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Inflation Adjustments for Defense Acquisition

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Executive Summary

This paper discusses an analysis of cost indexes carried out by the Institute for Defense Analyses (IDA) for the Cost Assessment and Program Evaluation (CAPE) directorate in the Office of the Secretary of Defense (OSD). The research is designed to help CAPE meet the task it was given by the 2009 Weapon Systems Acquisition Reform Act (WSARA), now part of Public Law 111-23, of assessing and updating the cost indexes that the Department of Defense (DoD) employs to ensure the use of realistic cost estimates. The paper addresses three questions:

- What problems are inflation adjustments meant to solve in DoD?

- How well do current indexes solve them?

- Are there other indexes that might do a better job?

The focus of the study is on aircraft procurement.

By way of terminology, "cost index," "price index," and "deflator" are used interchangeably in this paper, as are "cost growth" and "price growth." "Real" cost is used in more than one sense, as described in the table below.

Problems Inflation Adjustments are Meant to Solve

DoD uses price indexes and growth rates for project management and oversight. The table on page v provides a brief summary of the subject area; the bottom row lists the various management activities in which indexes and growth rates are employed:

- DoD program offices estimate the future prices of weapon systems in then-year dollars for purposes of budgeting individual aircraft acquisition programs.

- Program offices and congressional committees are also interested in the real cost growth of such programs.

- The Office of Management and Budget (OMB) focuses on the burden of the defense procurement budget (or portions thereof) on the economy.

- DoD leadership is concerned with how much the procurement cost of the defense budget (or portions thereof) would have risen for the same systems without quality improvements.

The remainder of the table describes the price and spending changes of interest in these activities and the sources of the changes that are involved. It also describes how price indexes are used to isolate the factors of interest.

Using aircraft procurement for illustration, the first column of colored cells indicates that the growth in then-year prices of interest to program offices includes price growth due to all the reasons for price change listed in the left-most column.

- The *costs of inputs* are measured by (a) the general inflation of the US market basket of goods and services, and (b) the increase in relative prices, beyond general inflation, of the labor, material, and capital inputs that are specific to the aircraft's production.

- *How aircraft are produced* is described by the production-related factors of labor and capital productivity, including movements along learning curves (declining cost as contractors learn more efficient production techniques) and effects related to the level of production in particular years (rate effects).

- The *economic context* of production is described by industry-related factors describing the changes in the market demand and supply of aircraft that affect producer selling prices and profits.

- *The characteristics of what is produced*, often referred to as "quality" changes, refers to the improvements in the aircraft's physical and operational specifications, such as its weight and speed (a proxy for payload), that affect its ability to perform the missions for which it is designed.

In budgeting, program offices must allow for the full expected price of their systems, including all reasons for price change. In calculating how much the real prices of their systems have changed, however, the focus of program offices and other concerned organizations is different. Now they want to capture all reasons for price increases except for general inflation. To do this, total price change is divided by a deflator reflecting the level of general inflation.

Content and Use of Inflation Adjustments

Reasons for Price Changes	Growth in price for a particular system	Growth in price for a particular system relative to general inflation	Growth in spending for a class of items relative to general inflation	Growth in spending for a class of items, adjusting for DOD's quality-constant price changes
General inflation	(green)	(blue)	(blue)	(blue)
Relative inflation of inputs	(green)	(green)	(green)	(blue)
Production-related factors	(green)	(green)	(green)	(blue)
Industry-related factors	(green)	(green)	(green)	(blue)
Quality changes	(green)	(green)	(green)	(green)
Basis of comparison	Average price	Average price	Total spending (price*quantity)	Total spending (price*quantity)
Use of Adjustment/ User	Prepare budget/ Program office	Measure real cost growth/ Program office, Congress, OSD	Measure real burden to the economy/OMB	Measure real quantity of defense-related goods purchased/ DoD leadership

(green) Reason for price change included in metric of interest (not included in adjusting deflator)

(blue) Reason for price change included in adjusting deflator (not included in metric of interest)

OMB currently mandates that DoD use the GDP deflator for calculating real prices. The real price growth referred to in the second column is used in Nunn-McCurdy analyses to identify individual weapon acquisition programs that have had significant cost growth and thus require management attention.[1] Management attention is indicated when a system's constant-dollar price during procurement exceeds the price estimate developed during an initial baseline by a congressionally-set percentage.

In the third column, total spending rather than average price is deflated by general inflation. The purpose here is to gain insight into the real burden of a portion (or all) of defense spending on the economy. All-DoD changes in spending deflated in this way are sometimes referred to as real growth in defense spending. As indicated by the green shading, this measure of real growth includes price increases due to changes in the prices of inputs to defense production that differ from the general level of inflation, changes in production-related factors, and changes in industry-related factors in addition to costs associated with changing quality. The first three of these factors provide nothing of value to DoD and, thus, contribute nothing to real defense capability from the Department's point of view. The measure might better be called real growth in the cost of defense.

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[1] Constant dollar affordability caps are now also used in mandatory Affordability Analyses at Milestones B and C.

The last column describes a measure of how much more valuable a portion (or all) of defense spending is to DoD. It includes increases in spending due to the purchase of both <u>more</u> items and <u>higher quality</u> items. To calculate this measure, total spending must be deflated by an index that captures all the reasons for price increases except for quality improvements. This is also called *real growth*, but in this case it better reflects products bought rather than resources used. The resulting measure might be termed real growth in defense program content, or real defense program growth.

If nominal prices for defense purchases have risen by more than general inflation for reasons other than quality improvements, deflating expenditures with a general inflation index will overstate real defense program growth.

Assessment of Current Indexes

The figure on page vii compares four price indexes related to or often used for aircraft procurement:

- The GDP deflator published by BEA, which OMB has mandated that DoD use for calculating constant-dollar budgets

- The National Defense deflator for military aircraft published by the Bureau of Economic Analysis (BEA) and referred to in this study as the BEA index

- The Producer Price Index (PPI) published by the Bureau of Labor Statistics (BLS) for the civilian aircraft procurement industry

- The index of Navy aircraft flyaway costs[2] developed by the Naval Air Systems Command (NAVAIR) and described in IDA Paper P-4707.[3] The NAVAIR index was included only for comparison, and was not analyzed in any depth except to note that it rose slightly more than the GDP deflator.

One goal of this research was to understand the source of the zero (slightly negative) growth rate of the BEA index. This growth rate is inconsistent with that of the BLS deflator and with the perception of DoD budget analysts that prices of military aircraft (even adjusted for quality improvements) have grown by several percent annually over recent years. Military and civilian aircraft are substantially different, of course, but they are similar enough to raise the question of why their growth rates should be so different.

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[2] Flyaway cost, as defined in P-5 Cost Analysis exhibits, is the sum of recurring and non-recurring procurement cost net of support. Recurring cost, by far the major component of total flyaway, is the sum of airframe (contractor furnished), electronics (contractor and government furnished), engines and engine accessories, armament, other government furnished equipment, and engineering change orders.

[3] NAVAIR uses Global Insight estimates for labor and material cost increases to estimate indexes for airframe, engine, and electronics that are combined into an index of flyaway cost for fixed-wing naval aircraft; Stanley A. Horowitz et al., "The Use of Inflation Indexes in the Department of Defense," IDA Paper P-4707 (Alexandria, VA: Institute for Defense Analyses, May 2012).

(The difference with the GDP deflator is not puzzling, since military aircraft are a negligible subset of the entire US market basket, and there is no reason why military aircraft prices should behave like the average of all prices.)

Examination of the different deflator algorithms used by BEA and BLS failed to determine a definitive explanation for the BEA's lower growth rate.

Inspection of the deflator algorithms shows that too low a growth rate would result from overestimating the quality change of new-design aircraft. BEA analysts find that estimating the cost of quality change in a radically new-design aircraft such as the F-35 over the F-15 is difficult as a practical matter, and they instead use the full price difference reduced by the degree of anticipated learning. Underestimating the learning adjustment would lead to overestimating the cost of quality change, leaving less of the price increase remaining for attribution to the growth of other factors that are captured by the price deflator. However, we lacked access to the BEA and BLS data needed to definitively resolve the issue.
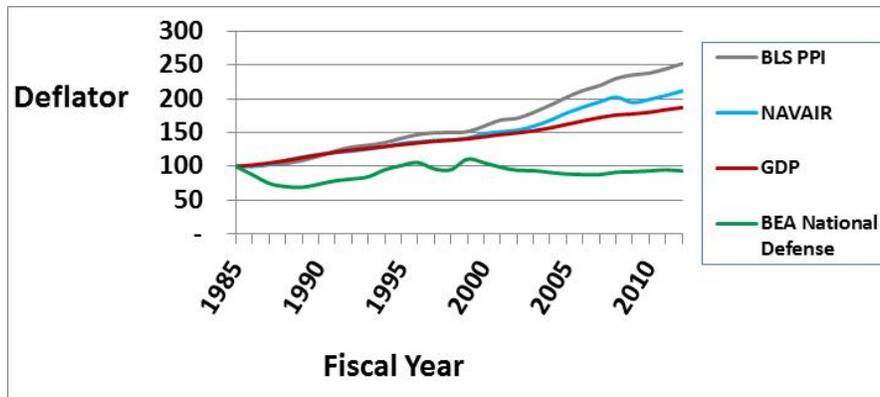
Deflators Commonly Used in Aircraft Analysis

Updated Indexes

The search for improved price indexes led to the consideration of hedonic methods, which are based on the system's characteristics rather than the cost of components. The current BEA index, for example, is based on the production costs of the aircraft's flyaway components—the airframe, propulsion, avionics, armaments, integration, and engineering change orders. A hedonic price index, by comparison, would be based on the aircraft's "quality" variables—its physical and operational characteristics such as weight (a proxy for payload) and speed. Statistical regression analysis would be used to relate the aircraft's system cost in nominal dollars to the quality variables and the year of production. The regression coefficients of production year would be used to calculate the
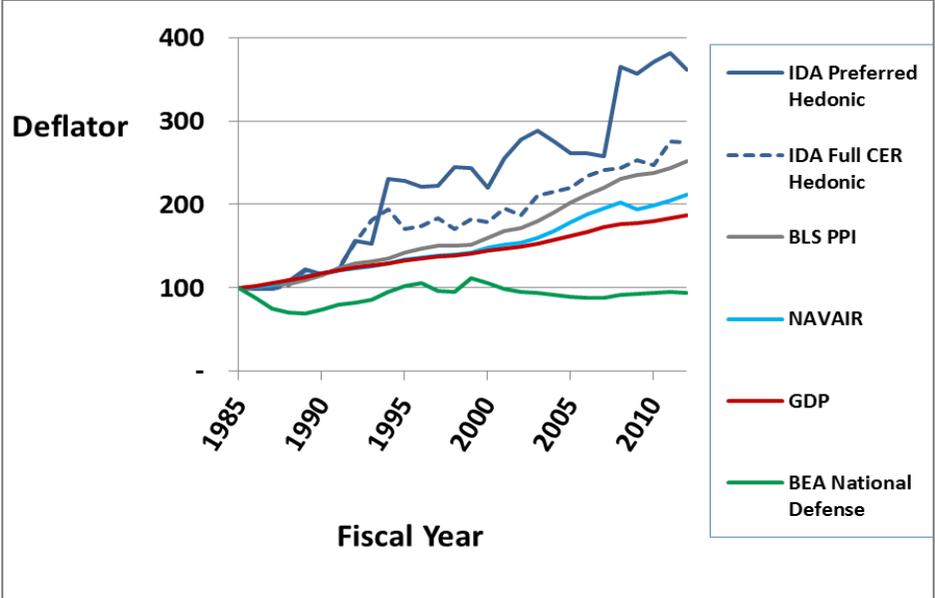
annual values of the price index; because the regression includes the quality variables, the price indexes are quality-constant outputs of the process.

Hedonic indexes possess several advantages over the indexes in current use:

- Hedonic indexes derive price indexes from regressions that directly relate nominal prices to specific, easily identifiable, quality-related features of the aircraft. These features are known with near certainty from legal contracts and Developmental and Operational Test and Evaluation.

- Hedonic indexes avoid the uncertainties of estimating the production cost of aircraft components, which are sometimes needed to estimate the cost of quality improvements. BEA obtains aircraft component costs from P-1, P-5, and P-40 budget exhibits published by the DoD Comptroller[4] and supplemented by information from industry literature and general news.

- Current methods that estimate costs associated with quality improvements from overall price changes for new models, with a correction for learning, require strong assumptions that may not be warranted.

The figure on page ix compares the indexes analyzed by the study: two hedonic indexes calculated for 40 years of tactical military aircraft and the four current indexes (GDP deflator, BEA, BLS PPI, and NAVAIR). The hedonic indexes show higher growth rate than any of the four current indexes. If these indexes are indeed reliable, that would indicate that the BEA national defense aircraft price index and the GDP deflator both understate the growth in quality-constant prices for defense aircraft. Deflating nominal costs with either of them would overstate real program growth for tactical aircraft.

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[4] "Defense Budget Materials," Under Secretary of Defense (Comptroller), http://comptroller.defense.gov /budgetmaterials/budget2014.aspx.

Comparison of Current and Projected Price Indexes, 1985–2012

Contents

1. Introduction

A. Purpose of Study

This paper summarizes recent research on cost indexes that the Institute for Defense Analyses (IDA) performed for CAPE, the Cost Assessment and Program Evaluation directorate in the Office of the Secretary of Defense (OSD). The objective of the research was to provide CAPE with analysis to help it meet the task it was given in the 2009 Weapon Systems Acquisition Reform Act (WSARA), now part of Public Law 111-23: to "periodically assess and update the cost indexes used by the [Defense] Department to ensure that such indexes have a sound basis and meet the Department's needs for realistic cost estimation." The CAPE task order for this research[1] asks in general for analysis of cost indexes that the Department of Defense (DoD) uses in cost estimation, but specifically mentions the inflation rates that are issued by USD(C) for preparing the budget request for major systems. This study focuses on cost indexes in general, not just those that adjust for inflation.

CAPE asked IDA to perform several tasks in this regard. Two of the tasks are administrative in nature—(1) describe the processes OSD and the Services use to adjust for inflation in estimating the costs and budgets of major systems, and (2) identify the regulatory and statutory provisions that authorize the issuance of inflation rates by USD(C), the Under Secretary of Defense (Comptroller). These tasks were covered in previous IDA Paper P-4707 and are not discussed further here.[2]

The present study addresses several analytical tasks that respond to the "assess and update" requirements in WSARA. "Assessment" addresses how well current price indexes analyze DoD costs and budgets, and "update" consists of looking for alternative methodologies that could do a better job.

By way of terminology, "cost index," "price index," and "deflator" are used interchangeably in this paper, as are "cost growth" and "price growth." "Real" cost is used in more than one sense, as described in Chapter 2.

The research in this paper focuses on cost indexes for aircraft procurement. Left for follow-on work are analyzing the procurement of other weapon types and spending on

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[1] BA-7-3054 Amendment No. 2, Cost Indices Assessment.

[2] Stanley A. Horowitz et al., "The Use of Inflation Indexes in the Department of Defense," IDA Paper P-4707 (Alexandria, VA: Institute for Defense Analyses, May 2012).

the "other purchases" portion of the Operations and Maintenance and Military Personnel (MILPERS) accounts.

B. Organization of the Study and Major Results

This section describes the chapters of the paper with a brief indication of their major results. Current indexes are assessed in Chapters 2 through 4, an alternative hedonic methodology is discussed in Chapter 4, and Chapter 5 summarizes the comparison of all the indexes analyzed by the study.

1. Chapter 2, The Uses of Price Indexes and Growth Rates

This question was considered briefly in IDA Paper P-4707 and is addressed here in more detail. The chapter analyzes indexes expressed in nominal dollars, constant-dollar indexes (net of general inflation), and constant-quality indexes (net of changes in quality). These indexes vary in several dimensions:

- Their purpose (project management or oversight)

- The office of interest (DoD program office, DoD leadership, Office of Management and Budget (OMB), the Congress)

- The reasons for increasing output price

  – General inflation

  – Price of system-specific inputs

  – Production-related factors such as labor productivity and learning

  – Industry-related factors such as market demand and supply

  – Changes in quality, the system's physical and operational features that affect its ability to perform the functions for which it is procured. Weight (a proxy for payload) and speed are examples of quality for aircraft.

2. Chapter 3, Current Deflators

This chapter documents the considerable variance in the growth rates of four price indexes that are used frequently in analyzing aircraft procurement:

- The Gross Domestic Product (GDP) deflator published by BEA, which OMB has mandated that DoD use for calculating constant-dollar budgets

- The National Defense deflator for military aircraft published by the Bureau of Economic Analysis (BEA) and referred to in this study as the BEA index

- The Producer Price Index (PPI) published by the Bureau of Labor Statistics (BLS) for the civilian aircraft procurement industry

- The index of Navy aircraft flyaway costs[3] developed by the Naval Air Systems Command (NAVAIR) and described in IDA Paper P-4707.[4] The NAVAIR index was included only for comparison, and was not analyzed in any depth except to note that it rose slightly more than the GDP deflator.

The GDP and PPI indexes generally agree with the view of DoD budget analysts that aircraft prices have been growing by several percentage points a year on average over the recent past. The BEA index, however, shows no growth—in fact, a slightly negative price growth—in the prices of military aircraft averaged over the last 26 years. The algorithms and data for the BEA and BLS indexes are analyzed in an effort to understand the source of the difference. One finding is that the lower BEA growth rate might be due to overestimating the extent to which price increases are driven by improvements in quality.

3. Chapter 4, Alternative Method for Calculating Cost Growth

Turning to the WSARA "update" task, the analysis finds that hedonic indexes offer an attractive alternative. The GDP deflator suffers the drawback that it is not specific to defense systems such as aircraft. The BEA and BLS indexes are, indeed, specific to aircraft, but they are calculated from total system and quality costs which are estimated with some uncertainty. The BEA index removes the costs of quality increases in order to estimate changes in the price of identical products—products lacking quality improvements. Hedonic indexes, by comparison, calculate quality-constant price indexes by statistically regressing system cost on variables for time (e.g., year) and the quality features such as empty weight and maximum speed. The coefficients of time are used to calculate the values of the price index, and because the regression includes the quality variables, the price indexes are quality-constant outputs consistent with the values of the quality variables.

Hedonic indexes possess several advantages over the indexes in current use:

- Hedonic indexes derive price indexes from regressions that directly relate nominal prices to specific, easily identifiable, quality-related features of the aircraft. These features are known with near certainty from legal contracts and Developmental and Operational Test and Evaluation.

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[3] Flyaway cost, as defined in P-5 Cost Analysis exhibits, is the sum of recurring and non-recurring procurement cost net of support. Recurring cost, by far the major component of total flyaway, is the sum of airframe (contractor furnished), electronics (contractor and government furnished), engines and engine accessories, armament, other government furnished equipment (GFE), and engineering change orders.

[4] NAVAIR uses Global Insight estimates for labor and material cost increases to estimate indexes for airframe, engine, and electronics that are combined into an index of flyaway cost for fixed-wing naval aircraft.

- Hedonic indexes avoid the uncertainties of estimating the production cost of aircraft components, which are sometimes needed to estimate the cost of quality improvements. BEA obtains aircraft component costs from P-1, P-5 and P-40 budget exhibits published by the DoD Comptroller[5] and supplemented by information from industry literature and general news.

- Current methods that estimate costs associated with quality improvements from overall price changes for new models, with a correction for learning, require strong assumptions that may not be warranted.

4. Chapter 5, Results and Comparisons

Chapter 5 compares and discusses the price indexes analyzed by the study: the GDP, BEA, BLS, and NAVAIR indexes analyzed in Chapters 3 and 4 and two hedonic indexes calculated in Chapter 4.

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[5] "Defense Budget Materials," Under Secretary of Defense (Comptroller), http://comptroller.defense.gov /budgetmaterials/budget2014.aspx.

2.   The Uses of Price Indexes and Growth Rates

DoD uses price indexes and growth rates for project management and oversight. Table 1 provides a brief summary of the subject area; the bottom row lists the various management activities in which indexes and growth rates are employed:

- DoD program offices estimate the future prices of weapon systems in then-year dollars for purposes of budgeting individual aircraft acquisition programs.

- Program offices and congressional committees are also interested in the real cost growth of such programs.

- OMB focuses on the burden of the defense procurement budget (or portions thereof) on the economy.

- DoD leadership is concerned with how much the procurement cost of the defense budget (or portions thereof) would have risen for the same systems without quality improvements.

The remainder of the table describes the price and spending changes of interest in these activities and the sources of the changes that are involved. It also describes how price indexes are used to isolate the factors of interest.

Using aircraft procurement for illustration, the first column of colored cells indicates that the growth in then-year prices of interest to program offices includes price growth due to all the reasons for price change listed in the left-most column.

- The *costs of inputs* are measured by (a) the general inflation of the US market basket of goods and services, and (b) the increase in relative prices, beyond general inflation, of the labor, material, and capital inputs that are specific to the aircraft's production.

- *How aircraft are produced* is described by the production-related factors of labor and capital productivity, including movements along learning curves (declining cost as contractors learn more efficient production techniques) and effects related to the level of production in particular years (rate effects).

- The *economic context* of production is described by industry-related factors describing the changes in the market demand and supply of aircraft that affect producer selling prices and profits.

- *The characteristics of what is produced*, often referred to as "quality" changes, refers to the improvements in the aircraft's physical and operational

specifications, such as its weight and speed (a proxy for payload), that affect its ability to perform the missions for which it is designed.

In budgeting, program offices must allow for the full expected price of their systems, including all reasons for price change. In calculating how much the real prices of their systems have changed, however, the focus of program offices and other concerned organizations is different. Now they want to capture all reasons for price increases except for general inflation. To do this, total price change is divided by a deflator reflecting the level of general inflation.

Table 1. Content and Use of Inflation Adjustments

Reasons for Price Changes	Growth in price for a particular system	Growth in price for a particular system relative to general inflation	Growth in spending for a class of items relative to general inflation	Growth in spending for a class of items, adjusting for DOD's quality-constant price changes
General inflation	[green]	[blue]	[blue]	[blue]
Relative inflation of inputs	[green]	[green]	[green]	[blue]
Production-related factors	[green]	[green]	[green]	[blue]
Industry-related factors	[green]	[green]	[green]	[blue]
Quality changes	[green]	[green]	[green]	[green]
Basis of comparison	Average price	Average price	Total spending (price*quantity)	Total spending (price*quantity)
Use of Adjustment/ User	Prepare budget/ Program office	Measure real cost growth/ Program office, Congress, OSD	Measure real burden to the economy/OMB	Measure real quantity of defense-related goods purchased/ DoD leadership

[green] Reason for price change included in metric of interest (not included in adjusting deflator)

[blue] Reason for price change included in adjusting deflator (not included in metric of interest)

OMB currently mandates that DoD use the GDP deflator for calculating real prices. The real price growth referred to in the second column is used in Nunn-McCurdy analyses to identify individual weapon acquisition programs that have had significant cost growth and thus require management attention.[6] Management attention is indicated when a system's constant-dollar price during procurement exceeds the price estimate developed during an initial baseline by a congressionally-set percentage.

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[6] Constant dollar affordability caps are now also used in mandatory Affordability Analyses at Milestones B and C.

In the third column total spending rather than average price is deflated by general inflation. The purpose here is to gain insight into the real burden of a portion (or all) of defense spending on the economy. All-DoD changes in spending deflated in this way are sometimes referred to as real growth in defense spending. As indicated by the green shading, this measure of real growth includes price increases due to changes in the prices of inputs to defense production that differ from the general level of inflation, changes in production-related factors, and changes in industry-related factors, in addition to costs associated with changing quality. The first three of these factors provide nothing of value to DoD and, thus, contribute nothing to real defense capability from the Department's point of view. The measure might better be called *real growth in the cost of defense*.

The last column describes a measure of how much more valuable a portion (or all) of defense spending is to DoD. It includes increases in spending due to the purchase of both <u>more</u> items and <u>higher quality</u> items. To calculate this measure, total spending must be deflated by an index that captures all the reasons for price increases except for quality improvements. This is also called *real growth*, but in this case it better reflects products bought rather than resources used. The resulting measure might be termed *real growth in defense program content*, or *real defense program growth*.

If nominal prices for defense purchases have risen by more than general inflation for reasons other than quality improvements, deflating expenditures with a general inflation index will overstate real defense program growth.

3.   Comparison of Deflators

This chapter describes the general features of the GDP, BEA, BLS, and NAVAIR price indexes (Section A). It contrasts their historical growth rates (Section B), compares the algorithms used to calculate them (Section C), and applies the algorithms to a hypothetical case for illustration (Section D). The chapter ends with a discussion in Section E of three factors that might be responsible for the low historical growth rate of the BEA index: the difference in the BEA and BLS algorithms, the different data inputs they use, and their different methods for estimating quality change.

A. General Features

The general features of the GDP, BEA, BLS, and NAVAIR price indexes are:

- **GDP deflator.** This is a chain-weighted price index calculated from the prices and quantities of the entire US national market basket of goods and services.[7] It is calculated by BEA as part of the National Income and Product Account (NIPA), and is published in Table 1.1.4 on the BEA website.[8] The GDP deflator is only weakly linked to the growth in prices of military aircraft, since military aircraft are a subset of all DoD procurements and a negligible subset of the entire US market basket. The GDP deflator is included in this study for comparison and not analyzed further.

- **BEA National Defense Index for Military Aircraft.** This index is also calculated by BEA for the NIPA, and is published in Table 3.11.4 on the BEA website. It will be referred to as the "BEA index" as a point of terminology. It tracks the prices DoD pays for military aircraft and major components such as engines and avionics. Costs for systems are obtained from the P-1, P-5, and P-40

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[7] A chain-weighted index is considered to be a more accurate inflation gauge than the traditional fixed-weighted index because rather than merely measuring periodic changes in the price of a fixed basket of goods, it accounts for the fact that consumers' purchasing decisions change along with changes in prices. "Chain-Weighted CPI," Investopedia, http://www.investopedia.com/terms/c/chain-linked-cpi.asp.

[8] "National Data: National Income and Product Accounts Tables," Bureau of Economic Analysis, http://www.bea.gov/iTable/iTable.cfm?ReqID=9&step=1#reqid=9&step=3&isuri=1&903=4a.

budget exhibits published by the DoD Comptroller,[9] supplemented by information from industry literature and general news.

- **BLS Producer Price Index for Civilian Aircraft**. The PPI for the civilian aircraft production industry is calculated by the BLS from sales price data obtained from commercial producers, and published on the BLS website under industry code PCU 336411-3364113.[10] (BLS began publishing a PPI for military aircraft in 2013.)

- **NAVAIR Index for Naval Aircraft.** As described in IDA Paper P-4707, this index for naval aircraft flyaway costs was developed by NAVAIR. Global Insight estimates for increases in labor and material cost were used to estimate indexes for airframe, engine, and electronics. These indexes were combined into an overall index of flyaway cost for fixed-wing naval aircraft. This index is shown in the present study to provide additional information on price indexes for military aircraft, and is not analyzed further.

B. Historical Growth Rates

Figure 1 portrays the growth of four quality-constant indexes applied to DoD systems during the last 27 years, 1985–2012. The rates are normalized to 1985 = 100 for comparison. The annualized growth rates, shown in Table 2, show marked differences.[11] The zero (slightly negative) growth of the BEA index is especially inconsistent with the BLS index and the general view of OSD budget analysts that aircraft prices have been rising substantially during the recent past. Military and civilian aircraft are substantially different, of course, but they are similar enough to raise the question of why their growth rates should be so different. The remainder of this chapter looks for differences in methodology and data that might explain the disparities.

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[9] "Defense Budget Materials," Under Secretary of Defense (Comptroller), http://comptroller.defense.gov /budgetmaterials/budget2014.aspx.

[10] Bureau of Labor Statistics, http://www.bls.gov. PPIs are published for both industries such as aircraft production and commodities such as metals and metal products.

[11] The annualized growth rate of an index I between 1985 and 2012 is calculated by:

$$\left(\left(\frac{I_{2012}}{I_{1985}} \right)^{\frac{1}{27}} - 1 \right) \times 100.$$
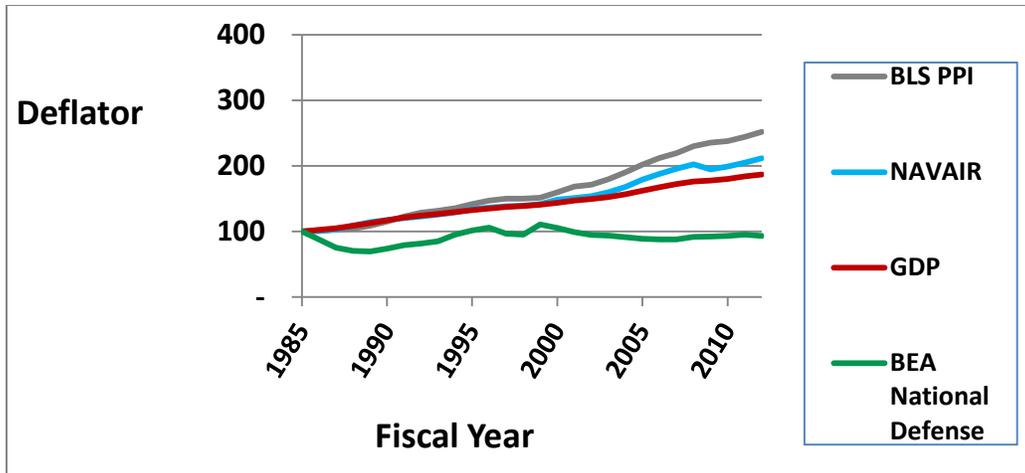
Figure 1. Price Indexes Often Applied to Aircraft

Table 2. Annualized Growth Rate during 1985–2012 of Deflators Used for Aircraft Procurement

Price Index	Annualized Growth Rate
BLS PPI	3.6 %
GDP	2.4 %
BEA National Defense	-0.3%
NAVAIR	2.8%

C. Algorithms

1. Introduction

The GDP deflator is not specific to aircraft and not discussed further. The BEA index is based on information in a chapter entitled "The Deflation of Military Aircraft" from an out-of-print book, *Price Measurements and Their Uses*.[12] The information has been brought up to date through informative discussions with one of the authors, Pamela Kelly, who is currently the Chief of the Government Division at BEA, and Mr. Peter Beall, a senior analyst in that division. The BLS algorithm is based on information in the subsection entitled "Description of Survey: Product change and quality adjustment" in

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[12] Richard Ziemer and Pamela A. Kelly, "The Deflation of Military Aircraft," in *Price Measurements and Their Uses*, ed. Murray Foss et al. (Chicago, IL: University of Chicago Press, January 1993): 307–348, http://www.nber.org /chapters/c7810.pdf.

Chapter 14, "Producer Prices," in the *BLS Handbook of Methods*,[13] as well as recent discussions with Lana Borgie and other BLS analysts.

The indexes published by BEA and BLS are averages over many aircraft in simultaneous production, but will be discussed here in the context of two aircraft programs. The analysis will allow us to make the analytical distinctions we seek.

We need to distinguish between *existing* and *new* aircraft since BEA uses different algorithms for each. An example is the Air Force F-15, which was produced for many years and will, to some extent, be replaced by the F-35. (Other examples are the Navy F/A-18 C/D which was succeeded by the E/F version, and the E/F version, which is being replaced in turn by the F-35C, the carrier-capable version of the F-35.) Once the F-15 had been produced for some years, BEA identified the yearly quality changes and estimated their costs from DoD budget exhibits and supplementary data. We will refer to such cases as *existing* models.

The F-35, in its first year of production, by contrast, was a *new* aircraft. Those that have been produced to date will require significant modification to become combat capable, and are therefore of lower quality than eventual designs. This complication will not interfere with our comparison of existing and new aircraft. The production of new aircraft is initially marked by especially high cost until the contractor discovers (or invests in) labor-saving production techniques (also known as *learning*) that lead to lower production cost in succeeding years. Calculating the price deflator for new aircraft raises the methodological issue that identifying their quality changes and estimating the incremental costs of these changes is difficult as a practical matter. BEA and BLS therefore abandon the attempt to isolate the specific procurement costs of increased quality. As the next sections indicate, they estimate quality costs by the known increase in the full total system cost with modifications to be discussed.[14]

2. BEA

The BEA algorithm is defined in equations (1), (1A), and (1B). D_k^{BEA} is the deflator in year k, the P_i are the system prices for each year i from the base year (year 1) to k, and the F_i are dimensionless ratios that capture the increase in price due to the estimated cost of quality improvements Q_i^{est}. (It is important to realize that deflator values are based on *estimated* quality change, which could differ substantially from the *actual* change, which

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[13] Chapter 14, "Producer Prices," in *BLS Handbook of Methods* (Washington, DC: BLS Division of BLS Publishing, Office of Publications and Special Studies, updated February 2014), accessible at http://www.bls.gov/opub /hom/pdf/homch14.pdf.

[14] Although we will be discussing cases where system prices are rising, the deflator algorithms can equally well handle situations where system prices are falling due to deflation or rapidly emerging new technology such as computers.

is unknown.) The F_i are calculated using eq. (1A) for existing aircraft and eq. (1B) for new aircraft. The variables are all obtained from the sources mentioned above. (The product term in eq. (1) starts with year 2, the earliest possible year of quality change relative to the base year, year 1.) Although omitted for simplicity, the terms in the equations for F_i are adjusted to contemporaneous dollars.

$$D_k^{BEA} = 100 \times \frac{P_k}{P_1 \times \prod_2^k F_i} \tag{1}$$

where

$$F_i = \frac{P_i}{P_i - Q_i} \text{ for "existing" models} \tag{1A}$$

$$F_i = \frac{(P_{i-1} + Q_i^{est})}{P_{i-1}} \text{ for "new" models} \tag{1B}$$

The F_i for new models differs from that for existing models in several respects:

- Because price is especially high due to limited time for learning, F_i is set equal to the proportional effect of contemporaneous estimated quality change Q_i^{est} on the *prior* year's price P_{i-1}, the price of the existing model.

- Q_i^{est} is set equal to the price difference between the existing and new aircraft, but with the following two adjustments.[15]

  – The price of the new aircraft is set at its estimated value after substantial learning has taken place. Otherwise, the costs of the new and existing aircraft would be calculated at much different production efficiencies and the extent of quality improvements would be overstated and the price index understated.

  – A general price index, normally the GDP deflator, is used to convert the prices of the existing and new aircraft after learning adjustment into contemporaneous dollars (i.e., for price i).[16]

If there were no quality changes (no new aircraft or quality changes to existing aircraft), the F_i would all be unity, the product term would be unity, and eq. (1) would set

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[15] The adjustments are handled explicitly in the model discussed in Chapter 4.

[16] The existing aircraft's initial price is in the year prior to introduction of the new aircraft. The conversion to contemporaneous dollars is needed in cases where the learning-adjusted price of the new aircraft is estimated by the future-year price of the 100th aircraft when it is delivered. The "100 unit method" (our terminology) was formerly used by BEA (as mentioned in Ziemer and Kelly, *Price Measurements*) and is also the procedure used in the simulation study of the BEA algorithm carried out in Chapter 4.

the deflator in year k to the ratio of the contemporaneous to base year price, P_k/P_1 x 100.[17]

The algorithm for calculating the price deflator expressed by equations (1, 1A and 1B) has a simple empirical interpretation. Price growth is the sum of two complementary effects: (a) quality change, and (b) all the other factors listed near the beginning of this section, whose effects are captured by the deflator. For a given system price P_i, the larger the actual quality change for existing aircraft in eq. (1A) or estimated quality change for new aircraft in eq. (1B), the larger the increases in F and the smaller the deflator D calculated by eq. (1). The more that is spent on quality change, the less that is left for the input prices and other factors mentioned in Chapter 2 that are captured by the price deflator. A corollary is that the larger the learning adjustment for new aircraft mentioned just above, the lower the estimated quality change and the larger the deflator.

3. BLS

BLS uses a different algorithm for the PPI. It uses eq. (2) instead of eq. (1) as the basic equation, and eq. (2A) instead of eq. (1A) for calculating F_i for both existing and new models.

$$D_k^{BLS} = 100 \times \prod_2^k F_i \qquad (2)$$

where

$$F_i = \frac{P_i - Q_i^{est}}{P_{i-1}} \text{ for existing and new models} \qquad (2A)$$

Although the BLS formalism looks different from the BEA algorithm, it is equivalent for existing models. That is, equations (2) and (2A) acting together are mathematically equivalent to equations (1) and (1A). Both algorithms can, in fact, be re-written as eq. (3), which expresses the deflator explicitly as a ratio of the contemporaneous to the base year system price multiplied by terms that reflect the quality changes that have occurred in the intervening years. For BLS, the costs of quality improvements are estimated through discussions with contractors.

$$D_k^{BLS} = D_k^{BEA} = 100 \times \frac{P_k}{P_1} \times \prod_2^k \frac{P_i - Q_i^{est}}{P_i} \text{ for existing models} \qquad (3)$$

The BLS and BEA algorithms produce different estimates for new models because the BLS algorithm makes no adjustment for learning and therefore attributes the full

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[17] By way of terminology, BEA uses the term "quality-adjusted base year price" for the denominator of the deflator—the base year price P_1 times the F_i product. The deflator is thus the contemporaneous price P_k divided by the quality-adjusted base year price.

increase in system price to quality change. The higher estimate of quality change would lead to a smaller growth rate of the deflator, which does not help to explain the relatively high growth rate of the published BLS deflator in Figure 1.

Since the focus of this analysis is on comparing algorithms, we are ignoring the complication introduced by the differences in how military and commercial aircraft are priced. Whereas military aircraft are bought on a cost-plus basis, new-model commercial aircraft are usually sold at prices below cost at the beginning of a production run[18] for purposes of competition, These "launch" discounts[19] to commercial customers could lower estimates of quality improvement, which might help to explain the relatively high growth rate for the BLS deflator in Figure 1.

D. Illustration

1. Contemporaneous Deliveries

Table 3 illustrates the BEA and BLS algorithms by applying the algorithms to the illustrative (shaded) data in the table. The table assumes, for simplicity, that each aircraft is delivered in the same year in which its contract is signed (the column heading).[20] The next section discusses how the deflator is calculated for the more realistic situation in which the deliveries from the contracts are stretched out over future years.

The table describes four cases: the BEA and BLS algorithms, and where Aircraft B is existing and new. The first two cases assume that Aircraft B is an *existing* aircraft that is similar to Aircraft A in basic design but with a $350 increase in system price ($600 – $250) in 2002. Production data indicate that $100 of this increase is a quality increase for component improvements, so the remaining $250 is therefore due to an increase in input prices and the other non-quality factors mentioned earlier. The BEA and BLS deflators are mathematically equivalent and thus yield the same deflators.

The second two cases assume that Aircraft B is a *new* aircraft, so that production data are no longer able to identify that part of the $350 price rise that is due to estimated quality changes Q_i^{est} in the deflator algorithms. The BEA deflator is calculated using the method where F_i is calculated according to eq. (1B), in which Q_i^{est} is set at what the full price of the new aircraft is estimated to be once it is lowered to the value after substantial

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[18] Douglas A. Irwin, and Nina Pavcnik, "Airbus versus Boeing Revisited: International Competition in the Aircraft Market," *Journal of International Economics* 64 No. 2:223-245, December 2004.

[19] Daniel Michels, "The Secret Price of an Airliner," *The Wall Street Journal*, July 9, 2012.

[20] The costs for the aircraft deflator are measured at the time of delivery. The deflator for ships is based on yearly progress payments because of their longer production times. Yearly progress payments for aircraft are recorded as additions to inventory and zeroed out at the time of delivery.

learning has taken place. We will use the learning adjustment described in Ziemer and Kelly (1993): learning is assumed (sufficiently) accomplished once the 100th aircraft is delivered (this procedure has since been superseded, as will be discussed later). This occurs in 2004 in Table 3, when the price is $450, yielding a quality change of $200 ($450 – $250). (The existing and new prices in 2001 and 2004 are not transformed to year 2000 dollars in the table for simplicity. The transformation will be considered, however, in the simulation analyzed in Chapter 4.)

The BLS algorithm uses eq. (2) for new aircraft, where quality change is set at the full $350 price increase ($600 - $250).

Table 3. Applying BEA and BLS Deflator Algorithms

	2000	2001	2002	2003	2004	2005
Basic Data						
Aircraft model	A	A	B	B	B	B
Price (P_i)	$200	$250	$600	$500	$450	$400
Increase in price		$50	$350	-$100	-$50	-$50
Cumulative deliveries	330	350	60	95	125	145
Deflator for existing model throughout						
BEA						
Quality change (Q_i^{est})			$100			
$F_i = P_i/(P_i - Q_i^{est})$	1	1	1.2	1	1	1
Cumulative product of the F_i	1	1	1.2	1.2	1.2	1.2
Quality-adjusted base year price	$200	$200	$240	$240	$240	$240
Deflator (D_k^{BEA})	100	125	250	208	188	167
BLS						
Quality change (Q_i^{est})			$100			
$F_i = (P_i - Q_i^{est})/P_{i-1}$	1.00	1.25	2.00	0.83	0.90	0.89
Cumulative product of the F_i	1.00	1.25	2.50	2.08	1.88	1.67
Deflator (D_k^{BLS})	100	125	250	208	188	167
Deflator for new model in 2002						
BEA						
Quality change (Q_i^{est})			$200			
$F_i = (P_{i-1} + Q_i^{est})/P_{i-1}$		1	1.80	1	1	1
Cumulative product of the F_i	1.0	1.0	1.8	1.8	1.8	1.8
Quality-adjusted base year price	$200	$200	$360	$360	$360	$360
Deflator (D_k^{BEA})	100.	125.	167	139	125	111
BLS						
Quality change (Q_i^{est})			$350			
$F_i = (P_i - Q_i^{est})/P_{i-1}$		1.25	1.00	0.83	0.90	0.89
Cumulative product of the F_i	1.00	1.25	1.25	1.04	0.94	0.83
Deflator (D_k^{BLS})	100	125	125	104	94	83

If new commercial aircraft are initially priced at lower levels than shown in Table 3 because of the "launch" discounts mentioned earlier, the result would be lower estimates of quality increase with correspondingly higher growth rates of the price deflator.

Figure 2 and Table 4 show the values of system price, deflators, and annual growth rates just calculated, all normalized to the value of 100 for the year 2000 for purposes of comparison. These results suggest three conclusions:

- This result supports the general point that the estimated quality change and the price deflator are inversely related. The more a given price rise is attributed to quality change, the less is available for increased spending on input prices and the other non-quality factors that are captured by the price index.

- Although the BEA and BLS deflators are equivalent for existing aircraft, the BLS deflator has smaller values and growth rate for new aircraft because it uses a higher, non-learning-adjusted value of quality change.

- The small BLS deflator for new aircraft will have a reduced effect on the growth rate of the combined fleet of existing and new aircraft.

The smaller growth rate for the BLS index runs counter to the ranking in Figure 1. It is not, therefore, explained by a simple application of the BEA and BLS algorithms. Other possible reasons are considered in Section E.

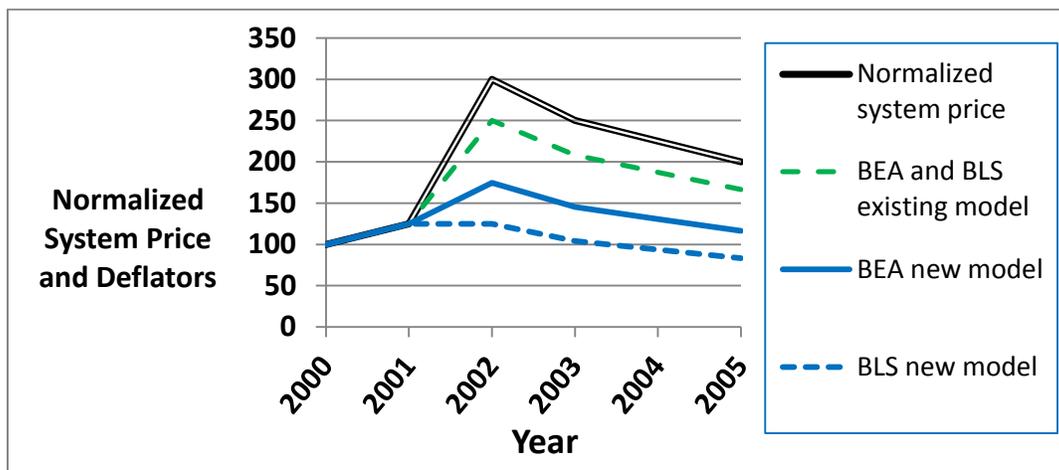**Figure 2. Normalized System Price and Deflators (Year 2000 = 100)**

Table 4. Annual Growth Rates

	Normalized System Price	Deflator		
		BEA and BLS Existing Model	BEA New Model	BLS New Model
2000	100	100	100	100
2005	200	167	111	83
Yearly Increase (%)	14.9%	10.8%	2.1%	-3.6%

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2. Deliveries over Time

As mentioned earlier, the calculations in Table 3 make the simplifying assumption that deliveries occur the same year in which contracts are signed. BEA uses the procedure described below for the more realistic case in which aircraft produced by a contract are normally delivered for several years after signing. Assume, in the following, that contracts are listed in rows and deliveries are listed in columns for each quarter:

1. For each contract, the unit system price is multiplied by the number of aircraft that are produced by that contract and delivered in each future succeeding quarter. Each contract thus generates a single row of "nominal expenditures" by quarter.

2. The process is repeated using the quality-adjusted base year prices instead of the system prices. Each contract generates a single row of "quality-adjusted expenditures" for each quarter.

3. Steps 1 and 2 are repeated for each contract, leading to a row of nominal and a row of quality-adjusted expenditures for each contract.

4. The nominal and quality-adjusted expenditures in each quarter (column) are summed over contracts (rows), and the total nominal and quality-adjusted expenditures are divided to yield the deflator for each quarter.

E. Possible Explanations for Disparity in BEA and BLS Growth Rates

This section looks at three factors to help explain why the BEA index has a much smaller historical growth rate than that of the BLS index: different algorithms, different data inputs, and different methods for calculating quality change. Although this analysis fails to identify the reason for the BEA index's small growth rate, the simulation of the BEA algorithm in the next chapter pursues the issue further.

1. Different Algorithms

As described above, only the BEA algorithm makes a learning adjustment to the price of the new aircraft in the year of introduction when estimating the costs associated with quality improvement; the BLS index attributes the entire price change to quality improvement. The two algorithms also use different F ratios that measure the effect of estimated quality change on price. BEA measures the effect on price in the year prior to introduction, whereas BLS uses price in the contemporaneous year.

These two factors—learning adjustment and F ratio—both lead the BEA deflator to be less than the BLS deflator, contrary to the state of affairs in the real world.

2. Different Data Inputs

a. BEA

BEA formerly used detailed data for its national defense deflator for aircraft. The procedure was described in Ziemer and Kelly (1993):

1. Deflators for each aircraft were calculated from the recurring production costs for the major components such as airframe, engines, and armament.

2. The results were aggregated over the components using total expenditures as weights.

3. The results were multiplied by the ratio of total contract price to recurring production cost in order to account for the fixed costs for General and Administrative (G&A), Facilities Capital Cost of Money (FCCM), Management Reserve (MR), and fee (profit).

4. The resulting deflators were aggregated over aircraft using total system expenditures as weights.

The component recurring flyaway costs were calculated from detailed data that contractors reported to DoD in Cost Data Summary Reports (CDSRs). Table 5 describes the distribution of these costs for a recent air vehicle and engine lots for the F-22. Recurring flyaway cost summed to almost 80 percent (98% x 81%) of total production costs.[21] As Table 6 illustrates, BEA now uses only the much less detailed summary data reported in DoD budget exhibits,[22] supplemented with information from general industry literature and general news. The DoD exhibits break down the flyaway costs into point estimates for avionics, propulsion, and airframe, but costs such as those for armament, flight controls, and utilities are not represented. There appears to be insufficient detail for an authoritative calculation of the costs of quality change. BEA turned from the CDSRs to the summary data because of limited budgets for producing the national defense deflators for the NIPA tables. (The staff working on national defense statistics has decreased by approximately 55 percent since 1993.)

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[21] Recurring flyaway costs are the sum of air vehicle costs (integration, airframe, propulsion, avionics, armament, and engineering change orders) from the Lockheed Martin CDSR for the F-22A (Lot 8, FY 2011) and engine costs from the Pratt and Whitney (United Technologies Corporation) CDSR for the F-119 engine (Lot 6, FY 2005).

Total flyaway adds in nonrecurring flyaway costs, *total production* includes support recurring and nonrecurring costs, and *total overall* includes fixed costs for G&A, Miscellaneous, Undistributed Budget, MR, FCCM, and Profit (Fee).

[22] Exhibits P-1, P-5, and P-40 in Procurement Programs and DoD Budget Justification Books, all listed in "Defense Budget Materials," Under Secretary of Defense (Comptroller), http://comptroller.defense.gov /budgetmaterials/budget2014.aspx.

Table 5. Sample of BEA Aircraft Cost Data

Input	Cost ($M, FY11)
Recurring Flyaway	$1,615
Total Flyaway	$1,637
Total Production	$2,171
Total Overall	$2,777
Recurring Flyaway as Percentage of Total Flyaway	98.7%
Total Flyaway as Percentage of Total Production	75.4%
Total Production as Percentage of Total Overall	78.2%
Recurring Flyaway as Percentage of Total Overall	58.2%

Table 6. Recurring Cost Detail, P-5 Budget Exhibit vs. CDSR

Major Category	P-5 Exhibits in DoD Budget Justification Books		Cost Data Summary Report
	F/A-18 E/F	**F-22**	**F-22**
Airframe	Total airframe contractor furnished equipment (CFE)	Total airframe CFE	9 entries (forward fuselage, center fuselage, wing, empennage, etc.)
Propulsion	Total engines and engine accessories	Total engines and engine accessories	11 entries (fan, compressor, high pressure turbine, etc.)
Avionics	Total electronics CFE and government-furnished equipment (GFE)	Total avionics	16 entries (radar, integrated processor, communication, navigation, identification (CNI) apertures, CNI antennas, inertial navigation system (INS), global positioning system (GPS), electronic warfare, etc.)
Armament	Total armament		4 entries (gun system, weapons carriage, etc.)

b. BLS

BLS bases its deflator on unit prices that contractors charge their civilian customers. BLS obtains these data from monthly reports by companies included in its aircraft industry sample of contractors that produce a significant percentage of the market. This sample is updated every five to seven years. We could not obtain data to carry this investigation further because BLS promises companies anonymity in return for their data.

3. Different Techniques for Estimating the Cost of Quality Change

a. General

BEA and BLS base their deflator estimates on contractor data. Identifying the quality changes of new aircraft and estimating their production cost requires analysis, not just accounting, and involves uncertainties discussed in the remainder of this section. Chapter 4 considers an alternative method, hedonic analysis, in which statistical regression techniques would be used to relate costs directly to major aircraft specifications such as weight and speed.

b. BEA

BEA accounts for learning by estimating what the new model would cost once substantial learning has taken place. Ziemer and Kelly (1993) estimate this cost by the unit cost of the 100th aircraft. Although the cost could alternatively be estimated by fitting a learning curve to the first-unit cost in the year the new model is introduced, BEA now uses a less-formal approach in which their analysts rely on historical experience and cost data from recent contracts. The implications of this change are discussed in Chapter 3.

c. BLS

BLS's sampling procedure mentioned above has some implications for how BLS treats quality change of new models. To take a completely illustrative example, suppose that BLS's current sample consists solely of Aircraft A, produced by Boeing. Boeing sends BLS monthly reports of the total production prices and how much of it is due to the cost of increasing quality. (This example assumes the aircraft has been in production for many years and that the quality costs can be estimated.) BLS calculates the increase in total cost from the previous year and subtracts the quality cost for purposes of calculating the quality-constant price deflator.

If Boeing now begins to produce a new Aircraft B, there are several cases to consider regarding whether Aircraft A continues in production and whether Aircraft B is a new aircraft in the sense we have defined. Suppose, first, that Boeing cancels Aircraft A during the shift to B. Boeing describes the shift to BLS, which calculates the deflator in the same fashion as long as the cost of increasing quality for Aircraft B can be estimated. But if B is a new aircraft whose quality cost cannot be estimated, BLS assumes it equals the full increase in price during the year of introduction, and calculates the index as above for succeeding years. The large cost of quality change in the year of introduction will lead to zero change in the index for that aircraft program, which cannot help to explain the high growth rate of the BLS deflator in Figure 1. However, for competitive reasons, contractors may sell early production commercial aircraft for less than their cost. This

would reduce or even eliminate the tendency to overestimate the portion of price increases attributable to quality improvements when a new model is introduced.

We lack access to BLS's aircraft data, as mentioned above, and cannot determine whether the situation just explained occurs often enough to explain the relatively high average growth rate in Figure 1.

4. Conclusion

This chapter has explored possible reasons why the BEA deflator for military aircraft shows a smaller historical growth rate than either the BLS deflator for civilian aircraft or the expectation of OSD budget analysts. Following are the findings of this analysis:

- The BEA and BLS deflators are mathematically equivalent, leading to the same values for existing aircraft, providing the two organizations were to estimate the same cost of quality change.

- BEA and BLS use somewhat different formulations for new models, but applying these formulations in a simple case predicts a relative ranking that is the opposite of the observed values shown in Figure 1. The BEA deflator shows a higher, not lower growth rate.

- The two organizations base their deflators on different data—recurring cost to the government for BEA and sales price for BLS—and further study would be needed to determine if the two variables have similar growth rates.

- Estimating the costs of quality change involves substantial uncertainty, but we lack the access to BEA and BLS data that would allow us to understand how these costs were estimated in practice.

4.   Hedonic Price Indexes for Tactical Aircraft

A. Introduction

This chapter responds to the WSARA "update" task mentioned in Chapter 1, which was to identify a price index that is better than current indexes at meeting DoD's need for a sound basis for cost estimation. The focus is on quality-constant indexes as defined in Chapter 2, which estimate what the price would have been for the same good absent any changes in the physical and operational characteristics or "quality" features of the system.

As described in Chapter 3, BEA and BLS currently calculate quality-constant indexes for aircraft by starting with system prices and subtracting the estimated unit procurement costs (or sales price) due to the quality changes. BEA adjusts for learning and rate of production.

The "update" discussed in the present chapter uses an entirely different, or "hedonic" methodology, described by eq. (20). Statistical regression is used to relate system cost in nominal, then-year dollars to dummy variables describing year, the physical and operational quality variables, and possibly control variables. The coefficients of the time dummy variables are used to calculate the price index. And because the regression includes the quality variables, the price indexes are quality-constant outputs consistent with the values of the quality variables.

$$\text{nominal system prices} = f(\text{year, quality variables, other control variables}) \quad (20)$$

Hedonic indexes are similar to cost estimating relationships (CERs), which also relate system price to quality variables, but where the price index has a much different role. In CER analysis, described by eq. (21), an economy-wide price index such as the GDP deflator is commonly used to first calculate the aircraft's price in real, or constant-dollar, terms before it is regressed on the quality variables. Choosing an index price beforehand is clearly not useful as a method for calculating price indexes.

$$\frac{\text{nominal system prices}}{\text{general price index}} = \text{real prices} = f(\text{quality variables, other control variables}) \quad (21)$$

The citations in footnote 28 indicate that hedonic methods are of increasing interest in statistical analysis. Landefeld and Grimm state that "The use of hedonic price indexes is increasing, and the components that are deflated by hedonic techniques account for 18 percent of GDP."[23] As stated in Chapter 1, hedonic indexes offer three outstanding features:

- Hedonic indexes derive price indexes from regressions that directly relate nominal prices to specific, easily identifiable, quality-related features of the aircraft. These features are known with near certainty from legal contracts and Developmental and Operational Test and Evaluation.

- Hedonic indexes avoid the uncertainties of estimating the production cost of aircraft components, which are sometimes needed to estimate the cost of quality improvements. BEA obtains aircraft component costs from P-1, P-5, and P-40 budget exhibits published by the DoD Comptroller[24] and supplemented by information from industry literature and general news.

- Current methods that estimate costs associated with quality improvements from overall price changes for new models, with a correction for learning, require strong assumptions that may not be warranted.

The remainder of this chapter describes the data analysis of several hedonic indexes for military tactical aircraft.

B. Data

The hedonic analysis used in this chapter follows the direct time-dummy variable approach formulated by Triplett, an early developer of hedonic analysis.[25] Table 7 shows the explanatory variables: five quality variables describing the aircraft; two variables describing the quantity, or number of aircraft produced for use in incorporating the effects of learning and production rate in the procurement process; and time, measured by year of procurement.

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[23] Brent R. Moulton, "The Expanding Role of Hedonic Methods in the Official Statistics of the United States" (Washington, DC: Bureau of Economic Analysis, US Department of Commerce, June 2001); C. Lanier Benkard and Patrick Bajari, "Hedonic Price Indexes With Unobserved Product Characteristics, and Application to Personal Computers," *American Statistical Association Journal of Business & Economic Statistics* 23, no. 1 (January 2005): 61–75; and J. Steven Landefeld and Bruce T. Grimm, "A Note on the Impact of Hedonics and Computers on Real GDP," *Survey of Current Business* 80, no. 12 (December 2000): 17–22.

[24] "Defense Budget Materials," Under Secretary of Defense (Comptroller), http://comptroller.defense.gov /budgetmaterials/budget2014.aspx.

[25] Jack E. Triplett, *Handbook on Hedonic Indexes and Quality Adjustments in Price Indexes: Special Application to Information Technology Products* (Paris, France: Organisation for Economic Co-operation and Development, 2006).

Strictly speaking, weight is not a quality variable, but heavier aircraft are able to incorporate more useful features. Weight is expected to act as a proxy for them.

The database is pooled cross-section and time-series data, often called "panel data" in the econometrics literature. "Time" is measured in the present analyses by fiscal years. The time-series covers the 40 fiscal years covering 1973–2012 inclusive. Each year other than the base year, 2012, is given a different time dummy in order to calculate different price indexes for each year. The cross-sections are the 22 aircraft programs shown in Table 8 consisting of 11 "original designs" plus 11 "derivatives" of these designs from series or block changes.[26]

Table 7. Explanatory Variables

Quality variables

    Empty weight in pounds

    Maximum speed in knots

    Advanced materials as percentage of structure weight

    Dummy variable for 5th generation aircraft[a]

    Dummy variable for STOVL aircraft[b]

Quantity variables

    Cumulative production

    Lot size (number of aircraft produced in a year)

Time dummy variables

[a] 5th generation aircraft are characterized by stealth, internal weapons carriage, avionics with information fusion and support of net-centric operations. In our sample, the F-22 and F-35 A/B/C are classified as 5th generation aircraft.

[b] The AV-8B and F-35C, aircraft with Short Take-Off and Vertical Landing capability needed for operations from small aircraft carriers and short unimproved airfield.

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[26] Military aircraft are described by MDS (Mission-Design-Series). For the F-14A, for example, the mission is fighter (F), the design is 14, and the series is A. The aircraft in the first column of Table 7 are new designs, with the exception of the F/A-18E, which was a major change from the previous F/A-18s, and the three F-35 variants, which are being built for different missions and produced in parallel. The aircraft in the second column are either new series (e.g., F-14B) or new block upgrades (e.g., the F-14A+ and the F-16C 25/30/50).

Table 8. Aircraft Programs

Original Designs	Derivatives (Series or Block Changes)
F-14A	F-14A+, F-14B
F-15A	F-15C, F-15C MSIP, F-15E
F-16A	F-16C Blocks 25/30/50
F/A-18A	F/A-18C Night Attack
A/V-8B	A/V-8B Night Attack, A/V-8B Radar
F/A-18E	
F-22A	
EA-18G	
F-35A	
F-35B	
F-35C	

C. Models for Analysis

Three hedonic models were selected for analysis. They are introduced in broad terms in Subsection 1 and in detail in Subsection 2.

1. Introduction

a. Full CER Hedonic Model

The Full CER model regresses nominal system price on all the explanatory variables listed in Table 7. (Despite the terminology, the "CER" model analyzed in this study is a hedonic model as defined by eq. (20), not the type of CER analysis that was defined by eq. (21) and that is unsuitable for calculating price indexes). The model meets the standard statistical and empirical criteria: it fits the data with a high R^2 of 0.97, the coefficients of the quality variables were all positive as expected (they all represent added cost), and the coefficients are all statistically significant at the 5 percent level or better.

By including the quantity variables in the regression, the coefficients of the quality variables are calculated holding quantity constant. But quantity affects system price, as does quality, so holding the quantity variables constant creates a problem by defeating the purpose of a general price index. General price indexes should reflect changes in productivity that are normalized away by the quantity changes.

b. Alternative Hedonic Model

The Alternative model avoids this problem by omitting the quantity variables. Reducing the number of explanatory variables means that the model explains less of the

price variation in the data, but it still leads to a reasonably high R^2 of 0.84. Excluding the quantity variables, however, creates a further problem in that aircraft with more capability or higher quality are usually bought in smaller quantities, and aircraft produced more recently are more capable (e.g., 5th generation capabilities) and are also bought in smaller quantities. This resulted in the model producing empirically unacceptable estimates for the coefficients of the quality variables: a negative coefficient for maximum speed, an unreasonably large premium for advanced materials, and an 85 percent premium 5th generation aircraft that is much higher than estimated by Nelson.[27] These are severe drawbacks, and this model will not be discussed further.

c. Preferred Hedonic Model

The Preferred model leaves out the quantity variables, to be consistent with the purposes of an overall price index, and avoids the unacceptable results of the Alternative model by fixing the quality variables at the values that were obtained from estimating the Full CER model. The coefficients of the time dummy variables, from which the values of the price index are calculated, are therefore the only parameters to be estimated (aside from a constant term). The Preferred model meets the statistical and empirical criteria discussed earlier for the CER model: high predictive power of the model and expected signs and statistical significance of the coefficients.

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[27] Richard Nelson et al., "(U) Cost Estimating for Modern Combat Aircraft: Adjusting Existing Databases and Methods to Include Low-observable Cost Considerations," Secret/PI/LR, IDA Paper P-3528 (Alexandria, VA: Institute for Defense Analyses, June 2001).

2. Detailed Analysis

a. Full CER Model

The Full CER model and definition of terms are shown in eq. (22), with additional detail in footnote 28. [28]

$$ln \; [\![UC]\!] \; _{tk}^{TY} = ln\big[f\big(Q_{(t-1)k}, q_{tk}, \mathbf{Z}_k, D_t, \boldsymbol{\beta}, \boldsymbol{\varphi}, \delta_t, \dots\big) + \varepsilon_{jk}\big] \tag{22}$$

where

- UC_{tk}^{TY} is the unit recurring flyaway cost in nominal (then-year) dollars for the kth aircraft program in year (or lot) t. The aircraft programs are listed in Table 8, and the data run from 1973 to 2012.

- $\mathbf{Z}_k$ is the vector of five quality variables for the kth aircraft. All the aircraft of type k are described by the same quality variables over time with the exception of weight, which captures year-to-year changes in quality. $\mathbf{Z}_1$, for example, is the vector of quality variables for the F-14A.

- Q and q are the quantity variables used in accounting for production rate and learning. $Q_{(t-1)k}$ is the cumulative quantity of the kth aircraft produced through t-1, and therefore available at the start of t. q_{tk} is the quantity of aircraft in the lot produced at time t. The midpoint cumulative quantity for lot t that determines the lot's position on the learning curve is calculated based on Q_{t-1} and q_{tk} .

- D_t .is the time dummy variable.

- $\boldsymbol{\beta}$ is the vector of coefficients for the quality variables.

- $\boldsymbol{\varphi}$ is the vector of coefficients for the quantity variables.

- δ_t are the coefficients of the time dummy variables (i.e., the price indexes).

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[28] Higher production rate leads to higher lot quantities, so that the fixed costs per lot are spread over more units with a resulting decrease in the unit fixed costs per lot. Fixed costs for each aircraft program were estimated as a function of peak estimated variable costs which are determined by the quality variables and peak production rate.

Learning is incorporated in the regression by assuming that production of the kth aircraft program in lot t, for example, is increased by the production of the other programs in lot t: $Q_{tk} = Q_{(t-1)k} + q_{tk}$, Q_{tk} is the cumulative number of aircraft of program k produced through lot t, $Q_{(t-1)k}$ is the cumulative number of aircraft of program k produced up to but not including lot t, q_{tk} is the number of aircraft of program k produced in lot t. There are two special cases where multiple aircraft models have common elements and are produced in the same factory. The resulting shared learning is captured in a third additive argument $(\lambda \sum_{l=1}^{k-1} q_{tl})$ portraying learning spillovers between the relevant models. The regression called for two different spillover parameters λ: one for the EA-18G and F/A-18E, and one for the F-35A, B, and C models.

- ε_{jk} is the normally distributed error term.

The model requires estimating 55 coefficients, for which there are the following 52 associated variables (variables and coefficients can be different in number for non-linear models):

- 5 quality variables (the coefficients on the variables are the same over aircraft programs and time).

- 2 quantity variables (the coefficients related to these variables are the same over aircraft programs and time).

- 40 time dummies (the 41 years during 1973–2013 less one for the 2012 base year).

- 5 program-specific dummies (which are also used to capture the learning effects of model changes).[29]

There are enough data to estimate all the coefficients: 150 non-zero values for the 441 aircraft-year combinations (11 original aircraft programs during the 40 years between 1973 and 2013). The time dummies were structured such that $\delta_{FY12}{}^{D_{FY12}} = 1$, making FY 2012 the base value. The model was estimated using the maximum likelihood technique.

The range of input values and regression coefficients of the quality variables for the full model are shown in Table 9. The coefficients on weight, speed, and materials composition are consistent with those reported in past CER studies.[30] Unit prices increase with weight, maximum speed, and more advanced materials. Estimates for the 5th generation and STOVL aircraft indicated 11 percent and 10 percent premiums for those capabilities. The 5th generation premium is consistent with values from an earlier IDA paper on the cost of stealth.[31]

As described above, the Full CER model fits the data well (adjusted R^2 of 0.97 and standard error in log space of 0.09), and the coefficients were all positive and statistically

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[29] The dummy variables indicate when a model change occurs within a program that results in a loss of learning.

[30] S. A. Resetar, J. C. Rogers, and R. W. Hess, "Advanced Airframe Structural Materials: A Primer and Cost Estimating Methodology," R-4016-AF (Santa Monica, CA: RAND Corporation, 1991); Bruce R. Harmon, J. Richard Nelson, and Scot A. Arnold, "Unit Cost Implications of New Materials: Preliminary Analyses of Airframe Experience (Revised)," IDA Document D-908 REV (Alexandria, VA: Institute for Defense Analyses, 1991); Obaid Younossi, Michael Kennedy, and John C. Graser, "Military Airframe Costs: The Effects of Advanced Materials and Manufacturing Processes," MR-1370-AF (Santa Monica, CA: RAND Corporation, 2001); and Bruce R. Harmon, "Cost Estimating Techniques for Tactical Aircraft Manufacturing Labor," Unclassified/PI/LR, IDA Paper P-4490 (Alexandria, VA: Institute for Defense Analyses, May 2010).

[31] Nelson et al., "(U) Cost Estimating for Modern Combat Aircraft," Secret/PI/LR.

significant at the 5 percent level or better. The coefficients of time led to a deflator with an annualized growth rate of 6.5 percent during the period 1973–2013, significantly higher than the GDP rate of 3.7 percent.

Table 9. Quality Variables and Parameter Estimates

	Dimension	Range of Values	Coefficient
Quality Variables			
Empty Weight	Pounds	12,800–43,000	0.83
Maximum Speed	Knots	533–1434	0.30
Advanced Materials	Percentage of structural weight	4%–53%	1.67
5th Generation[a]	Dummy variable	0 or 1	1.11
STOVL Capability[b]	Dummy variable	0 or 1	1.10
Quantity Variables			
Cumulative production	Production Units	12-1,467	-0.25
Lot size[c]	Production Units	4-228	-1.00
Time dummy variables			

[a] F-22 and F-35 A/B/C, characterized by stealth, internal weapons carriage, avionics with information fusion, and support of net-centric operations.

[b] AV-8B and F-35C, with Short Take-Off and Vertical Landing capability needed for operations from small aircraft carriers and short unimproved airfield.

[c] Lot size is expected to affect unit costs through the allocation of fixed costs.

The estimated exponent of cumulative quantity is -0.25, which corresponds to an 84 percent learning curve slope, a rate commonly reported in the aircraft econometrics literature.[32] Production rate effect was calculated by estimating the annual fixed cost for each program (see footnote 30). Learning spillovers due to commonality between the EA-18G and F/A-18E/F and F-35 variants were included in the model (see footnote 30). Loss of learning due to series/block changes was also accounted for.

Figure 3 shows the fit of the model by comparing the prices predicted by the regression to the actual system prices of the aircraft programs shown by the 150 data points represented by triangles. Note that although the regression is carried out for all 22 aircraft programs, the curves in Figure 3 combine results for the 11 original designs and their derivatives. The curve labeled "F-14A/B," for example, shows how well the regression fits the data for the original design F-14A and its derivatives F-14A+ and F-14B.

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[32] In the learning curve, $Cost = Q^{\log_2 S}$, so if $\log_2 S = -0.25$, S = 0.84.
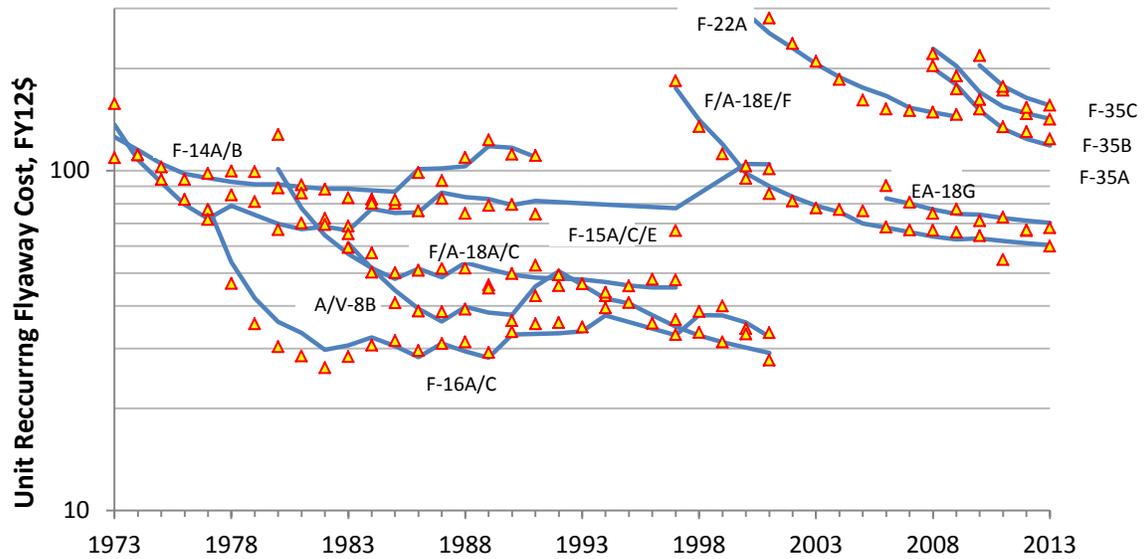
Figure 3. Fit of the Full CER Model to the Data

Figure 4 provides additional information through a Quality Index for each of the 22 aircraft programs. The Index was calculated for each program as the product of values of its quality variables, each weighted by the variable's regression coefficient and normalized to the calculated value for the F-35A. This type of exhibit can serve as a top-down check on more detailed costs.
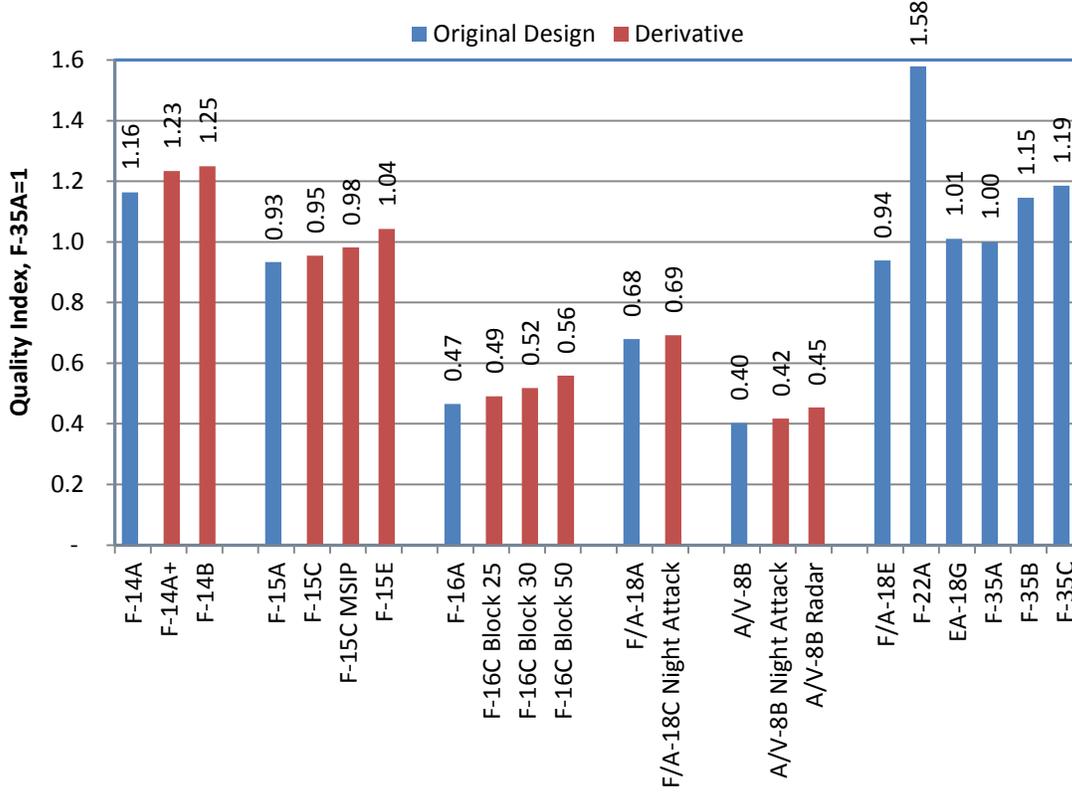
Figure 4. Estimated Quality Index for Tactical Aircraft (F-35A=1): Full CER Model Estimates

b. Preferred Hedonic Model

The functional form for the Preferred Hedonic model is shown in eq. (23). As described above, the quantity variables are omitted and the coefficients of the quality variables are set equal to their values obtained from estimating the Full CER model (indicated by the bar over $\boldsymbol{\varphi}$). The only parameters to be estimated are the coefficients of the 40 time dummy variables and an intercept term. The quality index values shown in Figure 4 are unchanged.

$$lnUC_{tk} = ln\big[f(\mathbf{Z}_k, D_t, \overline{\boldsymbol{\varphi}}, \delta_t) + \varepsilon_{jk}\big] \tag{23}$$

The Preferred model uses fewer explanatory variables than the Full CER model, which lowers the model's fit to an adjusted R^2 of 0.72 and the standard error in log space to 0.34. The index of the latter model was also substantially more volatile.

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5. Results of Hedonic Analyses and Comparisons

Figure 5 and Table 10 compare the numerical results—the annual indexes and annual growth rates—over the period 1973–2013 for the GDP deflator and the Full CER and Preferred Hedonic models.[33] Comparison is made with the GDP deflator because that is what is typically used to calculate real program growth. The hedonic models show much greater increases than the GDP deflator, in line with DoD manager expectations. They also show much greater year-to-year variability.
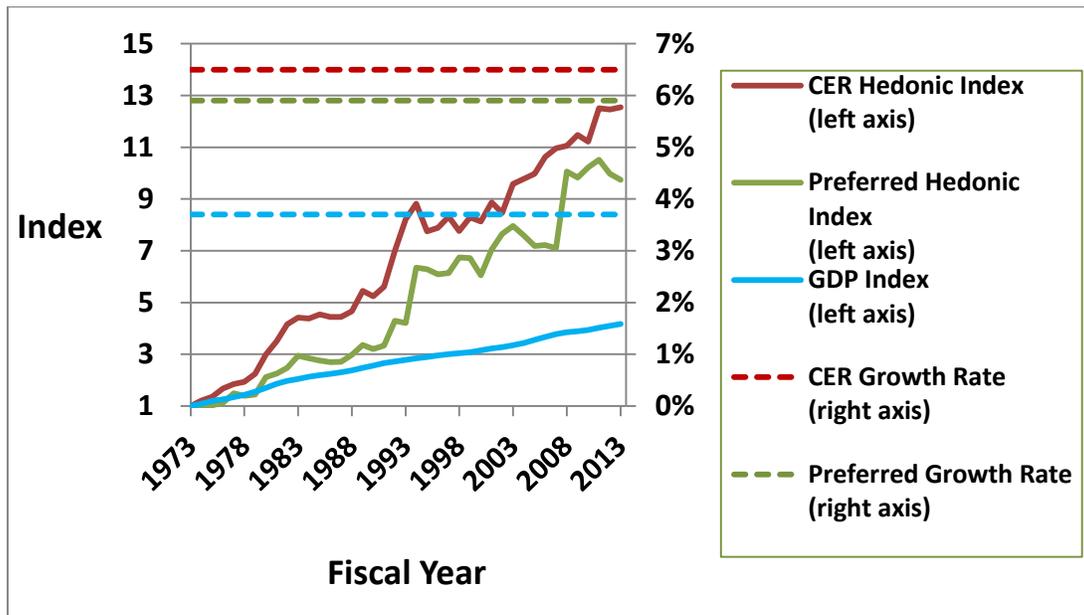

Figure 5. Hedonic and GDP Deflators

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[33] The annualized growth rate in percentage terms between index values of I_1 and I_{41} in years 1 and 41 is

$$\left(\left(\frac{I_{41}}{I_1}\right)^{\frac{1}{40}} - 1\right) \times 100.$$

Table 10. GDP and Hedonic Indexes and Growth Rates

Fiscal Year	Index			Annual Growth Rate		
	GDP	Full CER Hedonic	Preferred Hedonic	GDP	Full CER Hedonic	Preferred Hedonic
1973	1.00	1.00	1.00			
1974	1.09	1.21	1.03	9.0%	20.7%	2.8%
1975	1.19	1.36	1.02	9.5%	13.0%	-0.4%
1976	1.26	1.68	1.12	5.7%	23.0%	9.5%
1977	1.34	1.85	1.49	6.4%	10.5%	33.2%
1978	1.44	1.94	1.39	7.0%	4.6%	-6.9%
1979	1.56	2.25	1.44	8.3%	15.9%	3.7%
1980	1.70	2.99	2.12	9.1%	33.2%	47.3%
1981	1.86	3.51	2.25	9.4%	17.4%	5.9%
1982	1.97	4.17	2.47	6.1%	18.5%	9.9%
1983	2.05	4.42	2.94	3.9%	6.2%	19.0%
1984	2.13	4.38	2.84	3.8%	-1.0%	-3.5%
1985	2.19	4.54	2.76	3.0%	3.6%	-2.9%
1986	2.24	4.45	2.70	2.2%	-2.0%	-2.2%
1987	2.30	4.45	2.71	2.8%	0.0%	0.4%
1988	2.38	4.67	2.98	3.4%	4.9%	10.3%
1989	2.47	5.46	3.36	3.8%	17.0%	12.5%
1990	2.57	5.24	3.20	3.9%	-4.0%	-4.8%
1991	2.66	5.61	3.34	3.5%	7.1%	4.4%
1992	2.72	7.00	4.29	2.4%	24.8%	28.7%
1993	2.78	8.22	4.21	2.2%	17.4%	-1.9%
1994	2.84	8.82	6.34	2.1%	7.3%	50.5%
1995	2.90	7.74	6.28	2.1%	-12.2%	-1.0%
1996	2.95	7.88	6.09	1.9%	1.8%	-3.0%
1997	3.01	8.32	6.14	1.8%	5.5%	0.8%
1998	3.04	7.76	6.74	1.1%	-6.7%	9.7%
1999	3.09	8.29	6.71	1.5%	6.8%	-0.3%
2000	3.15	8.13	6.06	2.2%	-1.9%	-9.8%
2001	3.22	8.87	7.05	2.3%	9.1%	16.3%
2002	3.28	8.46	7.65	1.6%	-4.6%	8.5%
2003	3.34	9.58	7.95	2.1%	13.2%	4.0%
2004	3.44	9.77	7.59	2.8%	2.0%	-4.6%
2005	3.55	9.97	7.19	3.3%	2.0%	-5.3%
2006	3.67	10.62	7.22	3.2%	6.6%	0.4%
2007	3.77	10.95	7.10	2.9%	3.1%	-1.7%
2008	3.86	11.06	10.07	2.2%	1.0%	41.8%
2009	3.89	11.48	9.83	0.9%	3.8%	-2.4%
2010	3.94	11.22	10.22	1.3%	-2.2%	4.0%
2011	4.03	12.51	10.51	2.1%	11.5%	2.8%
2012	4.10	12.46	9.97	1.8%	-0.4%	-5.2%
2013	4.16	12.54	9.75	1.4%	0.7%	-2.2%
Annualized Growth Rate				3.7%	6.5%	5.9%

Figure 6 and Table 11 compare the growth rates of all indexes considered in this paper since 1985, the period for which all the indexes are available.
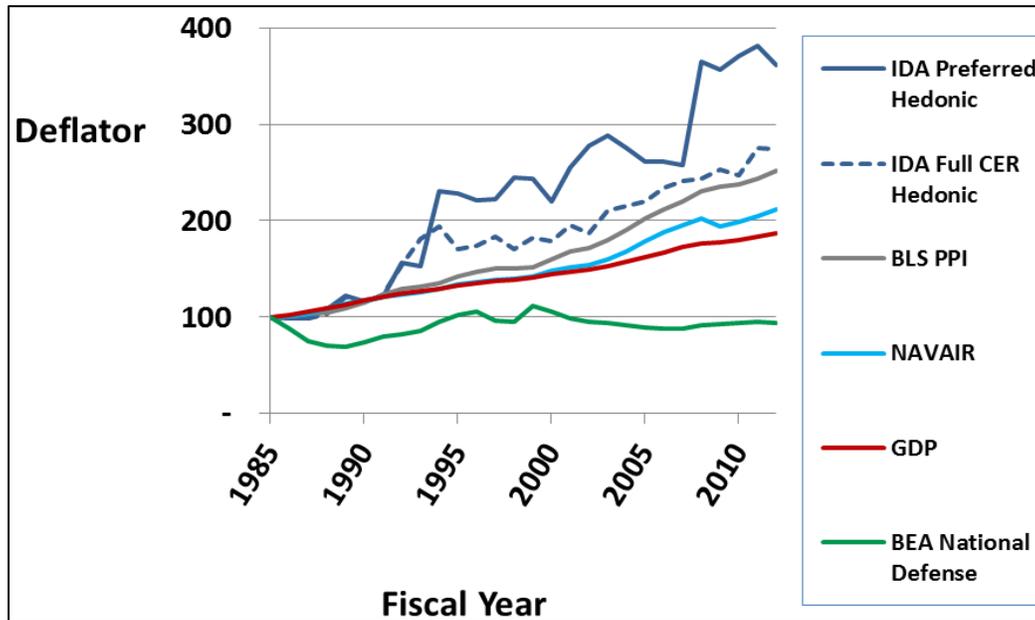

Figure 6. Comparison of Current and Projected Price Indexes, 1985–2012

Table 11. Deflator Growth Rates, 1985–2012

Price Index	Annualized Growth Rate	Coverage	Input Type of Data
IDA Preferred Hedonic Model	4.8%	Navy and Air Force tactical aircraft	Physical features
IDA Full CER Hedonic Model	3.8%	Navy and Air Force tactical aircraft	Physical features
BLS PPI	3.6%	Civilian aircraft	System cost and quality change
NAVAIR	2.9%	Navy tactical aircraft	Input prices of production labor and material[a]
GDP	2.4%	All US goods and services	Chained spending on output prices and quantities
BEA National Defense Aircraft	-0.3%	All DoD aircraft	System price and quality change

[a] Separate price indexes are first developed for individual resource categories: (1) airframe labor, (2) airframe materials, (3) engine labor, (4) engine materials, (5) electronics, (6) other GFE, and (7) overhead. These indexes are then combined by a weighted sum using their expenditures as weights to obtain an overall index for flyaway cost.

The two hedonic indexes show a relatively high growth rate that agrees with the perception in the DoD acquisition community that the GDP deflator understates annual

quality-constant price increases, and the BEA index greatly understates them. This implies that real program growth in the area of tactical aircraft procurement has been less than is generally calculated. IDA is extending hedonic and related analysis on price indexes to missiles, ground vehicles, and submarines.

Illustrations

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Abbreviations

BEA	Bureau of Economic Analysis
BLS	Bureau of Labor Statistics
CAPE	Cost Assessment and Program Evaluation
CDSR	Cost Data Summary Report
CER	Cost Estimating Relationship
CFE	Contractor Furnished Equipment
CNI	Communication, Navigation, Identification
DoD	Department of Defense
FCCM	Facilities Capital Cost of Money
G&A	General and Administrative
GDP	Gross Domestic Product
GFE	Government Furnished Equipment
GPS	Global Positioning System
IDA	Institute for Defense Analyses
INS	Inertial Navigation System
MILPERS	Military Personnel
MR	Management Reserve
NAVAIR	Naval Air Systems Command
NIPA	National Income and Product Account
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
PPI	Producer Price Index
STOVL	Short Take-Off and Vertical Landing
USD(C)	Under Secretary of Defense (Comptroller)
WSARA	Weapon Systems Acquisition Reform Act

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