öström (1995). *Försvarets kostnader och produktivitet [Costs and productivity in the Swedish Armed Forces]*. Rapport till Expertgruppen för studier i offentlig ekonomi [Report to the expert group of studies in public economics]. Stockholm: Finansdepartementet.
- Neset, Arne and Erling Gunnar Wessel (1995). *Teknologisk fordyrelse og driftskostnadsvekst – Konsekvenser for Forsvarsanalysen 1996 [Technology based cost escalation and increased operating costs – Consequences for the Norwegian Defence Analysis 1996]*. FFI-rapport 1995/02878. Kjeller: Norwegian Defence Research Establishment (FFI).
- Nordlund, Peter (2016). 'Defence-specific inflation – the Swedish perspective'. In: *Defence and Peace Economics* 27.2. ISSN: 1024-2694. DOI: [10.1080/10242694.2015.1096571](https://doi.org/10.1080/10242694.2015.1096571). (Visited on 05/01/2016).

-
- NOU 2013:13 (2013). *Lønnsdannelsen og utfordringer for norsk økonomi*. Oslo: Departementenes servicesenter. Informasjonsforvaltning.
- OECD (2001). *Measuring productivity. Measurement of aggregate and industry-level productivity growth*. Paris: OECD. URL: <https://www.oecd.org/std/productivity-stats/2352458.pdf>.
- Office for National Statistics (2016a). *CPI: Consumer Prices Index (% change)*. URL: <https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/d7g7> (visited on 26/01/2016).
- Office for National Statistics (2016b). *RPI All Items Excl Mortgage Interest (RPIX): Percentage change over 12 months*. URL: <https://www.ons.gov.uk/economy/inflationandpriceindices/timeseries/cdkq> (visited on 26/01/2016).
- Office of the Secretary of Defense (2017). *Inflation and Escalation Best Practices for Cost Analysis: Analysis Handbook*. Cost Assessment and Program Evaluation.
- Phillips, Maxie W. (1991). *Weapons Acquisition: Products And Their Problems*. Marine Corps University Command and Staff College. URL: <http://www.globalsecurity.org/military/library/report/1991/PMW.htm> (visited on 13/01/2016).
- Presterud, Ane Ofstad and Morten Øhrn (2015). *Effektive materiellanskaffelser i Forsvaret – en studie av incentiver i investeringsprosessen [Efficient acquisition processes in the Norwegian Armed Forces – a study of incentives in the acquisition process]*. FFI-rapport 2015/00555. Kjeller: Norwegian Defence Research Establishment (FFI). URL: <http://rapporter.ffi.no/rapporter/2015/00555.pdf>.
- Pugh, Philip G. (1986). *The Cost of Seapower: The Influence of Money on Naval Affairs from 1815 to the Present Day*. London: Conway Maritime Press.
- Pugh, Philip G. (1993). 'The Procurement Nexus'. In: *Defence and Peace Economics* 4.2, pp. 179–194. URL: <http://www.tandfonline.com/doi/abs/10.1080/10430719308404758> (visited on 30/08/2014).
- Pyles, Raymond A. (2003). *Aging Aircraft: USAF Workload and Material Consumption Life Cycle Patterns*. Monograph MR1641. Santa Monica, CA: RAND Corporation. URL: http://www.rand.org/pubs/monograph_reports/MR1641.html (visited on 18/12/2015).
- Ruehrmund Jr., James C. and Christopher J. Bowie (2010). *Arsenal of Airpower: USAF Aircraft Inventory 1950–2009*. Arlington, VA: Mitchell Institute for Airpower Studies.
- Røgeberg, Lasse, Tor Skoglund and Steinar Todsén (2004). *Report on the Project Quality Adjusted Input Price Indices for Collective Services in the Norwegian National Accounts. Report from a Project Co-financed by Eurostat*. Documents 2004/9. Oslo: Statistics Norway.
- Simpson, Helen (2009). 'Productivity in Public Services'. In: *Journal of Economic Surveys* 23.2, pp. 250–276. ISSN: 1467-6419. URL: <http://onlinelibrary.wiley.com/doi/10.1111/j.1467-6419.2008.00562.x/abstract> (visited on 05/01/2016).
- Singh, Kulwant (1997). 'The Impact of Technological Complexity and Interfirm Cooperation on Business Survival'. In: *Academy of Management Journal* 40.2, pp. 339–367. ISSN: 00014273. DOI: [10.2307/256886](https://doi.org/10.2307/256886).

-
-
- Solomon, Binyam (2003). 'Defence specific inflation: A Canadian perspective'. In: *Defence and Peace Economics* 14.1, pp. 19–36.
- Spinney, Franklin C. (1980). *Defense Facts of Life*. ADA111544. Defense Technical Information Center.
- Spinney, Franklin C. (1998). 'Defense Death Spiral'. URL: <http://pogoarchives.org/labyrinth/01/05.pdf>.
- Statistics Norway (2014). *The Norwegian Armed Forces - StatRes*. URL: http://www.ssb.no/en/offentlig-sektor/statistikker/forsv_statres/aar/2014-07-01 (visited on 25/01/2016).
- Stoll, Laurence and Stan Davis (1993). *Aircraft Age Impact on Individual Operating and Support Cost Elements*. Pautuxent River, MD: Naval Aviation and Maintenance Office (NAMO).
- Verikios, George (1998). *Measuring Output of Government Administration, Defence and Property and Business Services: Some Estimates for Australia*. Centre of Policy Studies/IMPACT Centre Working Paper g-127. Victoria University, Centre of Policy Studies/IMPACT Centre. URL: <https://ideas.repec.org/p/cop/wpaper/g-127.html> (visited on 19/12/2015).
- Xie, Ming and Chin Diew Lai (1996). 'Reliability analysis using an additive Weibull model with bathtub-shaped failure rate function'. In: *Reliability Engineering & System Safety* 52.1, pp. 87–93.
- Åmot, Elisabeth Lindseth (2014). *Erfaringer fra interneffektiviseringen i Forsvaret 2009–2012 – En kvantitativ analyse [Experiences from the internal efficiency process in the Norwegian Armed Forces 2009–2012]*. FFI-rapport 2014/01087. Kjeller: Norwegian Defence Research Establishment (FFI). URL: <http://rapporter.ffi.no/rapporter/2014/01087.pdf>.
- Åmot, Elisabeth Lindseth (2015). "Tiltakene hadde kommet uansett" – erfaringer fra interneffektiviseringen 2009–2014 ["The measures would have been implemented anyway" – experiences from the Norwegian Armed Forces internal efficiency process 2009–2014]. FFI-rapport 2015/00765. Kjeller: Norwegian Defence Research Establishment (FFI). URL: <http://rapporter.ffi.no/rapporter/2015/00765.pdf>.

A Estimation bias

Assume that the separation of activity based costs are incomplete, i.e. not all the costs are dependent on activity. And that the true function (based on eq. (6.9)) takes the following form:

$$\frac{T_{t,a}}{T_{t-1,a}} = \tilde{r} \frac{\gamma \tilde{a}_t + (1 - \gamma)h}{\gamma \tilde{a}_{t-1} + (1 - \gamma)h} \quad (\text{A.1})$$

Where $\tilde{a}_t = \sum v_i a_{t,i}$, and γ is the share of the costs that is activity based, while $(1 - \gamma)$ is the share of the costs that are independent of activity. By setting eq. (A.1) equal to eq. (6.9) and solving for r/\tilde{r} we get:

$$\frac{r}{\tilde{r}} = \frac{\gamma \tilde{a}_t + (1 - \gamma)h}{\gamma \tilde{a}_{t-1} + (1 - \gamma)h} \frac{\tilde{a}_{t-1}}{\tilde{a}_t} \quad (\text{A.2})$$

When $r/\tilde{r} > 1$ we overestimate the cost escalation, since the estimated cost escalation, r , is greater than the true cost escalation, \tilde{r} . This proves to be the case when $a_{t-1} > a_t$, which is the case in most of the period we analyze (see fig. 6.3).²⁵ Further the share of costs that is misclassified increases, γ increases, the overestimation of the cost escalation increases. This can be shown by differentiating eq. (A.2) with respect to γ .

²⁵If changes in structural costs also are taken into account the argument becomes somewhat more complicated, but still applies.

B Activity

Figure B.1, B.2, B.3, and B.4 show the historic activity for each weapon system.

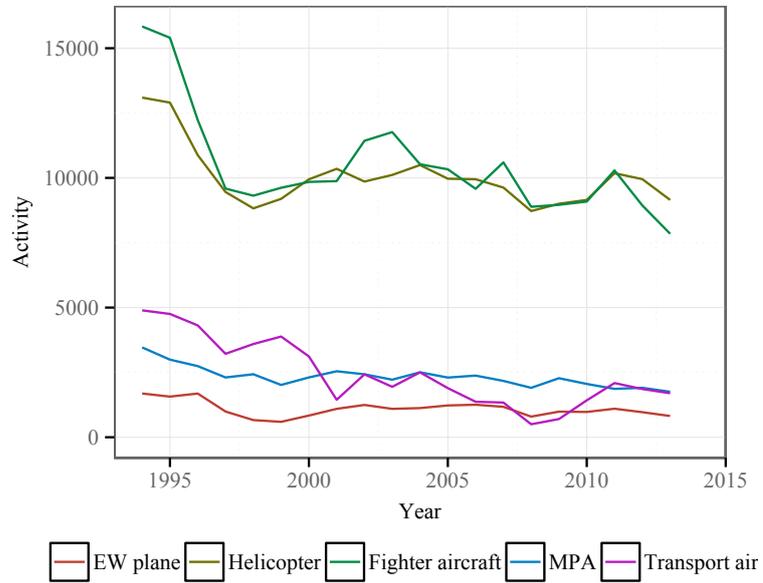


Figure B.1 Activity in the Air Force.

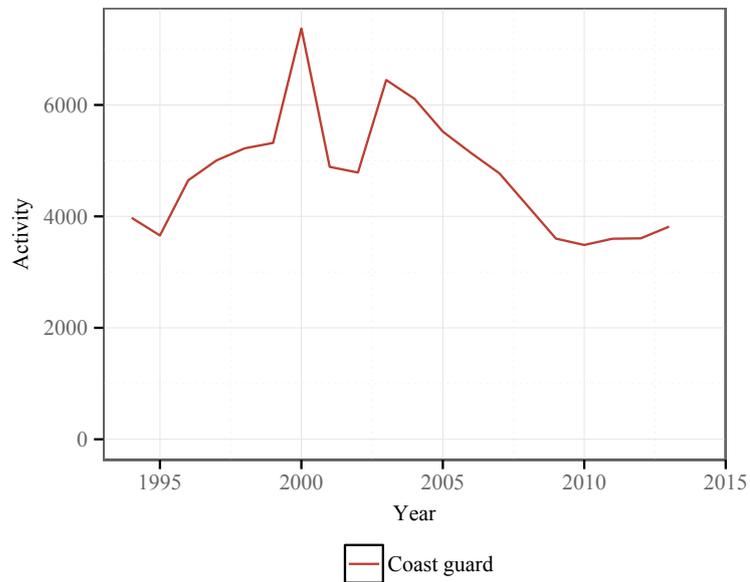


Figure B.2 Activity in the Coast Guard.

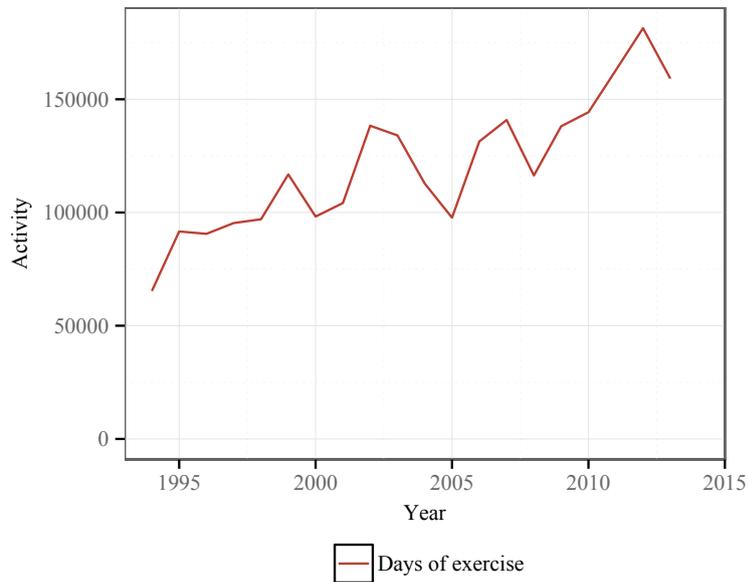


Figure B.3 Activity in the Army.

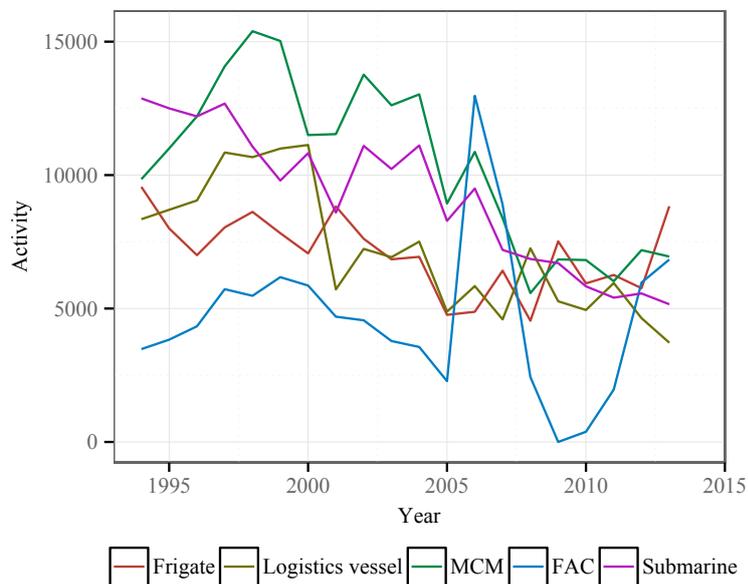


Figure B.4 Activity in the Navy.

Table B.1 show the activity correlation matrix. As can be seen, the different activity measures are quite strongly correlated. This could be both due to common shocks, for example increased budgets, and due to cross prioritization, for example reducing one type of activity to be able to increase another type of activity.

	EW plane	Frigate	Helicopter	Days of exercise	Fighter aircraft	Coast guard	MPA	Logistics vessel	MCM	FAC	Transport aircraft	Submarine
EW plane	1	0.077	0.826	-0.375	0.81	-0.194	0.751	-0.094	-0.012	-0.038	0.406	0.442
Frigate	0.077	1	0.332	-0.362	0.333	-0.048	0.464	0.36	0.436	-0.034	0.555	0.425
Helicopter	0.826	0.332	1	-0.486	0.927	-0.108	0.826	0.143	0.105	-0.046	0.653	0.541
Days of exercise	-0.375	-0.362	-0.486	1	-0.565	-0.347	-0.775	-0.654	-0.51	0.075	-0.643	-0.807
Fighter aircraft	0.81	0.333	0.927	-0.565	1	-0.05	0.854	0.27	0.225	-0.12	0.695	0.652
Coast guard	-0.194	-0.048	-0.108	-0.347	-0.05	1	0.053	0.464	0.605	0.282	0.117	0.45
MPA	0.751	0.464	0.826	-0.775	0.854	0.053	1	0.36	0.383	-0.043	0.674	0.777
Logistics vessel	-0.094	0.36	0.143	-0.654	0.27	0.464	0.36	1	0.73	0.06	0.715	0.763
MCM	-0.012	0.436	0.105	-0.51	0.225	0.605	0.383	0.73	1	0.302	0.583	0.796
FAC	-0.038	-0.034	-0.046	0.075	-0.12	0.282	-0.043	0.06	0.302	1	0.038	0.143
Transport aircraft	0.406	0.555	-0.034	-0.643	0.695	0.117	0.674	0.715	0.583	0.038	1	0.773
Submarine	0.442	0.425	0.541	-0.807	0.652	0.45	0.777	0.763	0.796	0.143	0.773	1

Table B.1 Activity correlation matrix.

C What is the cost of a weapon?

The following chapter is taken from Hove and Lillekvelland (2015) and shows the difference between various types of investment costs.

C.1 What is the cost of a weapon?

If we want to measure investment cost escalation, we must define what a unit cost is. Unfortunately, there exist a whole range of definitions. Figure C.1 and the following list show an example of such definitions, though varying definitions exist.²⁶

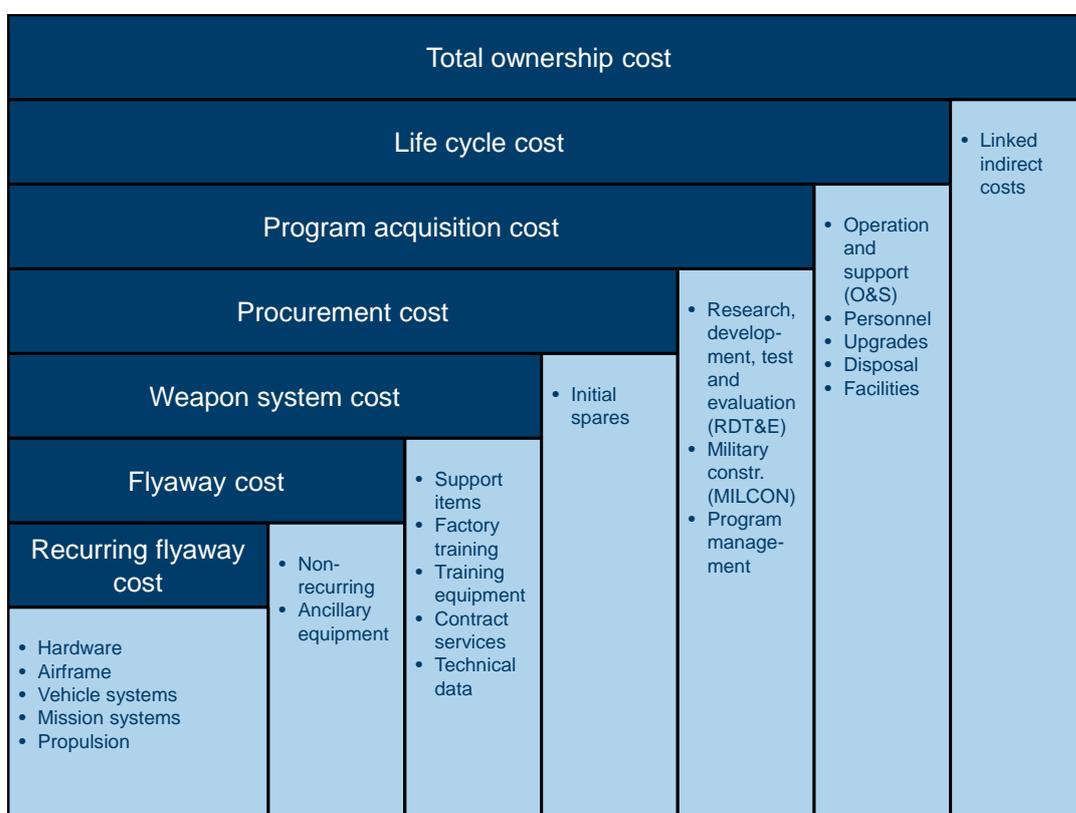


Figure C.1 Illustration of various definitions of cost. See associated list for more details.

Recurring flyaway cost covers the "basic" equipment of a system, such as the airframe, engines and avionics in a fighter. The recurring flyaway cost per unit is often denoted unit recurring flyaway (URF).

Flyaway cost (FAC) (or Rollaway/Sailaway for such systems) includes the recurring flyaway cost, as well as *non-recurring* flyaway costs, such as "startup" costs (which are often apportioned over the entire production series) and customer specific tailoring. An example of such

²⁶Our definition is similar to that of Defense Acquisition University (DAU) at their Defense Acquisition Portal (DAP) (<https://dap.dau.mil/acquipedia/Pages/ArticleDetails.aspx?aid=419dcd24-0e78-4279-a50a-9c122c4f0630>), though our illustration differ significantly.

tailoring is Norway and Canada having brake chutes fitted to their F-35s. **FAC** is an often quoted cost.

Weapon system cost (confusingly also known as *total flyaway cost*), is composed of **FAC** as well as support items, factory training, training equipment, contract services, technical data packages and various contract services related to initial support. These costs are generally amortized over the entire purchase.

Procurement cost includes the weapon system costs as well as initial spares. The cost per unit is known as average procurement unit cost (**APUC**) and is, together with **FAC** an often quoted cost.

Program acquisition cost adds research, development, test and evaluation (**RDT&E**) and military construction (**MILCON**), such as test facilities, to the procurement cost. These costs are often fixed, i.e. they do not vary with the number of units produced. The unit cost, known as program acquisition unit cost (**PAUC**), can therefore be much higher than **APUC** if production quantities are small (and/or if **RDT&E** or **MILCON** are very high).

Life cycle cost (LCC) adds all the building of facilities, as well as the lifetime operational and upgrade costs of a system to the program acquisition cost. These costs include fuel, spares, replenishment, depot maintenance, system support, modifications, disposal, as well as hiring, training, supporting, and paying the personnel. There is no one life cycle cost (**LCC**) method, therefore one should be wary of assuming that all **LCC** analyses contain the same cost elements.

Total ownership costs also includes the indirect effects of a purchase, though these costs are not borne by the customer. Such indirect costs can include the building of a new bridge to an island of an enlarged defence base, since the current bridge can no longer sustain the increased traffic. As for **LCC**, this is more of a concept than an established methodology, so estimates are difficult to compare.

Even without examples, we understand that an **URF** quote and a **LCC** per unit quote will differ significantly, as will an **URF** and a **PAUC** quote. Table C.1 illustrates an example of the different unit costs one can obtain. The rightmost column does not reflect research and development (**R&D**) and production costs, whereas the mid column does. Consider for example the F-22, where including **R&D** and production costs almost doubles the unit cost.

Aircraft Type	Unit Total Cost ^{1,2}	Unit Production Cost ¹
Combat aircraft		
Eurofighter Typhoon ³	170	110
Saab JAS 39 Gripen	86	78
Dassault Rafale	153	70–91 ⁴
Boeing F-15E Strike Eagle ⁵	NA ⁶	122
Boeing F/A-18E/F Super Hornet	107	67–88 ⁴
Lockheed Martin F-22 Raptor	381	200
Lockheed Martin F-35 Lightning II	162	137 ⁷
Transport aircraft		
Airbus A400M Atlas	216	118
Boeing C-17 Globemaster II	328	245
Lockheed Martin C-130J Super Hercules	NA ⁶	73

¹ Million US dollars at 2011 prices and exchange rates.

² Includes R&D costs and production costs.

³ According to Hartley (2012), "no capital charges [are] included in the price."

⁴ Sources differ.

⁵ McDonnell Douglas until their merger with Boeing in 1997.

⁶ Not available.

⁷ Alternative estimates range from \$197mn (F-35A) to \$238mn (F-35C). Costs are estimated prior to large-scale production and are averages for F-35A/B/C.

Table C.1 Examples of unit prices with different types of costs included. Table from Hartley (2012).

About FFI

The Norwegian Defence Research Establishment (FFI) was founded 11th of April 1946. It is organised as an administrative agency subordinate to the Ministry of Defence.

FFI's MISSION

FFI is the prime institution responsible for defence related research in Norway. Its principal mission is to carry out research and development to meet the requirements of the Armed Forces. FFI has the role of chief adviser to the political and military leadership. In particular, the institute shall focus on aspects of the development in science and technology that can influence our security policy or defence planning.

FFI's VISION

FFI turns knowledge and ideas into an efficient defence.

FFI's CHARACTERISTICS

Creative, daring, broad-minded and responsible.

Om FFI

Forsvarets forskningsinstitutt ble etablert 11. april 1946. Instituttet er organisert som et forvaltningsorgan med særskilte fullmakter underlagt Forsvarsdepartementet.

FFIs FORMÅL

Forsvarets forskningsinstitutt er Forsvarets sentrale forskningsinstitusjon og har som formål å drive forskning og utvikling for Forsvarets behov. Videre er FFI rådgiver overfor Forsvarets strategiske ledelse. Spesielt skal instituttet følge opp trekk ved vitenskapelig og militærteknisk utvikling som kan påvirke forutsetningene for sikkerhetspolitikken eller forsvarsplanleggingen.

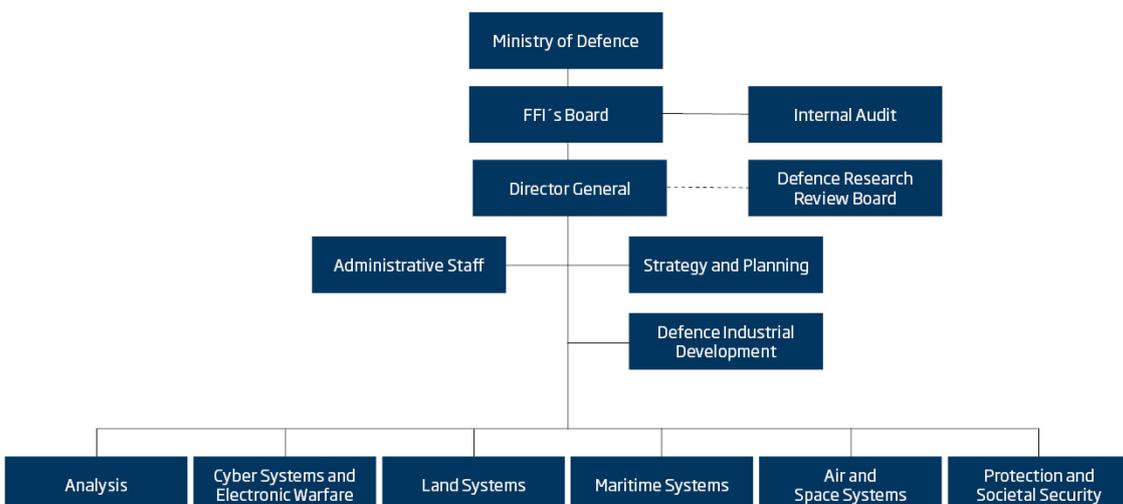
FFIs VISJON

FFI gjør kunnskap og ideer til et effektivt forsvar.

FFIs VERDIER

Skapende, drivende, vidsynt og ansvarlig.

FFI's organisation



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