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Defence specific inflation (DSI) of goods and services

A refinement of concepts and new estimates

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Summary

The growth in prices of goods and services, inflation, is often higher in the Armed Forces than in the general economy. The difference between defence inflation (DI) and the general inflation, for example as measured by the consumer price index (CPI) or the gross domestic product (GDP) deflator, can be substantial. This differential, called defence specific inflation (DSI), poses a major challenge to long term defence planning if budgets are not increased accordingly. This report aims to answer three questions:

Why is inflation higher in the Armed Forces than in the general economy?
DSI of goods and services can be caused by a number of factors. We particularly discuss the following:

- 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 DSI in the Norwegian Armed Forces?
We estimate DSI as the change in cost per unit of activity (days of sailing, flight hours and exercise days), in other words the change in cost per unit of output. Our results indicate an annual DSI of four to six per cent beyond CPI, far above what can be expected from productivity gains. Total costs show an upwards trend, whereas activity has been reduced. Though our estimation methodology probably overstate DSI somewhat, it is safe to say that defence inflation exceeds CPI.

What are the implications for long term planning?
If budgets are not increased, the performance of the Armed Forces (force effect) inevitably has to be reduced, unless productivity increases at a faster rate than costs. If DSI is 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 DSI 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

Veksten i prisen på varer og tjenester, inflasjon, er generelt høyere i forsvarssektoren enn i den øvrige økonomien. Forskjellen mellom inflasjonen på forsvarssektorens varer og tjenester og den generelle inflasjonen kan være merkbar. Forskjellen mellom de to kalles forsvarsspesifikk inflasjon og utgjør en stor utfordring for forsvarssektorens langtidsplanlegging dersom ikke budsjettene også øker. Denne rapporten svarer på tre spørsmål:

Hvorfor er inflasjonen høyere i forsvarssektoren enn i den øvrige økonomien?
Forsvarsspesifikk inflasjon på varer og tjenester kan være forårsaket av en mengde faktorer. 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 inflasjonen i forsvarssektoren?
Vi estimerer inflasjonen som endringen i kostnaden per enhet aktivitet (seilingsdøgn, flytimer og øvingsdøgn), med andre ord endringen i kostnad per enhet output. Resultatene indikerer en årlig forsvarsspesifikk inflasjon, altså ut over den generelle inflasjonen, på fire til seks prosent, langt høyere enn hva som kan forventes av produktivitetsvekst. Totale kostnader viser en oppadgående trend, mens aktiviteten er redusert. På tross av at våre estimeringsmetoder antageligvis overestimerer den forsvarsspesifikke inflasjonen noe, er den klare konklusjonen likevel at inflasjonen i forsvarssektoren er høyere enn den generelle inflasjonen.

Hva betyr forsvarsspesifikk inflasjon for langtidsplanleggingen?
Dersom budsjettene ikke økes, må ytelsen til slutt reduseres, med mindre produktiviteten øker mer enn kostnadsveksten. Hvis ikke den forsvarsspesifikke 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 forsvarsspesifikk inflasjon:

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

Contents

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. Defence specific inflation (DSI) describes a rate of inflation that exceeds the general rate of inflation in the economy. In this report, we aim to refine the concept of DSI of goods and services and explain various reasons as to why this phenomenon exists. We make a distinction between intra- and intergenerational DSI, where intragenerational DSI is the cost increase within a generation of a weapon system, while the intergenerational DSI is the increase between two generations. We also emphasize the difference between input and output DSI. 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 DSI.

Based on Norwegian defence accounts and activity data, we then estimate historical DSI. We measure DSI as the cost increase per unit of a resource, 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 DSI is important. Then, we proceed to define DSI more closely in Chapter 3, before we explain reasons as to why we experience DSI in Chapter 4. In Chapter 5, we review the available literature on DSI, based on the various reasons from Chapter 4. In Chapter 6, we provide a method, present data and results for estimating Norwegian DSI 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 review of available literature which we hope will spur future studies into the topic. DSI is important to understand for defence policy makers and defence bureaucrats because a high rate of defence inflation 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 DSI.

1.3 Audience

This report is primarily aimed at defence economists, defence policy makers and defence bureaucrats. 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 DSI important?

The purpose of this report is to define DSI, explain underlying causes, and to measure DSI. But why is DSI 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 price growth for the armed forces, though not costs originating from increased capabilities (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 are no cuts in operation and support (O&S), there will be almost no room for any investments by the year 2034. By 2034, DSI will have increased operating costs by some twelve per cent. This obviously poses a significant challenge for long term defence planning, and difficult decisions lie ahead.

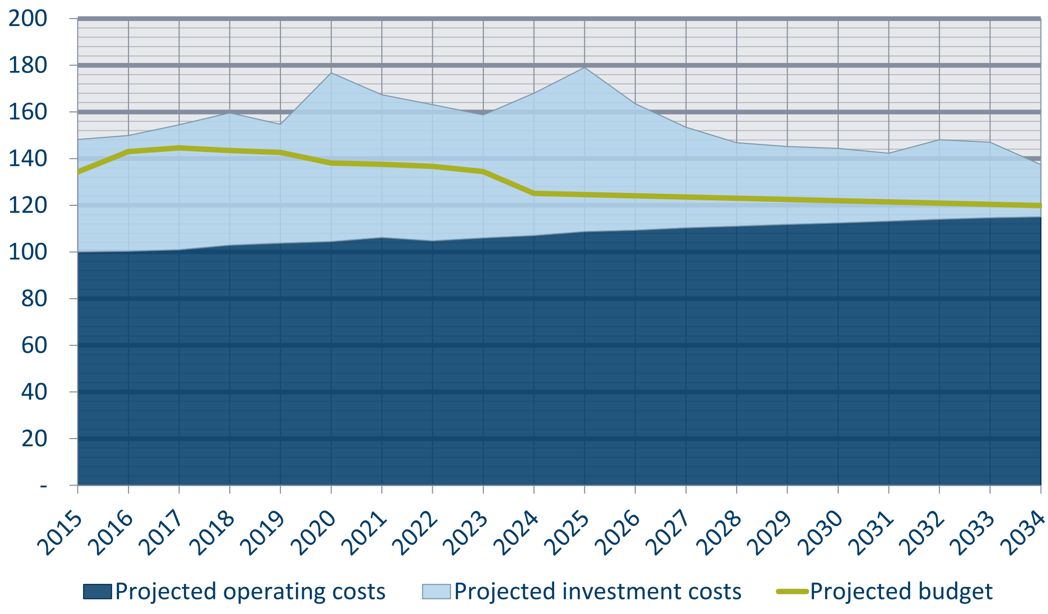

Figure 2.1 *Projected costs of the Norwegian Armed Forces 2015–2034. Costs deflated by the annual budgetary technical compensation. Operating costs indexed at 100 in 2015. The annual budget is reduced by 0.5 per cent, as is the default annual budget reduction for all ministries. The reduction is meant 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 then 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, DSI is not an entirely unknown phenomenon. Several countries make use of defence inflation indices, including Canada, (Solomon 2003), the United States (Horowitz et al. 2012; Connor and Dryden 2013; Horowitz, Harmon and Levine 2016) and the United Kingdom (Jones and Woodhill 2010; Hartley 2016). Norwegian studies, which we will return to in Section 5.2, have attempted to measure DSI, but without constructing defence inflation indices. In general, DSI is greater in magnitude than standard measures of inflation such as consumer price index (CPI). In subsequent chapters, we discuss causes of DSI and review previous literature.

3 What is DSI?

3.1 Evolution of costs of defence

DSI is a part of what we in this report will call evolution of costs of defence (ECO–DEF). ECO–DEF encompasses the evolution of both investment costs as well as operating costs. Figure 3.1 illustrates the concepts currently in use in Norwegian long term planning, while the dark blue parts are of particular interest in this report. A substantial literature has investigated the concepts of investment cost escalation (ICE) and DSI in defence. We discuss ICE and DSI futher in Section 3.3.

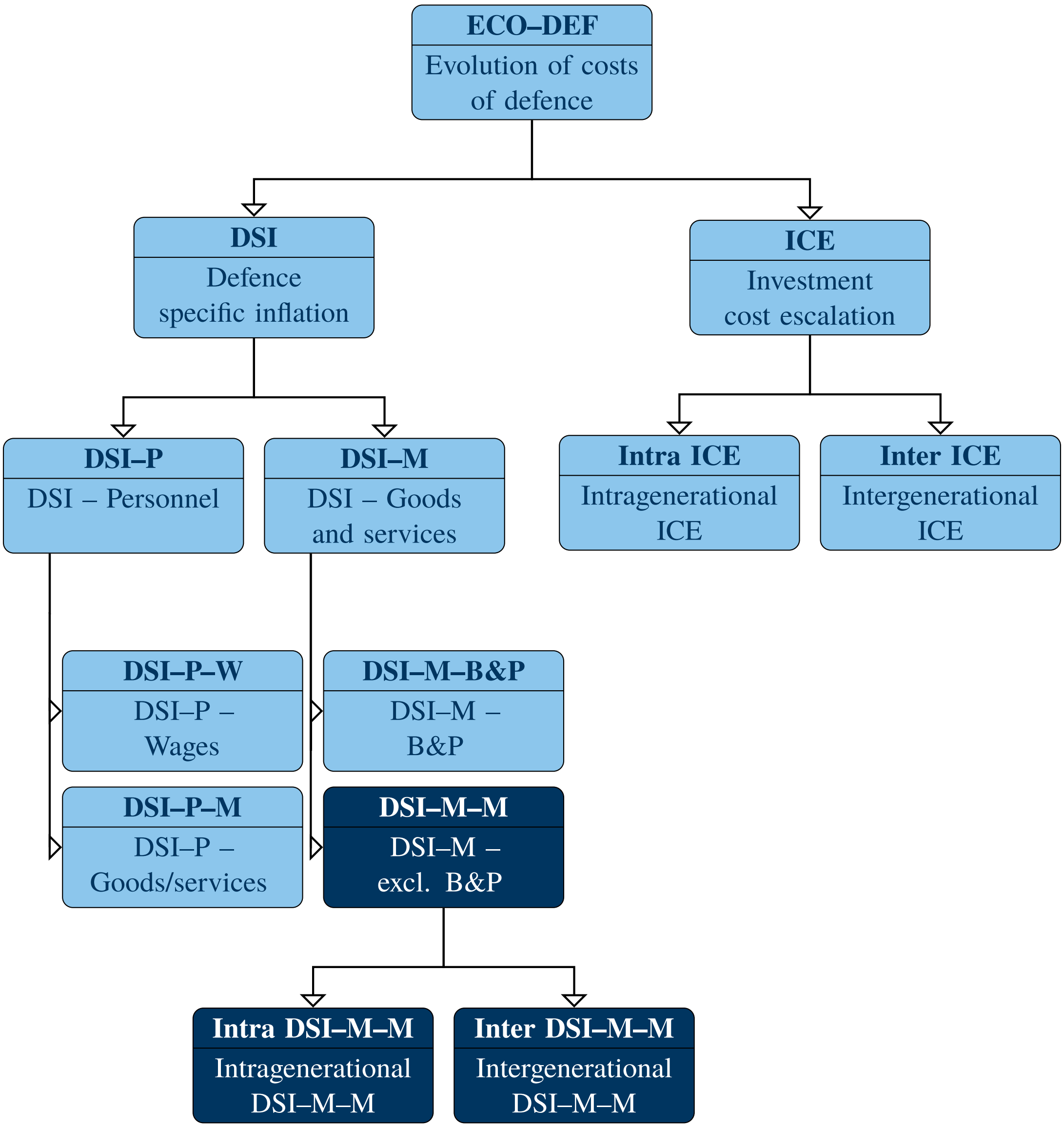

Figure 3.1 *The various cost evolution concepts. Abbreviations: Defence specific inflation = DSI, evolution of costs of defence = ECO–DEF, investment cost escalation = ICE, goods and services = M, personnel = P, buildings and property = B&P, wages = W. For a full list of abbreviations, see page 53.*

In previous FFI works, the ICE concept was discussed by Hove and Lillekvelland (2016). DSI–P was discussed by Gulichsen, Johansen and Pedersen (2011) and will be further discussed in future Norwegian Defence Research Establishment (FFI) works. A more detailed review of the FFI studies are given in Section 5.2. DSI–M, and in particular DSI–M–M (indicated by the dark blue color in Figure 3.1), forms the topic of the remainder of this report, though we refer to the concept as DSI for simplicity.

In this report, we employ the following definition:

Defence specific inflation – Goods and services (DSI–M)

DSI–M is defined as the annualized long run increase in operating costs of goods and services
– *per measurement unit*, here per unit of activity, and
– *beyond a base price index*, here CPI.

3.1.1 Measurement unit

The measurement unit depend on what we want to measure. We can distinguish between input and output measurements, which we will discuss further in Section 3.4. If we want to measure inflation per unit of activity (output), the measurement unit can be fighter aircraft hours, submarine sailing days, et cetera. If we want to measure inflation per unit of weapons systems (input), 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 cost escalation per unit of activity. While activity is no perfect measure of defence output, it is difficult to measure the core defence production, namely the amount of peace and security produced (see also Anagboso and Spence 2008, 2009; Jones and Woodhill 2010; Hartley 2010, 2016).

3.1.2 Base price index

The base price index provides a real, or constant, price index. If we measure the annual price increase of the goods and services bought by the Armed Forces, we measure defence inflation (DI). If we measure DI relative to a base price index, we find the DSI. In other words, if defence inflation (DI) is three per cent and general inflation is two per cent, DSI is one per cent. Figure 3.2 illustrates the concepts, as well as distinguishing between economy driven price change and customer driven price change. Economy driven price change is a result of for example increasing labour costs at suppliers or increased prices of nuts and bolts. Much of this price change is shared by the general economy, here measured by CPI[1]. Customer driven price change can for example be a result of more expensive spares as we upgrade from F-16 to F-35. This change is therefore a result of choices. A similar split is used for example by Arena et al. (2006, 2008) and Nordlund (2016)[2]. This distinction is important for example in Norway, where the budget is supposed to increase

[1] We could also use other price indices, for example the gross domestic product (GDP) deflator. The choice of deflator matters, as we shall see in Section 5.1.1.

[2] Nordlund (2016) uses a different terminology, where *Defence specific cost escalation = Defence specific inflation + Customer driven cost escalation* instead of *Defence specific inflation = Economy driven price change + Customer driven price change*.

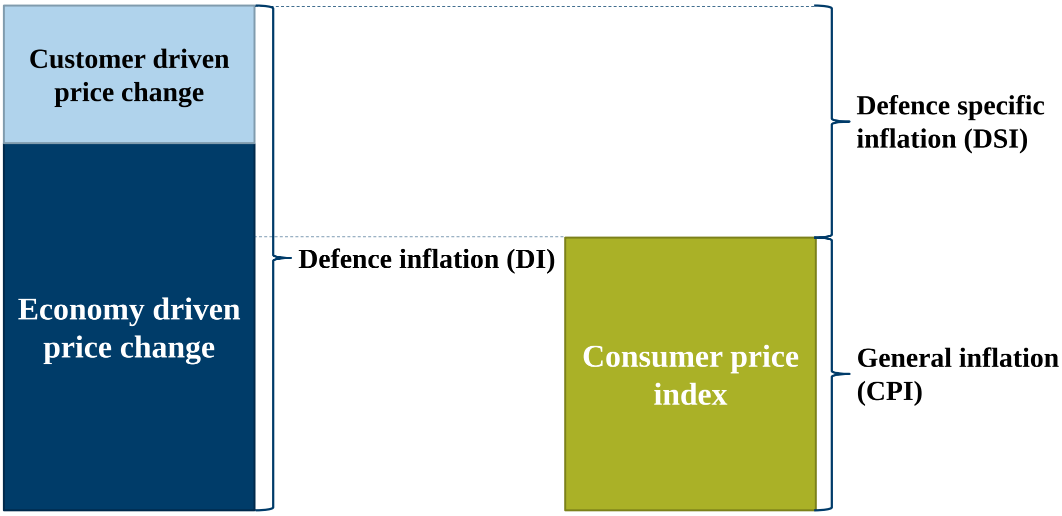

Figure 3.2 *Separation of DI into general inflation, here measured by CPI, and DSI. DI is the sum of economy driven price change (for example the price growth of fuel) and customer driven price change (for example more expensive spares caused by upgraded weapon systems).*

by the economy driven price change each year, through the annual budgetary technical price and wage compensation. Any customer driven price change is not automatically compensated. The distinction between economy driven price change and customer driven price change is not clear cut in practice. Price growth of fuel is an economy driven price change, while more expensive spares caused by upgraded weapon systems is a customer driven price change. There are, however plenty of costs which are not as easy to categorize.

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. For example, in Norwegian long term defence planning, equipment is assumed to be replaced in the same quantity as the current stock once it has to be replaced. Therefore, real/constant DSI is used. In the United States (US), the Bureau of Economic Analysis (BEA) national defence deflator and the Bureau of Labor Statistics (BLS) Producer Price Index (PPI) are constant-quality DSI, or hedonic, indices (Horowitz, Harmon and Levine 2016).

		Base price index	
		No	Yes
Measurement	Input	Nominal/current DI	Real/constant DSI
	Output	Current-quality DI	Constant-quality DSI

Table 3.1 *Types of inflation indices depending on measurement (input or output) and whether or not we employ a base price index in the calculations.*

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

3.2 Defence inflation and investment cost escalation

When discussing increasing costs in the Armed Forces, we refered to the terms DSI and ICE in Section 3.1. In general, DSI refers to cost increases of overall defence production, i.e. operating costs. ICE refers to the evolution of investment costs. Total ICE is the increase in costs between generations of a weapon system, for example from F-16A/B to F-35A. In Hove and Lillekvelland (2016), we distinguished between intragenerational ICE (ICE within a generation of a weapon system, for example from F-16A/B to F-16E/F), intergenerational ICE (ICE between generations of a weapon systems, for example from F-16E/F to F-35A) and cost growth (cost increases within an acquisition project, for example from the launch of the Joint Strike Fighter (JSF) programme until the production of the F-35).

Hartley (2016) 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*. Hartley and Solomon (2016) emphasize the importance of this distinction and of the importance of considering their mutual influence. DSI is related to ICE in the sense that they share common drivers. A driver that increases DSI often also increases ICE, and vice versa. If titanium prices increase, replacement parts are more expensive to produce (DSI), while parts of new aircraft are also getting more expensive to produce (ICE). If we swich to a more expensive composite material in new aircraft (ICE), future spares become more expensive as well (DSI). In Section 3.3, we consider a conceptual separation between intra- and intergenerational DSI, much in the same way we considered intra- and intergenerational ICE in Hove and Lillekvelland (2016).

3.3 Intra- and intergenerational DSI

3.3.1 Intergenerational DSI

In many cases, it is instructive to make a distinction between intra- and intergenerational DSI. 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 US 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]Data 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) 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.

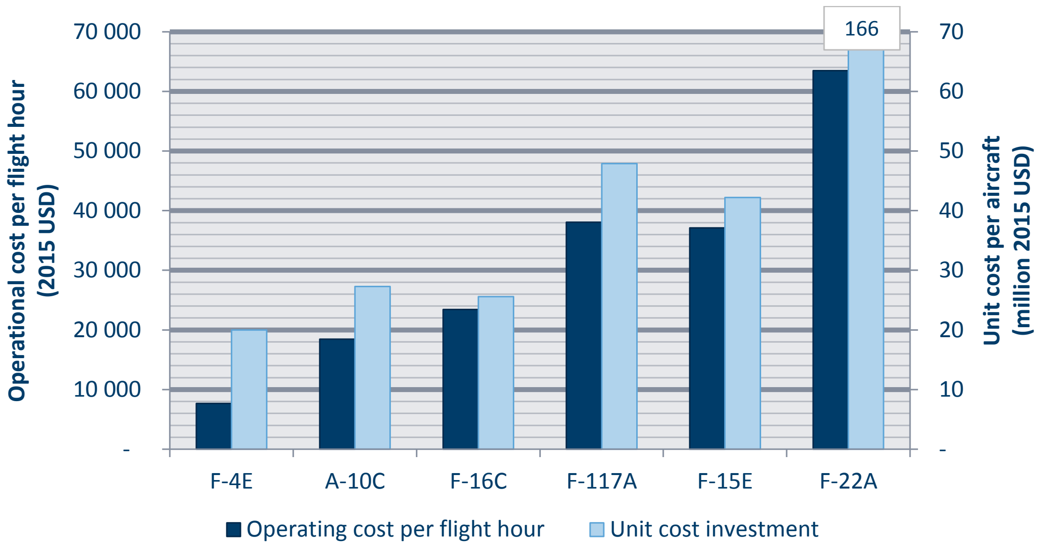

Figure 3.3 *Operating and aquisition costs for selected US fighter and attack aircraft.*

3.3.2 Intragenerational DSI

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 DSI.

Figure 3.5 illustrates a conceptual picture of intra- and intergenerational DSI (similar figures are found in Nesset and Wessel 1995; Jones and Woodhill 2010). The figure illustrates the intragenerational inflation 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 $P_{1982,\text{F-16}}$ to $P_{2020,\text{F-16}}$ (the curve AB) for the F-16 fighter. In 2020, operating costs start at $P_{2020,\text{F-35}}$ for the F-35. The slope of curve AB is the average rate of inflation for the F-16 (intragenerational DSI). The shift from $P_{2020,\text{F-16}}$ to $P_{2020,\text{F-35}}$, BC, is the intergenerational DSI from the F-16 to the F-35. The total DSI trend at a generational change is given by AE.[4]

[4]Within 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.

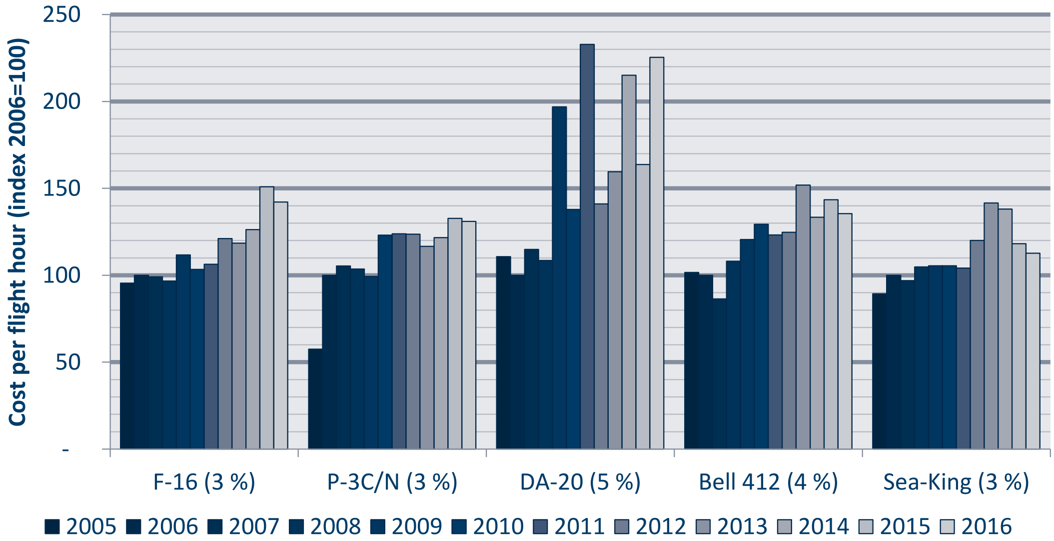

Figure 3.4 *Costs per flight hour. Selected Norwegian Air Force systems. Average annual cost increase in parenthesis (excluding F-16 in 2015 and 2016, P-3C/N in 2005 and DA-20 in 2009, 2011, 2014 and 2016. The following observations are omitted: F-16 in 2015 and 2016 due to extraordinary repairs, P-3C/N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

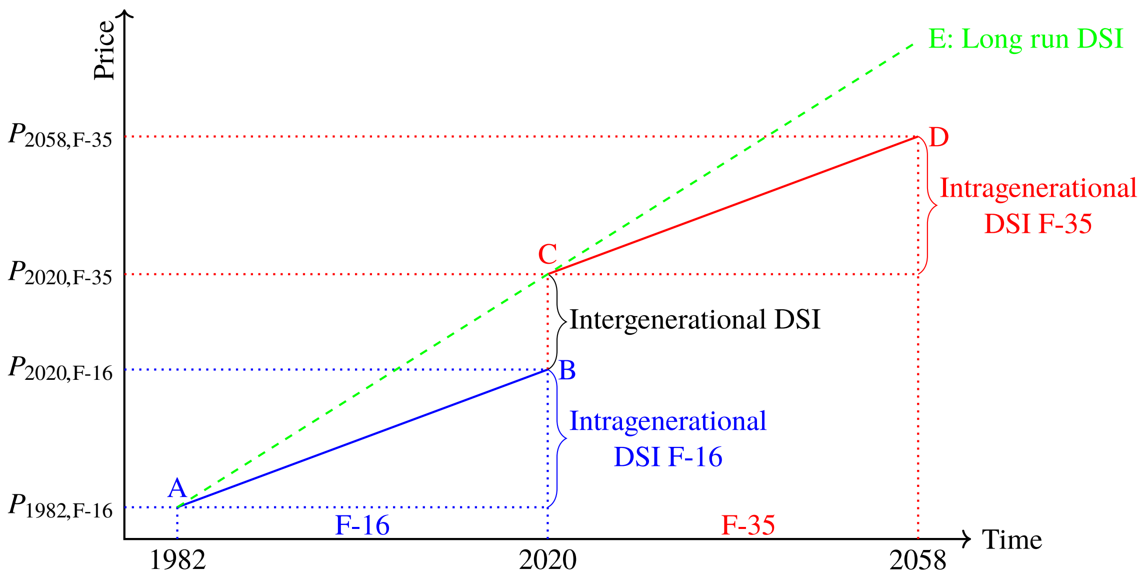

Figure 3.5 *Intra- and intergenerational DSI. During its lifetime, operating costs rise from $P_{1982,F\text{-}16}$ to $P_{2020,F\text{-}16}$ (the blue curve AB) for the F-16. In 2020, operating costs start at $P_{2020,F\text{-}35}$ for the F-35. The slope of curve AB is the average rate of inflation for F-16 (intragenerational DSI). The shift from $P_{2020,F\text{-}16}$ to $P_{2020,F\text{-}35}$, BC, is the intergenerational DSI from the F-16 to the F-35. The total DSI 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 DSI is whether we are measuring DSI of input or output prices. Figure 3.6 illustrates the conceptual difference between input and output prices: The input DSI is the DSI of all the input factors of production. If the Air Force uses two factors of input in equal amounts, where one factor has a price increase of 15 per cent, while the other has a price increase of 5 per cent, the total input DSI 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 DSI (or increase it, if productivity were to fall). Defence itself has no profit, but if the defence industry is a part of the DSI measure, profits could be relevant.

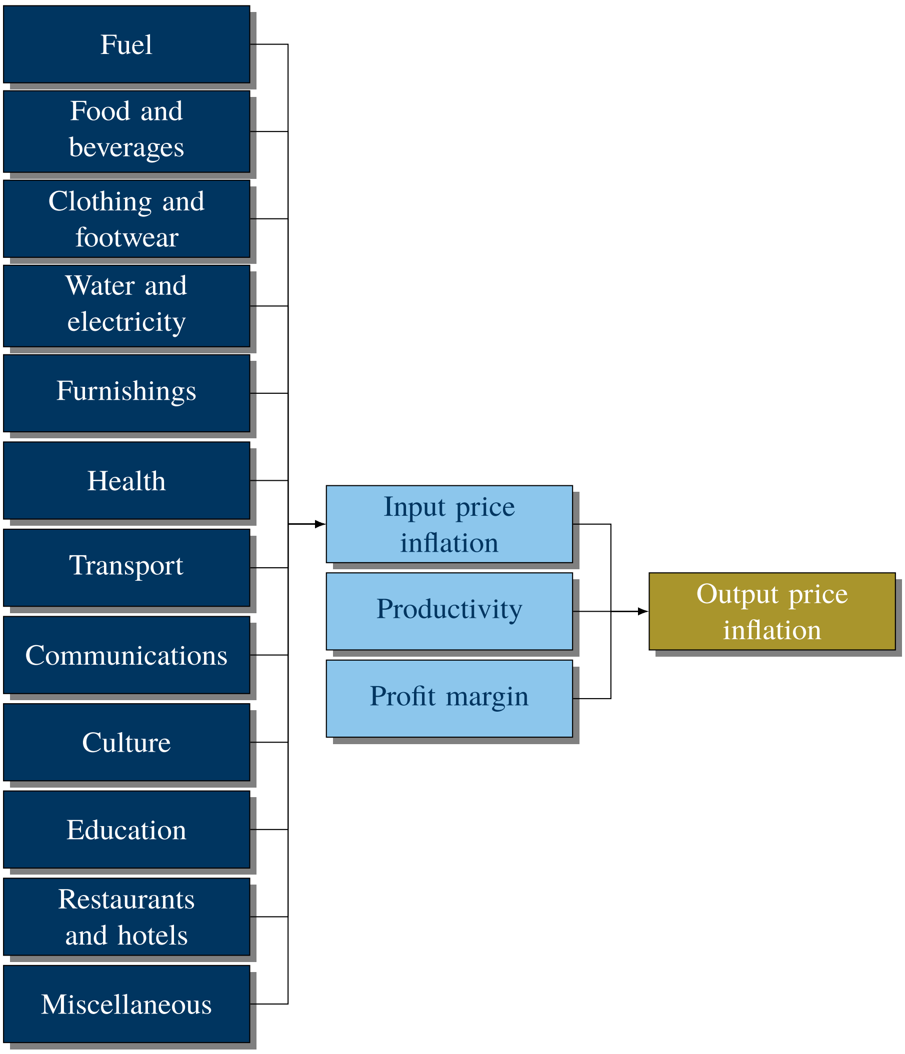

Figure 3.6 *The general relationship between input and output price indices. Each box in the left hand column represent a price index. The indices are weighted together into the input price inflation. Output prices equal input prices adjusted for productivity changes and profit margin.*

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 2011). 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.

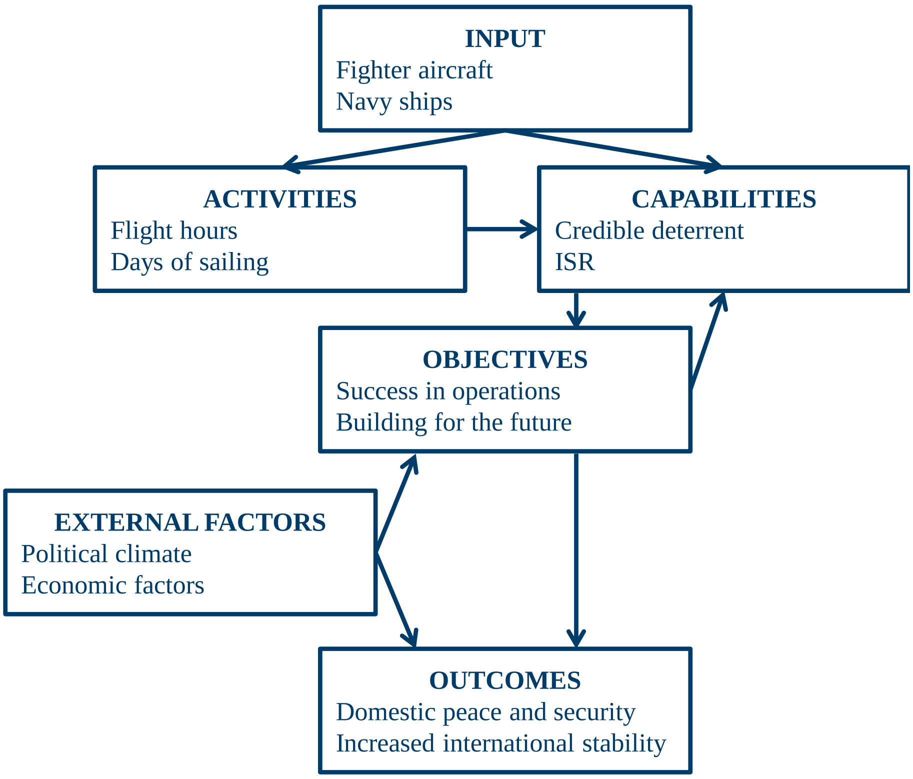

Figure 3.7 *Relationship between inputs, output and outcomes. Activities, capabilities and objectives are output. Figure from Anagboso and Spence (2008, 2009).*

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), Murray et al. (1995) and Verikios (1998) use training data as proxies for force quality. Activity will be a better measure the more training is related to force quality. 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, aggregation[5], 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 – flight hours, sailing days and exercise days. In our empirical study in Chapter 6, we measure DSI as a function of activity data. Currently, we do not have sufficient data or definition to measure DSI as a function of capabilities or objectives.

3.4.3 Input or output?

The choice between input and output inflation 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 DSI. 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 method is the correct choice. If the aim is to measure the inflation in defence production, a good output measure

[5] Cost weights can be used, but, as Tellis et al. (2000) discuss, there is no one-to-one link between cost and importance, though there probably is a positive correlation.

would be preferrable. In their definition of United Kingdom (UK) DI, Jones and Woodhill (2010, p. 10) say that for their purposes, allowing DI to incorporate all 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. Therefore, they adopt a definition of DI 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 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.

3.5 What slips away: substitution

When we measure DSI of goods and services, we could over- or underestimate DSI depending on substitution. For example: if wages increase, we could see a substitution between labour and capital reflected in a reduction in the number of crew members and an increase in the number and complexity of technological components. As long as our unit of measurement is the number of units of a weapon system or the activity level, this should increase estimated DSI of goods and services and reduce estimated DSI of labour[6], while leaving the overall DSI effect ambiguous. This substitution is more of an intergenerational consideration (see Section 4.4.2). For example, the number of crew members of the P-3 Orion aircraft is eleven, whereas it is seven for the new P-8 Poseidon.[7]

[6] Had the unit of measurement been man years, DSI of labour would have increased.

[7] See https://en.wikipedia.org/wiki/Lockheed_P-3_Orion and https://en.wikipedia.org/wiki/Boeing_P-8_Poseidon.

4 Theoretical foundations behind DSI

In this chapter, we discuss possible contributors to DSI. 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 DSI, whereas the rest of the causes mentioned in this chapter serve as further explanations as to why DI differs from general inflation. 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 DSI – it is the continuous reinforcement of the factors over time which produce DSI.

4.1 DSI 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 goods and services, we would expect higher price growth than for industries consuming goods and services where production is automatized.[8] 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, total inflation (DI) is higher than general inflation (for example 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 DSI.

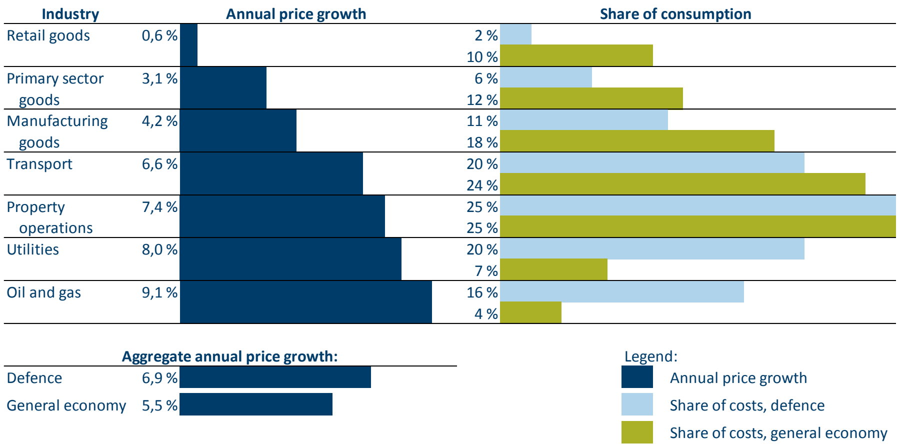

Figure 4.1 *Example of input factor mix. In this economy, there are seven forms of input factors. Retail goods has the lowest annual price growth, oil and gas has the highest. Furthermore, defence (light blue bars) and the general economy (green bars) consume a varying share of these goods. By multiplying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

[8] Real 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 DSI 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.[9] 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 and Bowen 1966; Baumol 2012), where the labour intense public sector cannot increase productivity to the extent the private sector can.

4.3 DSI as a function of technological complexity: the importance of relative effect

Figure 4.2 (based on data from Deo, Starnes Jr. and Holzwartz 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).

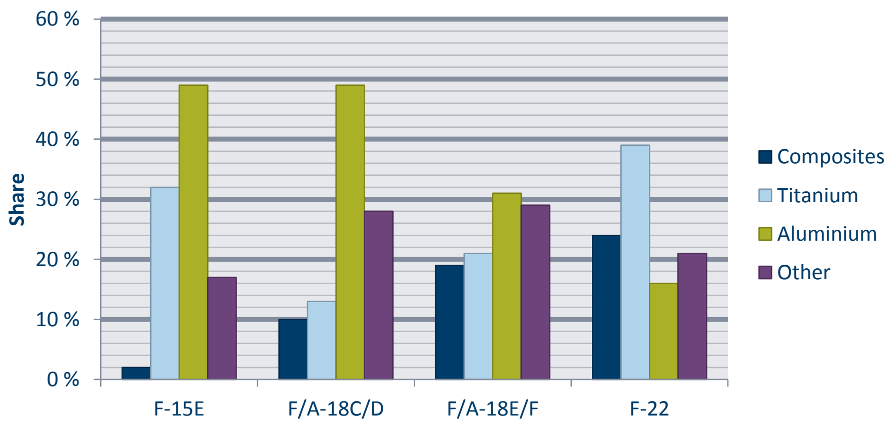

Figure 4.2 *Share of composites, titanium, aluminium and other types of material in various fighter aircraft. Data from Deo, Starnes Jr. and Holzwartz (2001).*

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.

[9] $\frac{1,10}{1,02} - 1 \approx 7,84\%$.

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 identify three ways in which increasing complexity magnify 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 DSI – 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 DSI. As weapon systems become more complex, the producers increase their dependence on specialized suppliers and specialized manpower. Singh (1997) argue that the risk of failure increases with more complex technologies.[10] 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 DSI, 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 (or effectiveness, as used by 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 and Pugh 1983; Pugh 1986, 1993; Kirkpatrick 1995, 1997, 2004) 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 of a weapon system might increase, the effectiveness relative to the weapons of the

[10] According 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.

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 DSI 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 DSI increases.[11] In other words, maintaining each successive generation of a weapon system for a longer time will contribute to DSI. Increase in the average age of weapon systems has for a long time been a known issue (CBO 2001).

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 DSI. Age affects both input (through input factor mix) and output (through productivity – increasing as a system matures, decreasing when it ages) DSI. During development of new weapon systems, technological complexity generally increases. In Section 4.3, we discussed this in further detail.

[11] That is, the second derivative is positive.

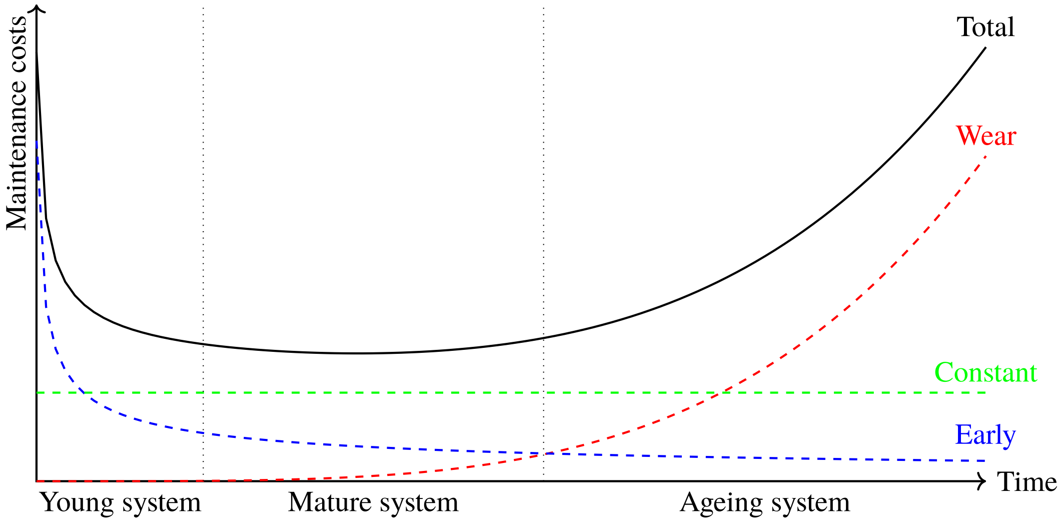

Figure 4.3 *The bathtub curve of maintenance costs. Costs decrease as early design and production flaws are corrected, but rise as wear takes its toll.*

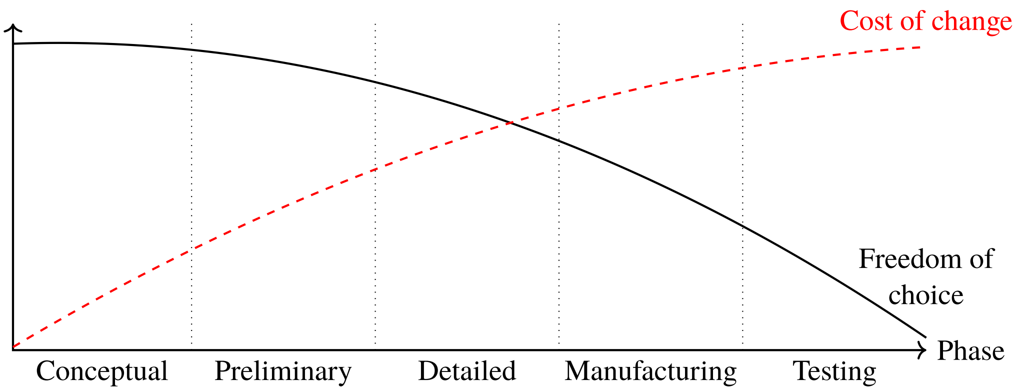

Figure 4.4 *New product design: Freedom of choice versus cost of change. Freedom of choice is reduced, while cost of change increases as development progresses. Figure based on* `http://enfinio.com/new-product-development/`

4.5 DSI 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 DSI. 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 buildings and property (B&P) 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.[12]

[12]In 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

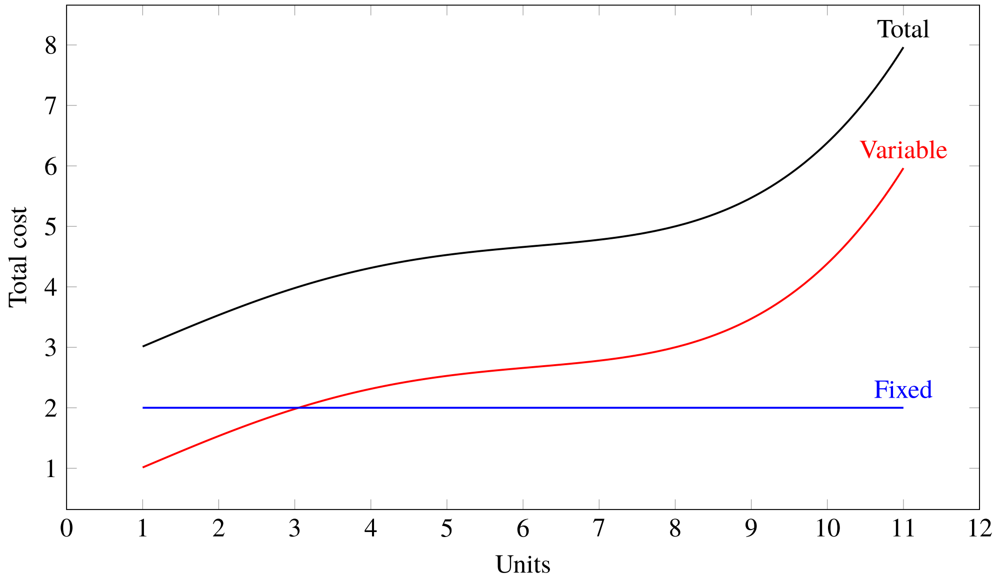

Figure 4.5 *Variable, total and fixed cost curves.*

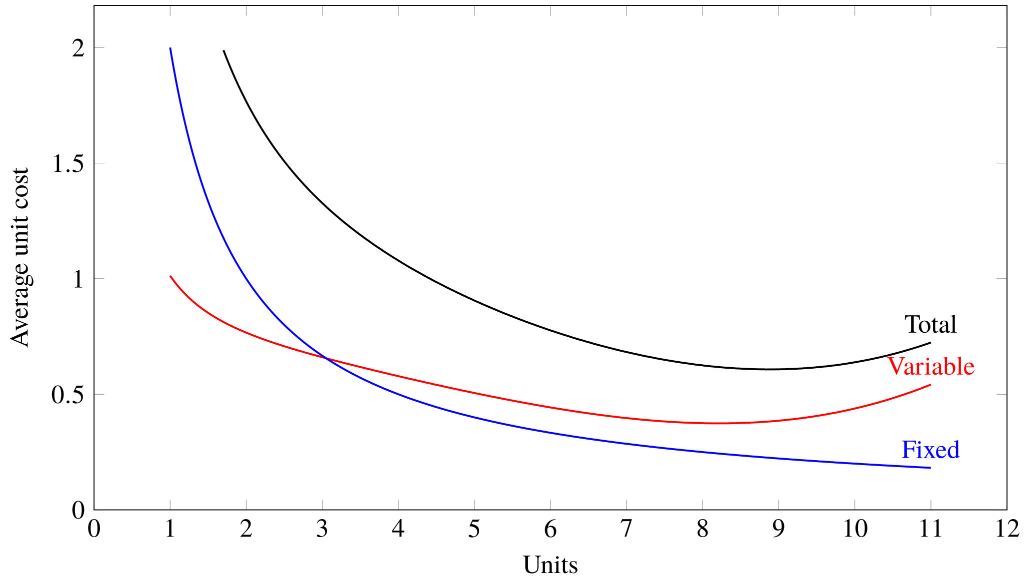

Figure 4.6 *Average variable, total and fixed unit cost curves.*

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 DSI 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 DSI 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 DSI. 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. Hartley (2016) argues that governments have significant buying 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. 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."[13,14] 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 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.

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

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units. However, this distinction is not necessary to state our point, thus we leave it out.

[13] `http://coursesa.matrix.msu.edu/~hst306/documents/indust.html`.

[14] Spinney (1980) uses the term *military industrial congressional complex* and Hartley (2016) the phrase *military-industrial-political complex*.

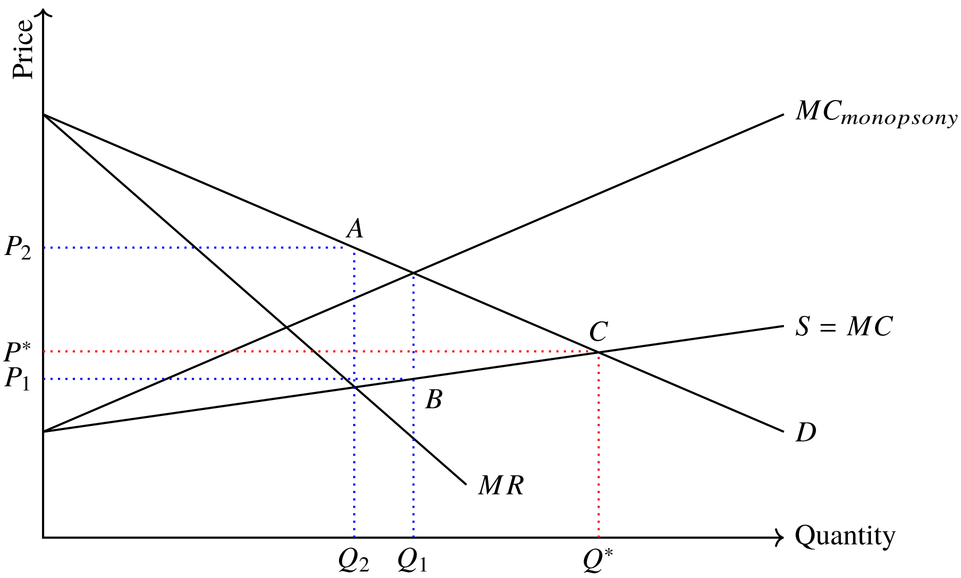


Figure 4.7 *Example of a bilateral monopoly in the defence market. In a perfectly competitive market, optimal price P^* and quantity Q^* are set at the intersect between supply S and demand D. In a monopoly, price P_2 and quantity Q_2 are determined where supply is equal to marginal revenue MR. In a 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.*

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 DSI, through more expensive spares, rapid repairs and so on. In order to be an DSI 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 inflation. The more we can substitute, the less the total inflation will be. Say we use the same amount of two input factors in the production of a good and both experience a cost escalation of four and eight per cent, respectively. If there is no scope for substitution, the aggregate inflation will be six per cent. If there is scope for substitution, the aggregate inflation 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 inflation 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.

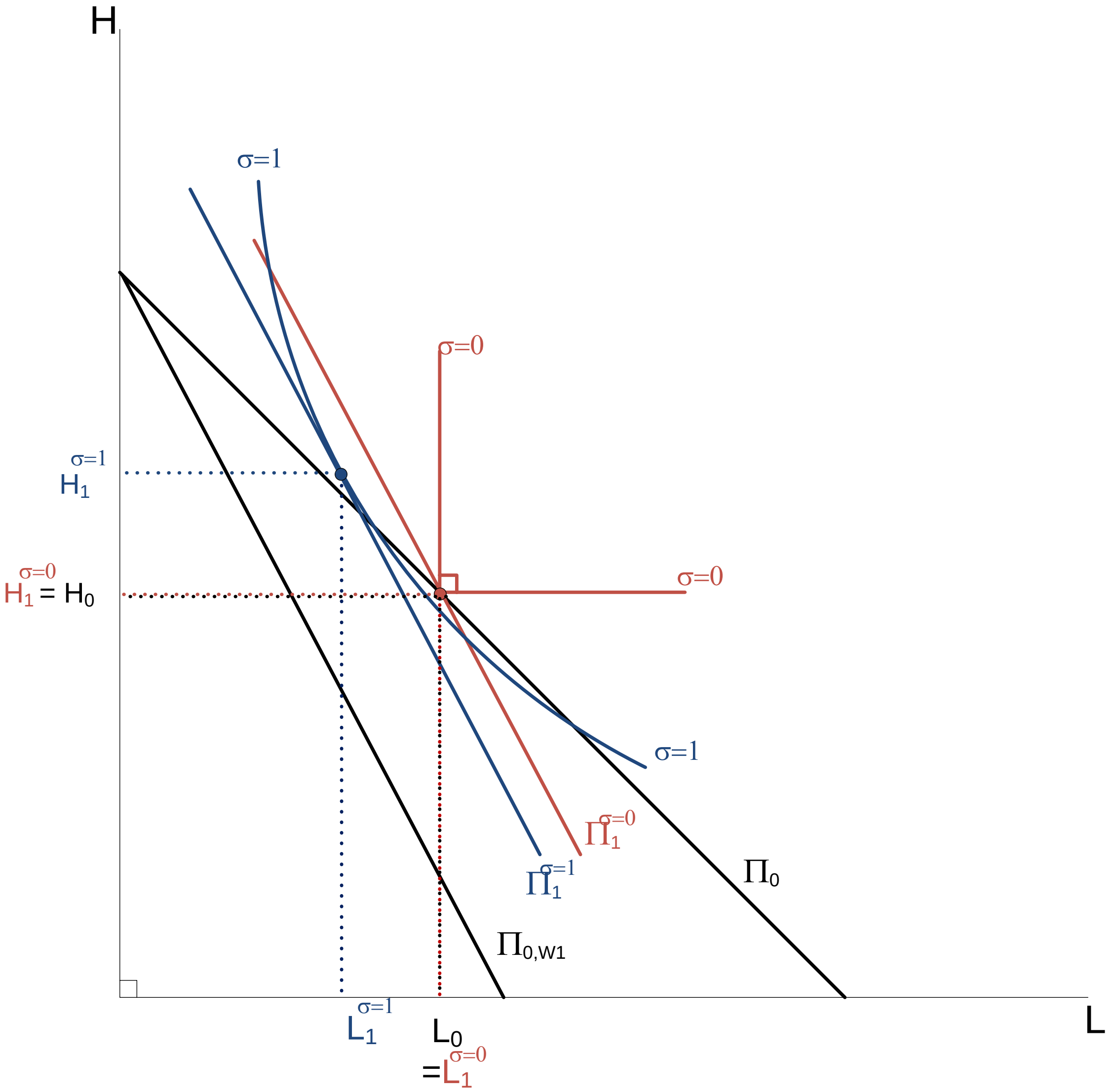


Figure 4.8 *The impact of regulations on DSI. Input factors L and H originally combine to use L_0, H_0 at the black cost curve Π_0. Unit cost of L then doubles, causing the cost curve to rotate around the H axis intercept. The new cost curve is $\Pi_{0,W1}$. Next, in order to maintain production, the cost curve has to shift outwards. In this situation, there is a moderate degree of substitution ($\sigma = 1$: the Cobb Douglas production function), so optimum input factor composition is $L_1^{\sigma=1}, H_0^{\sigma=1}$, as illustrated by the blue curves. This shifts the cost curve from $\Pi_{0,W1}$ to $\Pi_0^{\sigma=1}$. However, regulations requires the armed forces to use the same quantity of L, for example the number of officers, regardless of price. This in effect imposes an elasticity of substitution of $\sigma = 1$ (a Leontief production function), shifting the cost curve from $\Pi_0^{\sigma=1}$ to $\Pi_0^{\sigma=0}$, the red curves. This added cost increase from regulations can be interpreted as an efficiency loss. Figure from Gulichsen and Pedersen (2012).*

4.7 DSI 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 2015).

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 DSI, in that efficiency measures are not undertaken because nobody knows where they should be undertaken.

Politics influence DSI 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 DSI.

5 Review of empirical studies

5.1 Studies on the various reasons behind DSI

In this section, we review international and Norwegian studies on DSI and defence inflation. 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 DI in the 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).[15] The authors measure price growth within contracts, i.e. not including births and deaths of contracts. Thus, they measure an intragenerational inflation index, 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 (2016) compares the DI to the GDP deflator and finds that there is a great difference. Figure 5.1 summarizes the aggregate UK defence inflation 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. Using CPI as the base price index, the answer is somewhere in between. This emphasizes the importance of choosing a suitable base price index.

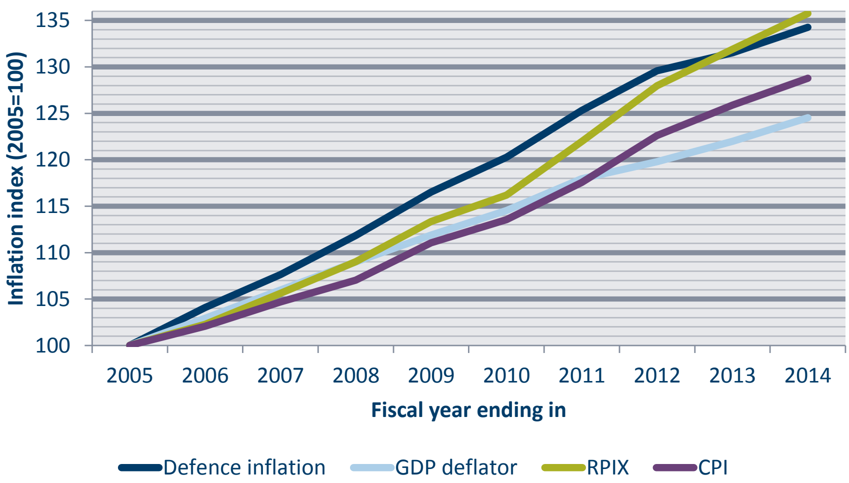
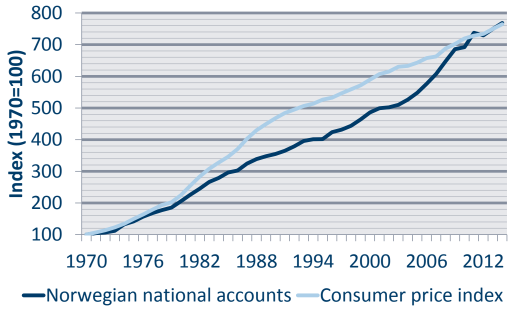


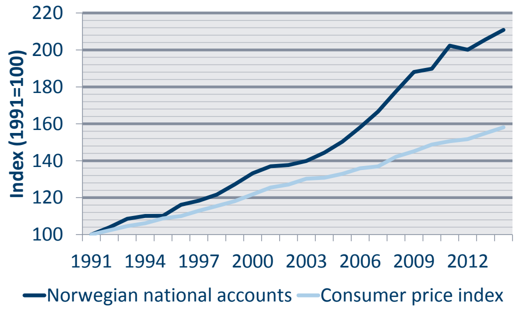
Figure 5.1 *UK Defence Inflation 2005–2014. Sources: Defence inflation: Hartley (2016), citing MoD (2014, 2015). CPI and RPIX: Office for National Statistics (2016a, 2016b). GDP deflator: HM Treasury (2016).*

[15]"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 national accounts data from 1970 (left) and from 1991 (right).[16] Overall, from 1970, there are no indications of defence specific inflation. From 1991, however, prices have risen nearly twice as fast in defence as CPI has risen.



1970–2014.



1991–2014.

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 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.[17] 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 CPI[18], though.

[16]Price 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 $p_{j,i} = p_{k,i} = p_i, \forall j, k$.

[17]The 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.

[18]Consumer Price Index – All Urban Consumers. `http://www.bls.gov/cpi/data.htm`.

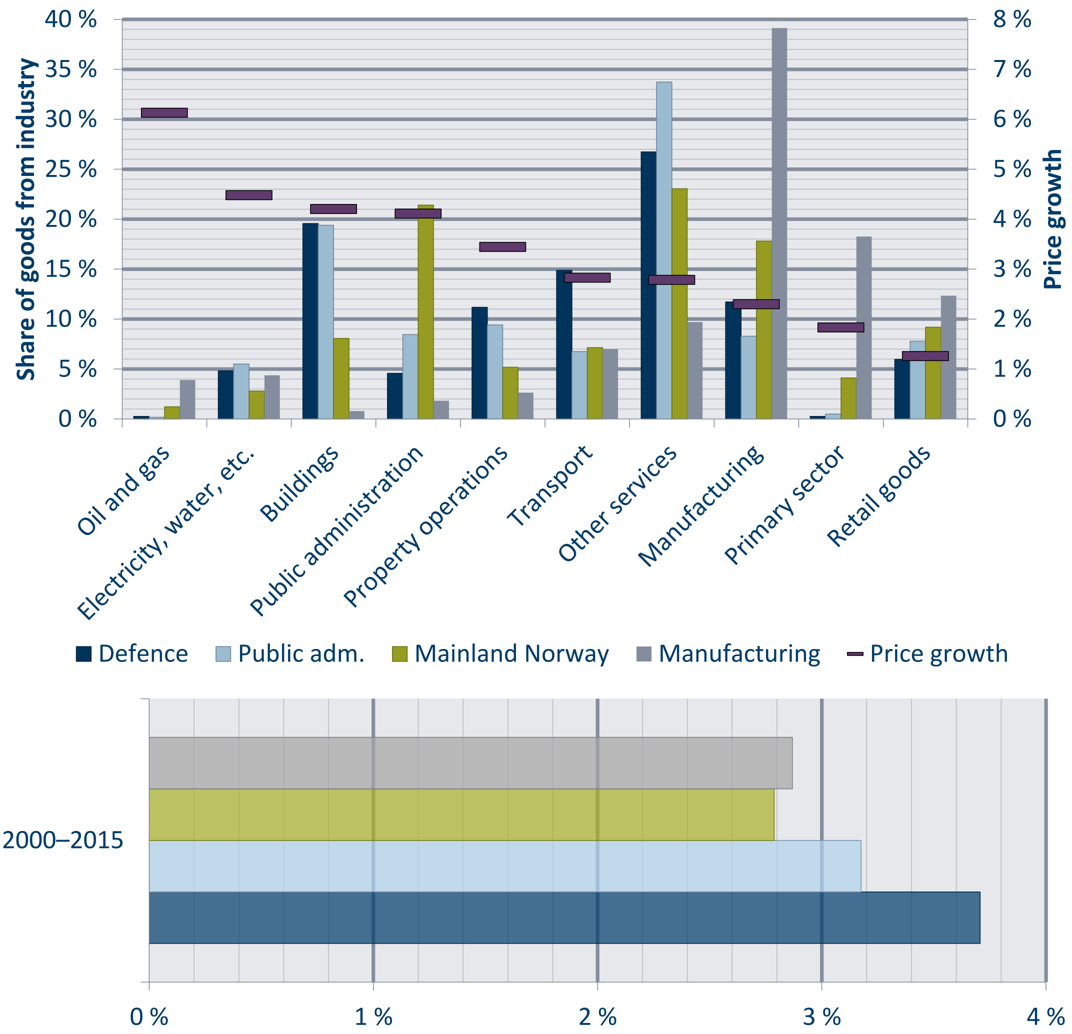


Figure 5.3 *Top part of figure: Share of intermediate consumption (left axis) originating from various industries for defence (dark blue columns), public administration (light blue columns), mainland Norway exclusive of public administration (green columns) and manufacturing (grey columns) 2010–2012. 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.*

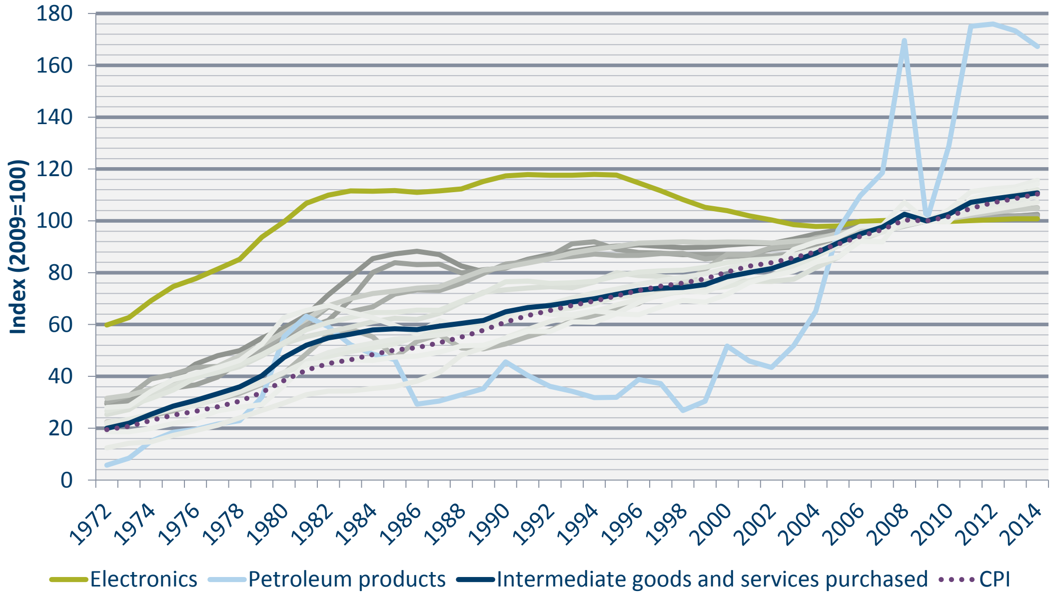


Figure 5.4 *Price indices for national defence components by type. Electronics and petroleum products are highlighted, as is the total price index for intermediate consumption. The other twelve sub indices are shown in greyscale. Indexed at 100 in 2009. Data from BEA (2015). Consumer Price Index – All 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 Todsen (2004) carried out research based on so-called quality-adjusted labour cost indices.[19] 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. 2015; Hove 2015), we expect a somewhat lower productivity growth than in the general economy. Also, Borge et al. (2015) find indications of Baumol's cost disease in the Norwegian Armed Forces.

[19] Quality-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 DSI. 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).[20] 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. US Air Force maintenance costs per flight hour typically grow about five per cent beyond economy-wide inflation (Keating and Arena 2016) and there was no correlation between age and costs. Dixon (2006) find maintenance cost increases at an annual rate of 3.5 per cent for aircraft six to 12 years old, but nearly unchanged rates for aircraft 12 to 25 years old.

CBO (2001) also addresses the issue of ageing in particular. The study cannot positively identify evidence for an effect of ageing on DSI, but stresses that the topic is complex and conclusions are difficult to reach. 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. Hildebrandt and Sze (1990), Levy (1991), Johnson (1993), Stoll and Davis (1993), Francis and Shaw (2000) and Pyles (2003) 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.
- To buy more of the current generation, i.e. substitute ageing F-16 with new F-16s. The risk is that the effectiveness of the system is reduced as adversaries increase their capabilities (see our discussion of relative effect in Hove and Lillekvelland 2016).
- 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.

Meyerhoefer and Trost (2006, p. 20) study fatigue and conclude that more research is needed to link fatigue forecasts to the age-related growth in operating and support costs. This is important

[20] In 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.

information, as it can be used to foresee large budgetary commitments and to early modify acquisition schedules or seek additional sources of funding.

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.

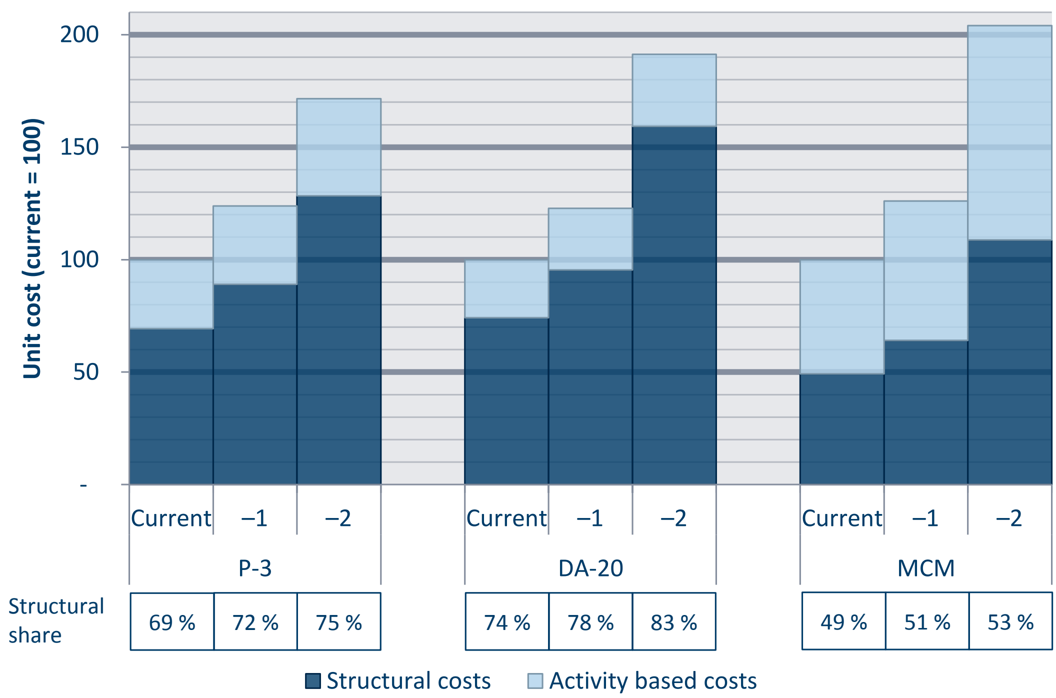


Figure 5.5 *Unit cost for the current number of P-3 MMA, DA-20 EW aircraft and MCM ships, and for a reduction of 1 or 2 units. Indexed at 100 for current number of units. Based on Krey and Presterud (2012). Structural shares of costs shown as per cent of total unit cost.*

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 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 FFI literature aimed at estimating total DSI of goods and services. With the exception of Kjernsbæk, Vamraak and Bruun (2005), all the reports aim to measure or estimate input based DSI. Gulichsen (2003) was the first report written independently on DSI, though the phenomenon was mentioned in previous works (for example Nesset and Wessel 1995). Gulichsen (2003) empirically estimates a DSI factor for personnel of 3.8 per cent and a DSI factor for goods and services of 2.1 per cent. The report recommends a DSI factor for personnel to be used in long term planning to be set at 2.45 per cent and the DSI 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 DSI is not strictly DSI, as it is not measured per unit. Goods and services DSI 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 DSI was about 3.75 per year above inflation in the period 1994–2002. These numbers were, not surprising, considering the activity level adjustment, higher the 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 DSI 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–MVT)) per cent. Combined with a conscript DSI of 5.1 per cent, the overall personnel DSI is estimated at 4.5 per cent. For goods and services, they built on the work of Kjernsbæk, Vamraak and Bruun (2005), producing an estimate of 2.4 per cent. However, Johansen and Berg-Knutsen (2006) also attempted going one step further, not only measuring historical DSI, but also providing arguments concerning future DSI. Figure 5.6 outlines the prospected future DSI of Johansen and Berg-Knutsen (2006). Johansen and Berg-Knutsen use annual defence accounts to categorize previous expenditures into three categories causing DSI:

- 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 by wage growth.

Johansen and Berg-Knutsen found shares of 37, 40 and 23 per cent respectively. As Johansen and Berg-Knutsen define DSI as being growth beyond CPI, the contribution of CPI on DSI 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-Knutsen use 3 per cent inflation 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 DSI per unit of input, this is not relevant in our case. In a steady state situation, Johansen and Berg-Knutsen argue that the activity level and defence structure does not contribute to DSI. In sum, a future DSI 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 DSI by emphasizing the DSI 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 inflation of personnel.

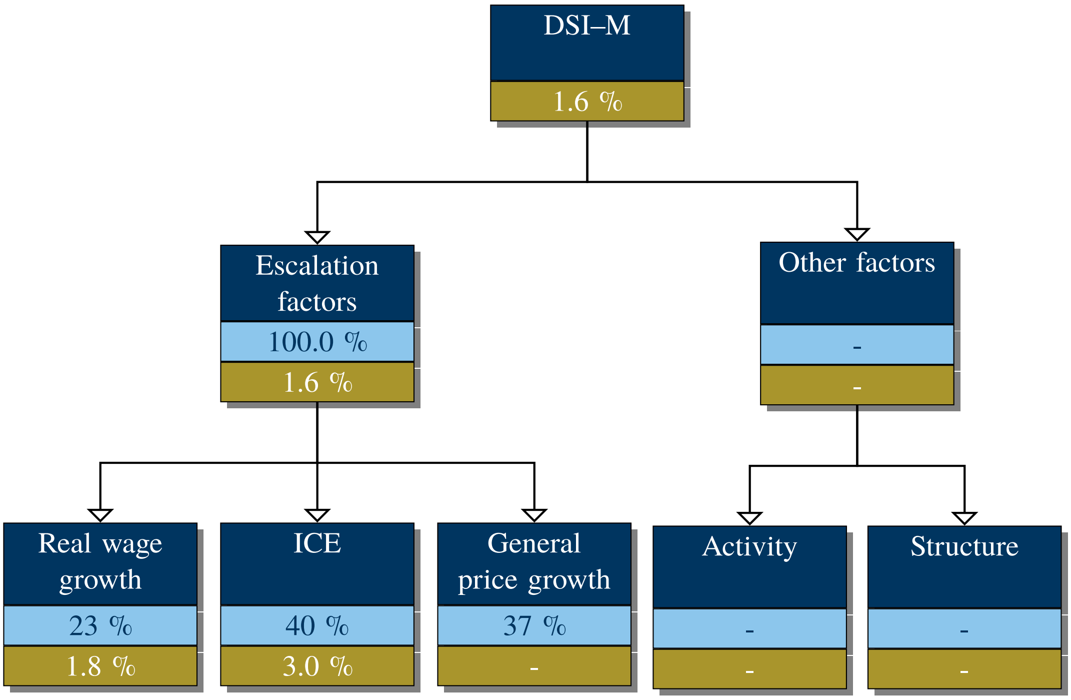


Figure 5.6 *Underlying drivers behind DSI of goods and services, including shares and annual growth (Johansen and Berg-Knutsen 2006).*

6 Estimates of DSI using activity as output

In previous chapters, we described why DSI exists and outlined existing research on DSI. In this chapter, we estimate historical DSI, 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 DSI, meaning that in light of Figure 3.1, we estimate DSI–M–M. This number should be viewed as a long-term average output DSI. As Figure 3.5 illustrated, the total DSI trend does not need to follow the intragenerational DSI trend, and will therefore not be precise when used on short time horizons.

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 DSI on goods and services. 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 goods and services required to operate one unit of a weapon system is not possible with the current Norwegian Armed Forces accounting system. The amount of goods and services 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 goods and services, $G_{t,i}$, needed to operate unit i at time t is:

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

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

The costs of operating unit i at time t, will be the vector of goods and services 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:

$$C_{t,i} = \bar{P_t}^T \bar{G_{t,i}} = \bar{P_t}^T \bar{Y}(a_{t,i}, e_{t,i}) \tag{6.2}$$

which is simply the sum of need for each type of good or service times the price of that good or service.

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

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

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 goods and services. 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 goods and services 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 goods and services 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

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

where $\bar{V}_i$ is the amount of each good or service required to produce one unit of activity, and $\bar{S}_i$ is the amount of each good and service required that is independent on activity. (6.4) means that the required amount of goods and services required to operate system i (by assumption) is linearly dependent on activity. Activity is the only reason for changed needs of goods and services, 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:

$$C_{t,i} = p_t v_i a_{t,i} + p_t' s_i \tag{6.5}$$

First consider total structural costs:

$$T_{t,s} = p_t' \sum_{\forall i} s_i \tag{6.6}$$

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

$$\frac{T_{t,s}}{T_{t-1,s}} = \frac{p_t' \sum_{\forall i} s_i}{p_{t-1}' \sum_{\forall i} s_i} = r' \tag{6.7}$$

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

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

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

Which means that activity based costs change at a constant rate, r, times the change in total activity weighted by the volume of goods and services required to produce each type of activity. There are two possible routes to estimate the average growth in activity related 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 method[21]. In Section 6.3, the results from both methods are presented.

[21] The maximum likelihood method is an estimation method that allow for nonlinear relationships.

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	21	1,069,229	205,532	756,306	1,461,366	1000 2015-NOK
Activity related costs	21	3,482,845	762,753	2,193,466	4,665,435	1000 2015-NOK
EW plane	20	1,094	301	594	1,687	Hours
Frigate	20	7,062	1,420	4,542	9,557	Days
Helicopter	20	10,041	1,164	8,721	13,096	Hours
Army exercise	20	120,806	29,222	65,348	181,401	Days
Fighter aircraft	20	10,498	2,042	7,846	15,839	Hours
Coast guard	20	4,758	1,064	3,487	7,372	Days
MPA	20	2,328	405	1,752	3,463	Days
Logistics vessel	20	7,211	2,379	3,720	11,129	Days
MCM	20	10,378	3,128	5,578	15,392	Days
FAC	20	4,660	2,912	0	12,972	Days
Transport aircraft	20	2,448	1,299	500	4,893	Hours
Submarine	20	9,173	2,641	5,160	12,874	Days

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. We have only included costs 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).[22] In total this includes a little more than half the Armed Forces' goods and service expenses. All costs are in 2015 NOK.

We only use costs related to goods and services, i.e. not investment costs, wages or property costs. Throughout the period, costs related to goods and services have had its own accounts, and aggregated costs are simple to collect.

Separating activity related costs and structural costs are more challenging. 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 categorized as activity based. We have chosen to categorize all maintenance costs as activity based costs. Some maintenance is dependent on activity,

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

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. The total expenditure in each category can be seen in Figure 6.1. 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).

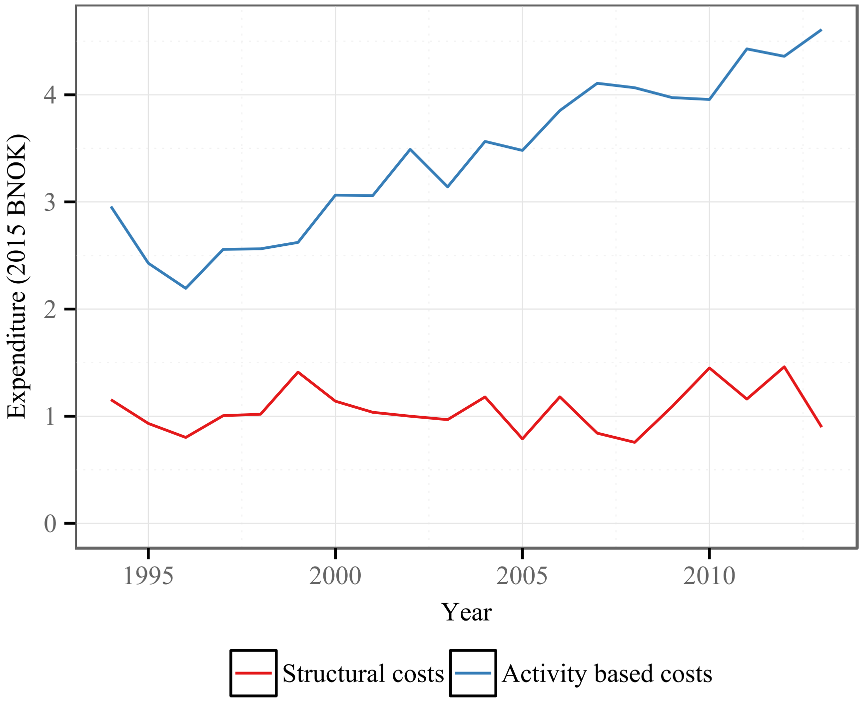


Figure 6.1 *Cost categories.*

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, 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.

Aggregate weighted activity ($\sum_{\forall i} v_i a_{t,i}$ in (6.8)) is calculated by weighting the different types of activity by their cost. Cost per unit of activity was calculated by Kjernsbæk, Vamraak and Bruun (2005), using 2002 data. As 2002 is near the middle of the dataset, we use the same weights as Kjernsbæk, Vamraak and Bruun (2005). The activity measures are first weighted together within each branch by the costs of activity for each weapon system. Second, the aggregate activity for each branch is weighted together by the total activity related costs for each branch, found in Section 6.2.1.

The activity weights can be found in Table 6.5. The aggregate activity can be seen in Figure 6.2.

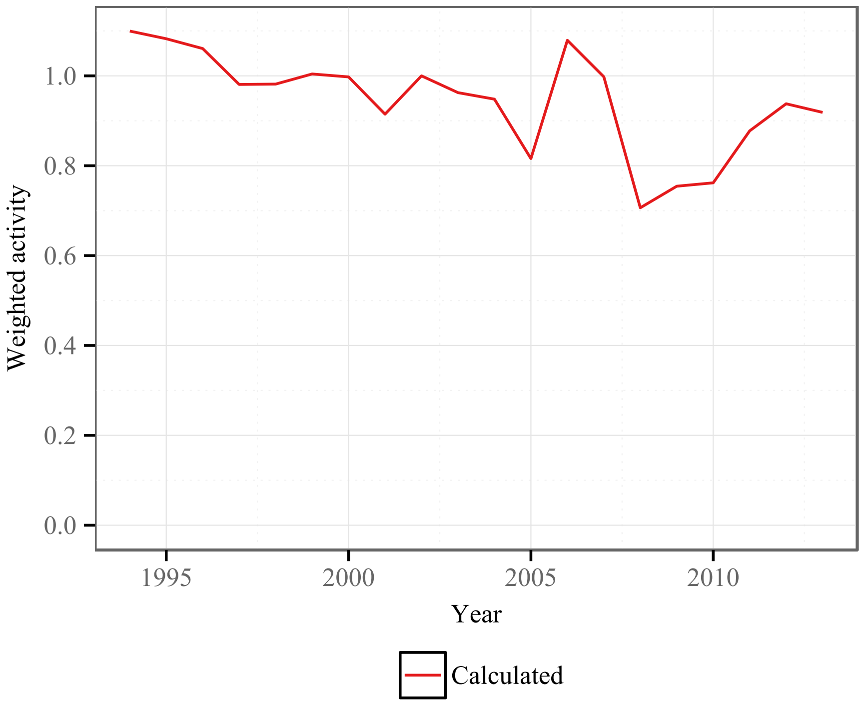


Figure 6.2 *Weighted total activity.*

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 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 DSI, given constant activity levels.

6.3 Results

6.3.1 DSI based on calculated weights

As stated in Section 6.1, the average DSI can be calculated using (6.9) and the weighted activity found in Section 6.2.2. The results are reported in Table 6.2.

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

Table 6.2 *Estimates of DSI. DSI for activity based costs calculated based on calculated activity weights.*

Column DSI is the mean DSI, 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 conventional significance level, meaning that we cannot conclude with certainty that the DSI rate is positive. As the data set is quite small, this is not surprising. The average activity based DSI is quite high, about 4 percentage points above CPI, while DSI on structural costs are somewhat lower, about 2 percentage points above CPI. As there is one DSI estimate for structural costs and one DSI estimate for activity based costs, it is not straight forward to compare the results to previous results. Kjernsbæk, Vamraak and Bruun (2005) found an total DSI of about 3 per cent, while Johansen and Berg-Knutsen (2006) found an total DSI on 2,4 per cent. This is between the average DSI on structural costs and activity based costs, indicating that the results are quite similar. As the method and data used by Kjernsbæk, 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.[23] As there are an infinite number of solutions to the minimization problem, the weight of fighter aircraft is forced to 1.[24] The results from the regression are reported in Table 6.3.

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 changed prioritization between weapon systems (negative correlation).

[23] We used (6.9) in log form in our estimation.

[24] From (6.9), if $v_i = \gamma h_i$, where $\gamma \neq 0$, then $r\frac{\sum_{\forall i} v_i a_{t,i}}{\sum_{\forall i} v_i a_{t-1,i}} = r\frac{\sum_{\forall i} \gamma h_i a_{t,i}}{\sum_{\forall i} \gamma h_i a_{t-1,i}} = r\frac{\sum_{\forall i} h_i a_{t,i}}{\sum_{\forall i} h_i a_{t-1,i}}$, 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)
DSI	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 6.3 *Estimates of DSI based on estimated activity and estimated activity weights for each weapon system.*

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.[25] 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 6.4.

	Estimate	Std. Error	z value	Pr(z)
DSI	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 6.4 *Model selected using AIC.*

Although the number of parameters is a lot fewer in Table 6.4, the DSI estimate remains fairly stable, and well within the standard error. 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. There are no signs of autocorrelation in the residuals.

Table 6.5 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 in Figure 6.3 are quite similar. *Calculated* is aggregated activity using the calculated weights, while *estimated*

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

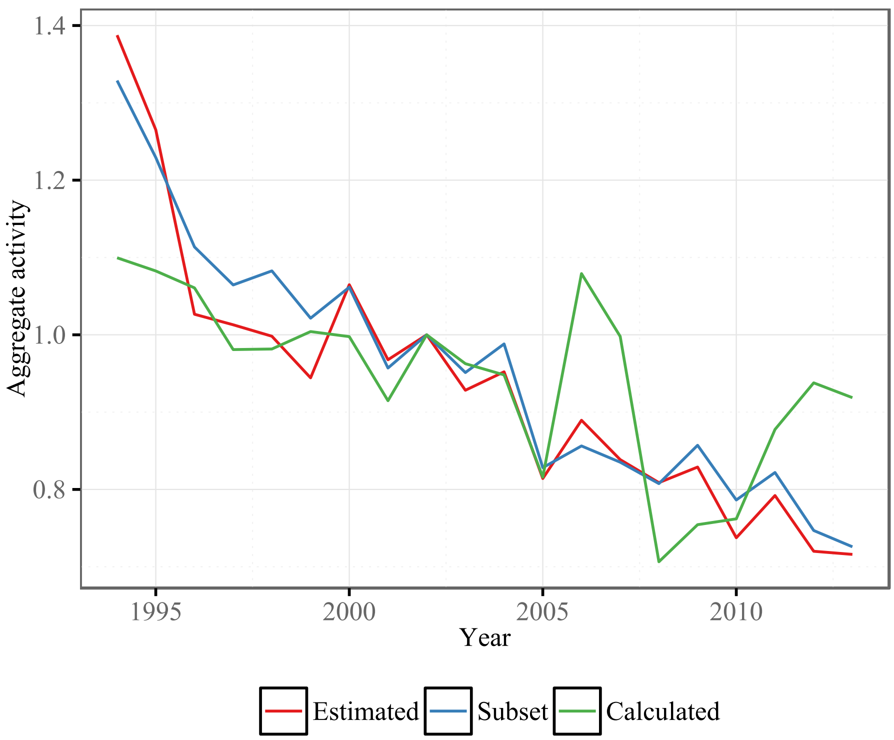


Figure 6.3 *Aggregate activity using three different aggregation results.*

and *subset* is the aggregated activity using the full dataset and the 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.

	Calculated	Estimated	Subset
EW plane	5.324	-4.526	
Frigate	1.131	0.750	0.830
Helicopter	0.537	0.554	
Days of exercise	0.166		
Fighter aircraft	1.000	1.000	1.000
Coast guard	1.689	-0.185	
MPA	5.351	5.061	6.980
Logistics vessel	0.225	0.716	1.456
MCM	0.186	-0.650	
FAC	2.195	0.222	
Transport aircraft	3.366	-0.261	
Treningsfly	1.602		
Submarine	0.112	0.805	
Man years Army		-1.927	

Table 6.5 *Estimated and calculated weights. Rescaled such that fighter aircraft equals* 1.

The DSI rate on activity based costs in the different approaches varies from about 4 to 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 Kjernsbæk, Vamraak and Bruun (2005). Keating, Boito and Woods (2015) finds that maintenance costs in the US Air force grows at roughly five per cent annually (cited in Keating and Arena 2016).

Although results that are similar to the ones we find exist, we suspect that we overestimate DSI on activity based costs. In other words, we expect DSI to be somewhat lower than six per cent. This overestimation is likely to occur because of imperfect separation of activity based 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 DSI on structural costs. A further discussion and formal explanation of this subject can be found in Appendix A.

Substitution between goods and services and personnel might lead to further bias in our estimates (see Section 3.5). 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 DSI, since the reduction in personnel costs is omitted from the dataset. This will lead to further overestimation of DSI. 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 2015), 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 DSI 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 DSI. Parts of the organization with high share of activity based costs are expected to have higher total DSI than parts of the organization with less activity based costs. Figure 6.4 shows the share of activity related costs for each of the cost chapters 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 DSI not only depends on the share of activity related costs, but also on the size of the branch. The consequence of a high DSI is small if the initial monetary size is small, while the consequence of even a small DSI rate on a large monetary size might be huge. For example, an annual DSI rate of one per cent results in a 22 per cent increase in costs over 20 years.

Figure 6.5 shows the size and estimated DSI of each branch in the Norwegian Armed Forces. The further up and to the right a cost chapter is, the greater the consequence of DSI. The curved lines show combinations of expenses and DSI 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

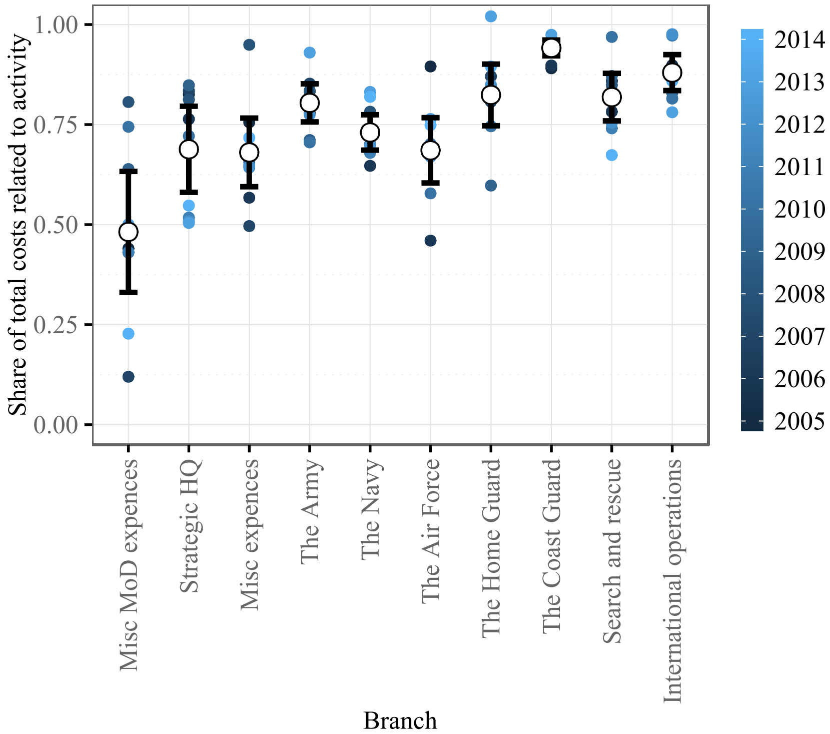


Figure 6.4 *The figure shows activity shares in each branch with mean and 95 % confidence interval of mean.*

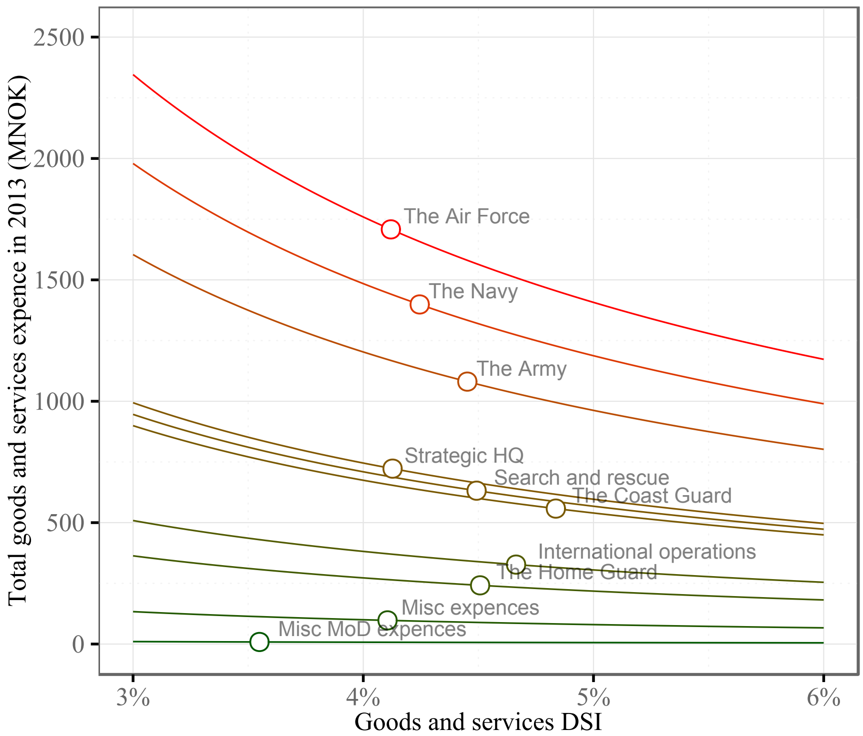


Figure 6.5 *Impact from DSI in each branch.*

has the highest DSI rate, but the size of expenses in the Coast Guard is too low for the DSI from the Coast Guard to make a significant impact.

6.4 Summary of the empirical analysis

In this chapter the DSI rate has been estimated using two different approaches. DSI on structural costs are estimated to be about two per cent, while DSI on activity based costs vary from about four per cent to about six per cent, depending on estimation strategy. The difference between DSI 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 DSI 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 estimates, we suspect that the DSI rates we find might be higher than the true rates. This makes it difficult to conclude with one single DSI estimate. Further, our estimation assumes a common DSI 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 DSI rates found in this report only provide a historic picture. Whether the DSI 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 DSI as being the part of defence inflation that exceeds general inflation. We have shown how it can be useful to distinguish between intra- and intergenerational DSI, 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 DSI.

Various Norwegian and international studies have estimated DSI, using a variety of methods. In this report, we have attempted to measure DSI 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 DSI. We estimate a DSI of structural costs of about two percent and an output DSI 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 DSI. However, the estimated DSI is so large we do not doubt that it is positive.

7.2 Implications for long term defence planning

If DSI 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 using DSI factors in long term defence planning. After 20 years, an annual DSI of three per cent will result in an 80 per cent cost increase. If this DSI 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 DSI:

- 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 DSI through other channels.

7.3 Countering DSI

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

- 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 DSI?
- 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. Of course, this would reduce the benefit of the helicopter for each country, but the question is if the reduced benefit is outweighed by the reduced cost.
- A stronger link between investment and operations. 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

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

- Measure input and output DSI, not just for goods and services, but also for others factors of production (as illustrated in fig. 3.1). For our next studies, we plan to discuss DSI of personnel, both wages and personnel related goods and services.
- Conduct more detailed studies of the causes of DSI. In this report, we present a very aggregate analysis. We cannot quantify which of the factors from Chapter 4 have the strongest influence on DSI. Smaller, case based, studies can shed further light on this issue. Such studies can also result in DSI 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.
- Develop a further understanding of the annual budgetary technical price and wage compensation (see Chapter 2), both how it is calculated and as a basis for a discussion of what should be compensated.

Abbreviations

AIC	Akaike information criterion
APUC	Average procurement unit cost
BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
B&P	Buildings and property
C4ISR	Command, control, communications, computers, intelligence, surveillance and reconnaissance
CE	Cost escalation
CPI	Consumer price index
DAP	Defense Acquisition Portal
DAU	Defense Acquisition University
DI	Defence inflation
DSI	Defence specific inflation
DSI–M	DSI – Goods and services
DSI–M–M	DSI – Goods and services – exclusive of B&P
DSI–M–B&P	DSI – Goods and services – B&P
DSI–P	DSI – Personnel
DSI–P–W	DSI – Personnel – Wages
DSI–P–M	DSI – Personnel related goods and services
ECO	Evolution of costs
ECO–DEF	Evolution of costs of defence
EW	Electronic warfare
FAC	Flyaway cost
FAC	Fast attack craft
FFI	Norwegian Defence Research Establishment
FH	Flight hour
FLO	Norwegian Defence Logistics Organization
FY	Fiscal year
GDP	Gross domestic product
Green Book	National Defense Budget Estimates
ICE	Investment cost escalation
Intra DSI–M–M	Intragenerational DSI–M–M
Inter DSI–M–M	Intergenerational DSI–M–M

Intra ICE	Intragenerational ICE
Inter ICE	Intergenerational ICE
ISR	Intelligence, surveillance and reconnaissance
JSF	Joint Strike Fighter
LCC	Life cycle cost
M	Goods and services
MCM	Mine countermeasure
MILCON	Military construction
MMA	Multimission maritime aircraft
MoD	Ministry of Defence
MPA	Maritime patrol aircraft
NEC	Network enabled capability
NOK	Norwegian Kroner
O&M	Operation and maintenance
ONS	Office for National Statistics
O&S	Operation and support
OSD	Office of the Secretary of Defense
P	Personnel
PAUC	Program acquisition unit cost
P–MVT	Personnel driven goods and services
POGO	Project On Government Oversight
PPI	Producer Price Index
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

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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 from form:

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

Where $\tilde{a}_t = \sum_{\forall i} v_i a_{t,i}$, 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:

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

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. 6.2).[26] 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.

[26] If 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.

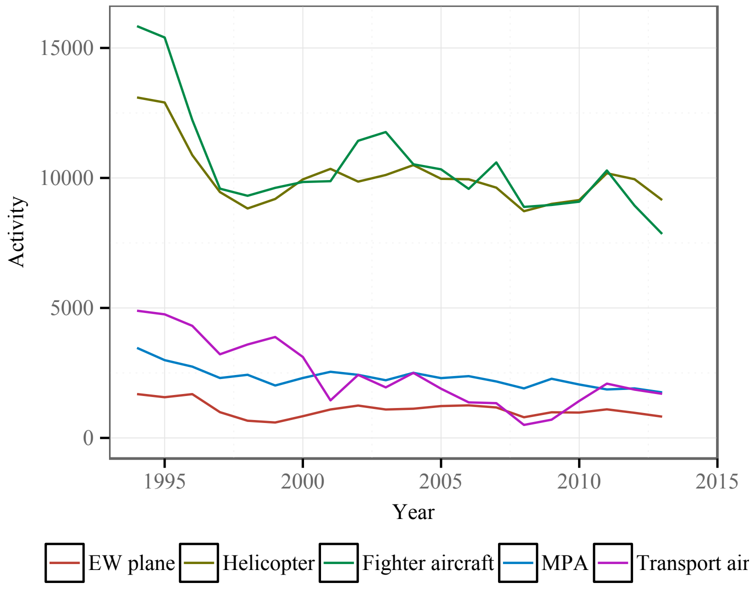


Figure B.1 *Activity in the Air Force.*

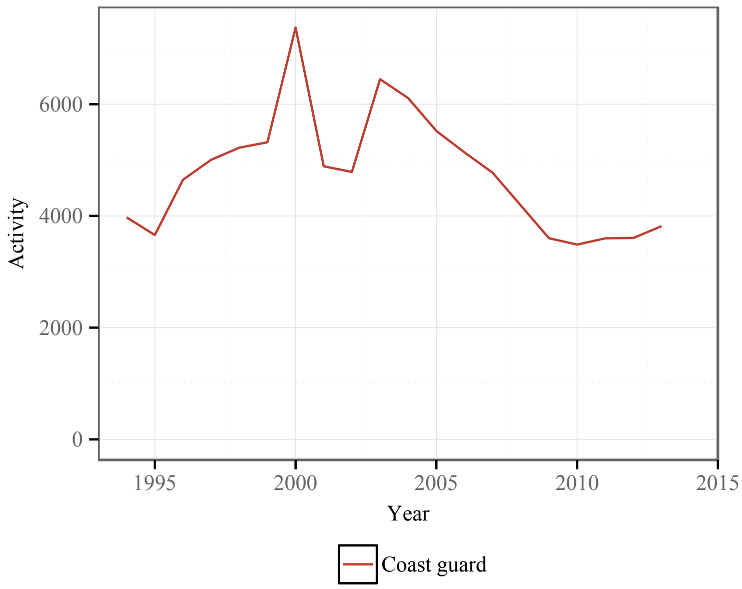


Figure B.2 *Activity in the Coast Guard.*

Table B.1 show the activity correlation matrix. As can be seen, the different activity measures

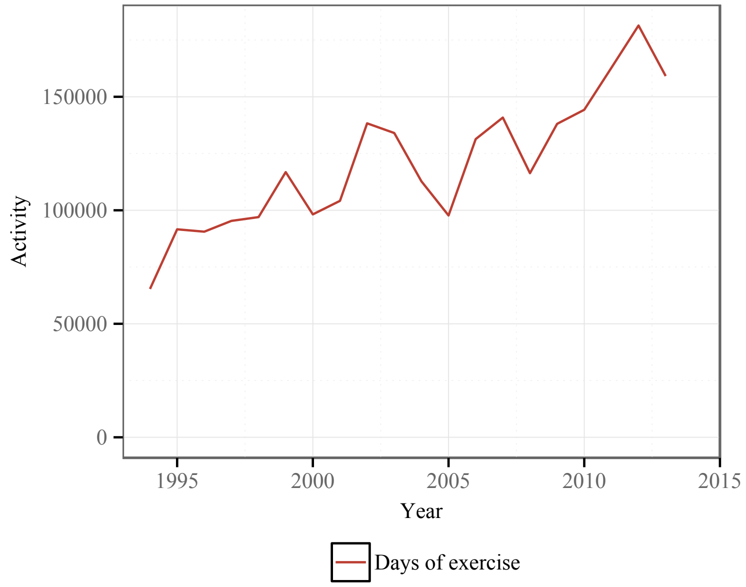


Figure B.3 *Activity in the Army.*

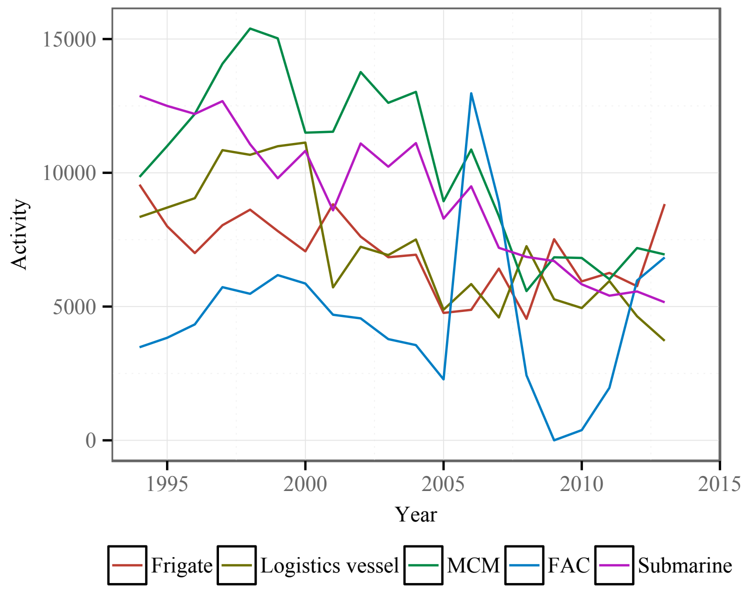


Figure B.4 *Activity in the Navy.*

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	0.653	−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.[27]

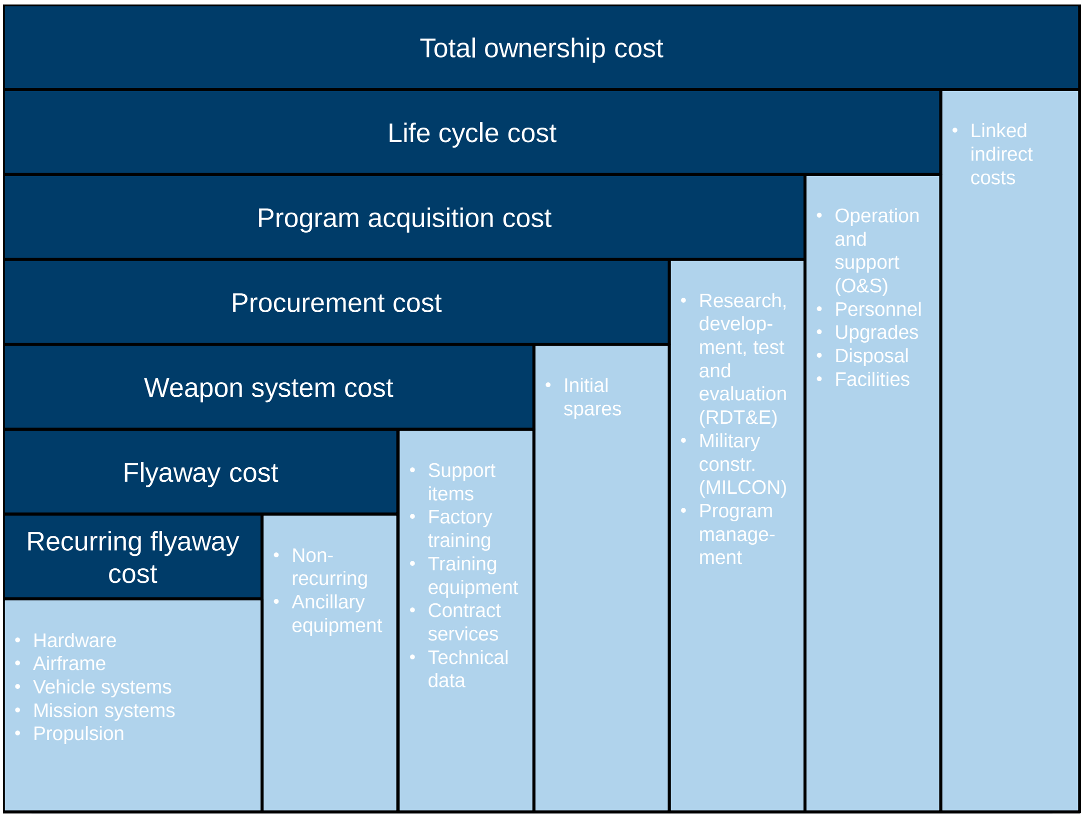


Figure C.1 *Illustration of various definitions of cost. See associated list for more details.*

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

[27] Our 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.

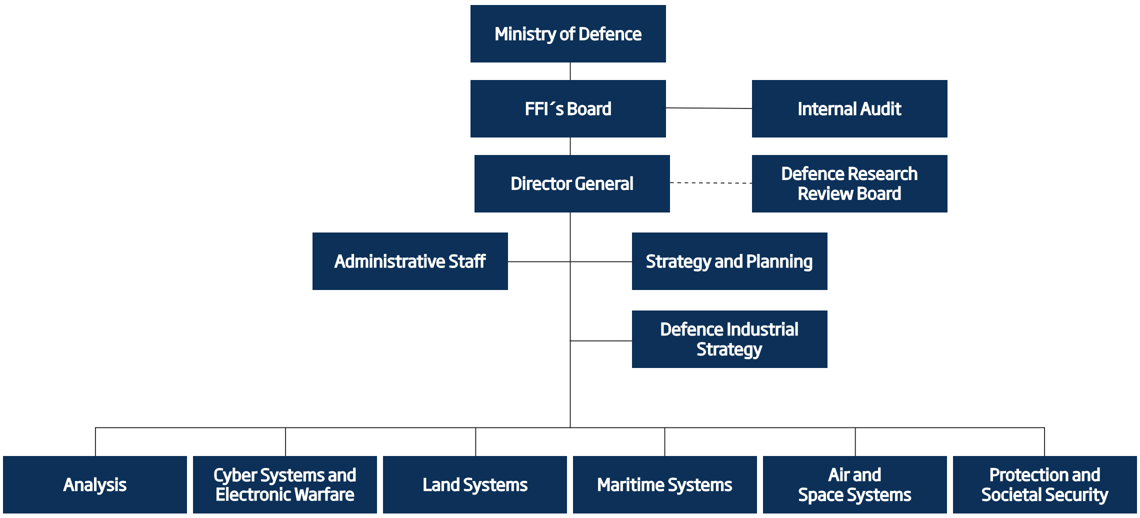
FFIs VISJON

FFI gjør kunnskap og ideer til et effektivt forsvar.

FFIs VERDIER

Skapende, drivende, vidsynt og ansvarlig.

FFI's organisation



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