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10 The Deflation of Military Aircraft

Richard C. Ziemer and Pamela A. Kelly

10.1 Introduction

The Bureau of Economic Analysis (BEA) entered into an agreement with the Department of Defense (DOD) in 1975 to develop a measure of defense purchases in constant prices and an official defense deflator. Prior to this effort, no official measures of price change for purchases of military-specific goods and services had been developed. Initial results of the study and the methodology were published in the report *Price Changes in Defense Purchases of the United States* (U.S. Department of Commerce 1979). Current- and constant-dollar estimates of defense purchases were incorporated into the national income and product accounts (NIPA) with the 1972 benchmark published in December 1980. Quarterly and annual series are available for the period 1972 to date and are published in the *Survey of Current Business.*

This paper may be considered a sequel to the general overview of the deflation of defense purchases found in an earlier work (Ziemer and Galbraith 1983). Although the paper focuses on aircraft, the techniques described apply to most other purchases of weapons systems by DOD. Defense purchases in constant dollars, other than weapons systems and compensation, are generally derived by deflation. Specification pricing, the same technique as employed by the Bureau of Labor Statistics (BLS), is used to develop price indexes from data on prices paid by DOD. These indexes are used to deflate current-dollar defense purchases. Categories of purchases for which price data are not available from DOD are deflated using proxy price indexes such as the producer price index (PPI). Constant-dollar purchases of military compensation are derived by extrapolating base year compensation by the number of active duty personnel by rank. Constant-dollar purchases of civilian compensation are de-

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rived by extrapolating base year compensation by the number of hours worked by employees by grade and step. A more detailed description of the methodology used in estimating the full range of national defense purchases may be found in U.S. Department of Commerce (1988).

The purpose of the paper is to describe in some detail the types of data that are available to BEA and the techniques used to transform these data into current- and constant-dollar defense purchases of aircraft. The paper is divided into three sections. The first section briefly reviews the general pricing techniques used in the development of prices for military equipment. The description focuses primarily on the way in which certain price-determining characteristics are treated and how this may differ from other price indexes such as the PPI and the consumer price index (CPI).

The second section, which contains the bulk of the paper, gives a detailed look at these techniques using a case study approach. We have devised price and quantity data for two hypothetical fighter aircraft. These data are used to portray many of the situations that we observe in the actual data. We hope that this detailed methodology will shed some light on what the published defense purchases series does and does not show.

The third section contains a brief summary of defense purchases of aircraft. These data illustrate the effect of these techniques on actual data.

10.1.1 Background

The goal of the defense price work was to develop measures of constant-dollar defense purchases within the framework of the NIPAs (U.S. Department of Commerce 1979, 21). This goal, coupled with the procedures used by DOD for purchasing weapons systems, dictated many of the procedures used in constructing the measures of price change. Following is a brief review of some of these procedures.

Defense purchases in the NIPAs are recorded on a delivery basis. This means that during the period that a given aircraft is being manufactured and DOD is making progress payments to the producer, BEA does not record a defense purchase. The progress payments appear as additions to business inventories. The purchase is recorded only when DOD takes delivery of the completed unit; at that time, there is also recorded a reduction in business inventories. The time lag between initiating production and the delivery of a completed unit can be as much as four years for some aircraft.

Most weapons systems are purchased by DOD as components of a system rather than as a single item. An aircraft, for example, usually has four major component contracts: engines, avionics (i.e., electronic devices for use in aviation), armament, and the airframe and assembly. In addition, there may be many smaller components that are purchased separately, such as tires and ejection seats. The engines, avionics, etc., appear as a defense purchase in the GNP when DOD accepts the item from the contractor, and at that time the price for these components will appear in the defense price index. These components are then furnished to the airframe and assembly contractor. When DOD accepts the completed aircraft, only the delivery of the airframe and assembly operation is recorded as a defense purchase in the GNP—the other components having been accepted earlier—and only then do the airframe and assembly price appear in the defense purchases price index.

Defense purchases of weapons systems in the NIPAs are derived primarily from data on quantities and prices of components delivered in each time period. The basic series are calculated as follows:

$$C_t = P_{it} \times Q_{it}, \tag{1}$$

$$K_t = P_{ib} \times Q_{it}, \tag{2}$$

$$D_t = \frac{C_t}{K_t}, \tag{3}$$

$$I_t = \frac{P_{it} \times Q_{ib}}{P_{ib} \times Q_{ib}}, \tag{4}$$

where C = deliveries in current dollars, D = implicit price deflator, P = price of item at delivery, t = time period of delivery, i = ith component ($i = 1, n$), K = deliveries in constant dollars, I = fixed-weighted price index, Q = quantity of item delivered, and b = base period.

While price and quantity estimates are collected and processed for many series, there are some items for which data are not readily available. For these items, an alternative measure for the purchase is used. Data on disbursements for a class of weapons systems (e.g., Air Force combat aircraft) are available from DOD. These data are adjusted to exclude progress payments on items for which price and quantity data are processed. The remaining disbursements are assumed to be for items that are paid for at the time of delivery and represent current-dollar purchases of unpriced items. Constant-dollar purchases are the value of the unpriced items deflated by the price index for priced items. Total purchases of weapons systems are the sum of the priced and unpriced items.

10.1.2 Measurement of Quality Change

The technique used to construct the detailed price series is of critical importance in the development of any measure of quality (or price) change. A technique known as specification pricing is used to develop the price measures for defense purchases. This is the same technique that is used by BLS in the PPI and CPI. Specification pricing consists of defining the price-determining characteristics for a given item that is to be priced and pricing items with identical characteristics over time. Price-determining characteristics for defense purchases are the physical characteristics of an item that influence its price. In addition to the physical configuration (e.g., number of engines, number of seats, etc.), price-determining characteristics for an aircraft would include

(1) materials or design that affect the aircraft's length of service, need for or ease of repairs, weight, speed, or maneuverability; (2) mechanical features that affect overall operation, efficiency, or the ability of a component to perform its function; and (3) safety features such as ejection seats. Price-determining characteristics would not include features of style, appearance, comfort, convenience, or design solely to make the aircraft appear different. Nonphysical criteria that affect the purchase price, such as the number of units purchased on a given contract or the rate at which the aircraft are to be produced, are not included as part of the specification to be priced.

Items being purchased, however, do not usually maintain the same specifications for long periods of time. Products are continually being modified, which can result in changes to the price-determining characteristics. When a change occurs in the price-determining characteristics of an item being priced, the change is evaluated to determine if it is a quality change. For defense purchases, the criteria for quality change are (*a*) that there is a physical change to the item and (*b*) that the change enhances the ability of the item to perform its mission. Each weapons system is designed for a particular mission within the overall defense program. A wide variety of missions are performed by various aircraft, from the delivery of nuclear bombs by the B-52, to long-range reconnaissance by the SR-71. Each of these missions requires an aircraft with somewhat different characteristics. The Navy's F-14 fighter aircraft, for example, has as its mission to protect a fleet of ships from enemy aircraft. This requires that it be fast, be maneuverable, have sophisticated electronics for detecting enemy aircraft at great distances, and be able to destroy the enemy aircraft before they reach the fleet. The Air Force's A-10 attack aircraft, on the other hand, has as its mission to supply close air support of ground troops. This mission requires less speed than a fighter aircraft, but the A-10 must be able to fly close to the ground, have some protective armor, and be able to destroy enemy tanks. Each physical change to an aircraft is examined to determine if it improves that aircraft's ability to perform its mission. If it does, the cost of producing that physical change is taken as the value of the quality change, and the price is adjusted accordingly. Any other change in the price paid by DOD for that item is defined as a price change.

This procedure is known as the "performance/cost-of-production" method of adjusting for quality change. Changes in performance are not used to value the quality of an item; they are used only to determine whether there has been a quality change. The value of the quality change is determined by the cost of producing the change. The following example may help clarify this technique. Assume a fighter aircraft that flies at Mach 1 with a price of $1,000 in period T. In period $T + 1$, a physical change is made to the aircraft that allows it to fly at Mach 2. An increase in speed helps a fighter aircraft perform its mission. The price of the aircraft increases to $1,500, but the cost of making the change was $300. These data yield a quality change of $300 and a price change of $200. Therefore, there is a price increase of 20 percent and a quality increase of 30 percent even though the speed of the aircraft has doubled.

Methods of adjusting for quality change other than the performance/cost-of-production method have been proposed. An alternative method of adjusting for quality change was presented in Gordon (1990). In the case of commercial aircraft, Gordon adjusted prices of identical models by a quality factor based on changes in net revenue relative to changes in the prices of aircraft purchased. Gordon found that, in the period 1965–82, net revenue rose much faster than price because jet technology brought about declining real costs for fuel, maintenance, and crew per unit of output (Gordon 1990, chap. 4). (For a discussion of the concepts of quality adjustment, see Triplett [1983]).

The procedures described above may yield somewhat different measures of price change than price indexes such as the CPI and PPI (U.S. Department of Labor 1988). The primary cause of this is the treatment of certain price-influencing characteristics. Listed below are four characteristics that are treated as price changes in defense purchases but not in the calculation of the PPI or CPI:

- *Buy size:* Differences in price due to a difference in the number of units ordered on one contract.
- *Production rate:* Differences in price due to changes requested by DOD in the production rate, such as for stretch-outs due to budget constraints.
- *Learning curve:* Differences in price due to differences in position on the learning curve (see below).
- *Producer:* Differences in price due to different producers for the same item.

In addition, any changes to a weapons system that are for the remedy of defects are defined as *not* being quality changes. It is assumed that, when a weapons system enters into production, it fits together and works.

10.1.3 Splicing Price Series

A major problem is encountered in the development of any quantity or price series when a product disappears and is replaced by a new product. The new product will not match the specifications of the old product; therefore, the price of the new product may not be directly comparable to the price of the old product. The old and new price or quantity series must be spliced together to form a continuous measure over time. There exist several procedures that can be used to handle this problem.

The first procedure is called a direct link procedure. The price of the new product is linked to the level of the price index for the old product. This procedure assumes that the entire difference in price level between the old product and the new, at the time of the introduction of the new product, is due to a difference in quality.

The second procedure is called a direct comparison. The price of the new item is directly compared to the price of the old item. This method assumes that there is no difference in quality between the two items and that any difference in the price paid is a price change.

The third procedure, and the one used for most new weapons systems, is to treat the new product as a quality adjustment to the old product. This is done by evaluating the physical differences between the old and the new products to determine whether there has been a quality change. If it is determined that there are quality differences, the cost of producing those physical changes is defined as the value of the changes, and the price is adjusted accordingly. Any other change in the price paid by DOD for the new item is a price change. However, when this procedure is used for introducing a new weapons system, the price of the new system must also be adjusted for learning-curve effects.

The learning curve represents the reduction in labor hours required for producing successive units of a new weapons system of a given technology. The new system may be superior to the system it replaces. However, the price of early units of the new system will be overstated relative to the old system, which has already experienced significant learning. In keeping with the cost analysis community, BEA assumes that, by the hundredth unit of production of a new fighter aircraft, additional learning is relatively minor. The price of the hundredth unit of the new system is compared with the price of the old system at the link point to yield the best estimate of the actual resource cost difference between the two systems. BLS waits to introduce a new product into its price index until that product has established a market share—at which time most learning has already occurred. BEA treats the higher prices for the first ninety-nine units over the hundredth unit of the new system as price increases relative to the old system. Each of these units is included in the price index as it is delivered. A more detailed discussion of learning curves and the technique for introducing new models is contained in appendix A.

10.2 Case Study

The case study uses two hypothetical aircraft to illustrate many of the data sources and procedures used in the preparation of defense purchases in the NIPAs. The case study highlights military aircraft, but the procedures are typical for most military equipment purchases. The case study begins with price derivation and continues through index creation. In the process, quality adjustments, learning curves, and splicing techniques are examined.

A new fighter aircraft, the F456, replaces an older fighter aircraft, the F123. Both aircraft include the same general component systems, but the F456 incorporates quality improvements in all components except engines. For this example, the aircraft are produced simultaneously for two years. Table 10.1 shows the price and quantity information for the last four contracts of the older aircraft, the F123. Table 10.2 shows the entire contract history for the newer aircraft, the F456. An addendum containing information pertaining to quality

Table 10.1 **F123 Unit Prices by Contract ($thousands)**

Contract number	8	9	10	11
Contract quantity (units)	70	75	75	75
Delivery year	1975	1976	1977	1978
Contractor-furnished equipment (CFE)	2,205.8	2,463.6	2,741.0	2,876.2
Airframe	1,359.4	1,506.2	1,652.8	1,737.9
Flight controls	194.7	218.0	246.7	257.0
Penetration aids	10.1	11.8	12.8	13.5
Communications equipment	8.9	10.2	12.0	12.5
Radar equipment	273.3	305.9	353.8	372.4
Fire control equipment	111.8	127.1	140.9	147.5
Weapons and armament systems	247.6	284.5	322.0	335.4
Navigation equipment	97.9	113.5	133.4	140.3
Navigation equipment (CFE)	89.8	104.5	123.5	129.8
Navigation equipment (GFE)	8.1	9.0	10.0	10.5
Government-furnished equipment (GFE)	2,097.3	2,335.1	2,489.6	2,594.4
Engines (2 per aircraft)	1,459.7	1,601.0	1,640.6	1,705.4
Other GFE	637.6	734.1	848.9	888.9
Total	4,400.9	4,912.2	5,364.0	5,610.9

change between contracts appears at the bottom of table 10.2. Notes providing additional information about the F456 also appear at the bottom of table 10.2.

To facilitate the presentation of this case study, we have made some simplifying assumptions:

1. Typically, aircraft deliveries for a given contract year begin a year or more after the contract year. In addition, deliveries for that contract can extend over more than one year. In the case study, only one contract is delivered in a year for each aircraft system. For example, all fifty-five F456 aircraft in contract 5 are delivered in 1981; therefore, we will refer to contract 5 as the 1981 F456.

2. The estimates will be shown annually; however, BEA produces quarterly estimates in current and constant dollars for the national income and product accounts.

3. Typically, the component prices developed for the estimation of defense purchases evolve from different sources. To start, prices are derived from budget estimates that contain a minimum of detail. Later, detailed contractor cost reports become available as the contract goes into production. At the completion of the contract, a final contractor cost report shows the final costs. As shown, the F123 and F456 prices represent estimates based on final contractor cost information. The data used for quality adjustment come from engineering change orders, which are DOD-approved engineering changes in the design or production of the weapon system.

4. The F123 contract history includes information for contracts 8–11. We excluded a substantial portion of the history for this aircraft; however, this

Table 10.2 **F456 Unit Prices by Contract ($thousands)**

Contract number	1	2	3	4	5	6	7	8	9	10	11	12
Contract quantity (units)	10	30	40	40	55	55	55	60	60	60	60	65
Delivery year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)	12,932.9	7,817.6	6,390.8	5,528.7	6,114.8	6,824.1	7,210.8	10,995.6	9,366.4	9,418.3	10,184.3	10,402.6
Airframe	8,321.5	4,895.0	3,965.3	3,407.7	3,696.3	4,057.5	4,306.9	5,733.2	5,204.6	5,507.5	5,775.2	5,889.0
Flight controls	652.4	567.3	521.2	494.3	687.0	682.3	725.2	764.3	815.1	840.4	873.2	897.8
Penetration aids	43.2	34.6	31.8	25.4	26.3	26.9	27.2	27.1	27.3	28.0	28.1	28.9
Communications equipment	86.8	44.5	35.6	23.1	23.6	25.1	28.0	29.6	30.1	31.4	33.7	38.0
Radar equipment	2,880.9	1,371.8	932.1	677.0	749.3	1,048.5	1,102.3	3,113.0	2,096.6	1,771.7	1,802.3	1,844.1
Fire control equipment	436.1	335.5	298.5	268.3	280.5	301.3	329.4	585.2	457.0	485.5	894.7	903.1
Weapons and armament systems	512.0	568.9	606.3	632.9	651.7	682.5	691.8	743.1	735.8	753.9	777.1	801.8
Navigation equipment	569.1	376.6	312.3	249.8	257.1	279.0	302.2	534.6	458.5	469.9	474.6	500.2
Navigation equipment (CFE)	523.8	349.2	289.9	230.4	2.1	2.2	2.8	10.8	3.2	3.3	3.7	3.9
Navigation equipment (GFE)	45.3	27.4	22.4	19.4	255.0	276.8	299.4	523.8	455.3	466.6	470.9	496.3
Government-furnished equipment (GFE)	3,675.0	3,554.8	3,723.3	3,835.2	4,949.0	5,103.9	5,690.7	6,793.6	6,900.3	8,004.1	7,694.8	8,172.0
Engines (2 per aircraft)	1,640.6	1,705.4	1,925.2	2,125.7	3,059.8	3,353.2	3,532.8	3,692.4	3,806.4	4,658.9	4,702.8	4,911.6
Other GFE	2,034.3	1,849.4	1,798.1	1,709.5	1,889.2	1,750.7	2,157.9	3,101.2	3,093.9	3,345.2	2,992.0	3,260.4
Total	17,176.9	11,749.0	10,426.4	9,613.6	11,320.9	12,207.0	13,203.8	18,323.7	16,725.2	17,892.3	18,353.6	19,074.9

Addendum: Quality issues: contract 3 = fire control software update, price declines; contract 5 = engine upgrade; contract 10 = engine upgrade; contract 5 = CFE navigation equipment to GFE; contract 6 = radar enhancement to offset advances in enemy missile technology; contract 6 = GFE mix of equipment changes, less quality; contract 7 = GFE mix of equipment changes, more quality; contract 8 = model B introduced; contract 9 = correction of minor deficiency in flight controls; contract 11 = GFE fire control to CFE.

Note: contract 1 = existing engine used for new aircraft; contract 3 = buy size for engines falls as older system disappears; contract 4 = bottom of learning curve (no learning for weapons systems); contract 9 = bottom of learning curve for new model except radar (10).

was done so as to highlight the F456 and to avoid duplication of examples. For the same reasons, we have made the unlikely assumption that no quality adjustments were needed for the F123.

Because of the nature of this case study, many of the complexities of the work to develop current- and constant-dollar defense purchases are obscured. The estimates are required long before good information becomes available. For example, learning curves must be determined with the first production contract, and the percentage changes in the level of quality for a product must be estimated before prices can be calculated.

10.2.1 Price Derivation

BEA uses many different data sources for price derivation, but the best source is the contractor cost report. An example of this type of report for the fifth F456 contract appears in figure 10.1. The report shows recurring and nonrecurring costs by element code, or system component, as of the date on the report. Estimates of these costs at the completion of the contract are also displayed. Additional sections provide information on the type or terms of the contract (sec. 5, Contract Type), the total value of the contract (sec. 6, Contract Price), and any cost-sharing arrangements that prove applicable (sec. 7, Contract Ceiling). Many editions of these reports exist for a single contract because of reporting requirements; however, the report where the "To Date" section equals the "At Completion" section, such as found in this example, is the final source of price information available to BEA.

The report indicates that the total of nonrecurring and recurring costs for the fifty-five F456 airframes (element code A1) is $246.8 million. When developing a time series for a chosen pricing component, BEA must attempt to maintain the composition of that item over time. As such, the costs described as nonrecurring, by definition, must be excluded from the price-estimating procedure. Given recurring costs of $181.4 million and a contract quantity of fifty-five airframes, the per-unit cost of the airframe is $3.299 million. To obtain the per-unit price, BEA multiplies the per-unit cost by a profit (or loss) factor that allocates a proportional value of total profit and general and administrative (G&A) costs to the individual components.

Generally, the profit factor equals the total contract price divided by the total manufacturing cost. For a firm-fixed-price contract as shown in the example, no adjustments need to be made to this formula. As a result, the profit factor for this contract is 1.120393, or 570,000/508,750. The estimated price for the airframe is $3.696 million, or $3.299 million × 1.120393. Cost-sharing agreements typical of many types of contracts complicate this procedure because of the additional elements of target and ceiling prices. Whatever the procedure, the final goal is to obtain the actual value of contractor profit given the negotiated terms of the contract.

The detail at which BEA derives prices often depends solely on the amount of data provided in the contractor reports. Most of the prices derived for the

COST DATA REPORT Dollars in 000's	1. Program Buy 5 - F456	2. ☐ RDT&E ☐ Procurement	3. Contractor ABC Aerospace, Inc.	4. Report as of 31 Dec 1982
5. Contract Type FFP	6. Contract Price 570000	7. Contract Ceiling N/A	REMARKS	

Element Code	REPORTING ELEMENTS	To Date			At Completion			
		Costs Incurred			Units	Costs Incurred		
		Non-Recurring	Recurring	TOTAL		Non-Recurring	Recurring	TOTAL
A	AIR VEHICLE - F456	65394	300277	365671	55	65394	300277	365671
A1	Airframe	65394	181453	246847	55	65394	181453	246847
A2	Flight Controls		33726	33726	55		33726	33726
A3	Penetration Aids		1291	1291	55		1291	1291
A4	Communication Equipment		1159	1159	55		1159	1159
A5	Radar		36783	36783	55		36783	36783
A6	Fire Control		13770	13770	55		13770	13770
A61	Software		6342	6342	55		6342	6342
A62	Other fire control		7428	7428	55		7428	7428
A7	Navigation Equipment		103	103	55		103	103
A71	System A		103	103	55		103	103
A72	System B		0	0	55		0	0
A8	Weapons Delivery		23994	23994	55		23994	23994
A9	Armament		7998	7998	55		7998	7998
B	SYSTEMS TEST & EVALUATION							11862
C	SYSTEM PROJECT MANAGEMENT							59384
C1	Engineering Management							23495
C2	Support Project Management							27393
C3	Other System Project Management							8496
D	DATA							38579
D1	Technical Publications							29391
D2	Engineering Data							2345
D3	Management Data							102
D5	Other							6741
E	KITS							5902
F	OTHER PROGRAM SUPPORT							27352
	TOTAL MANUFACTURING COST							508750
	General & Administrative							40000
	TOTAL COST							548750
	Profit							21250
	TOTAL PRICE							570000

Fig. 10.1 F456 cost report

F456 were calculated at the second level of element code detail (A1, A2), which is the lowest level of information shown for most elements. Although more detail exists for fire control and navigation equipment, inconsistencies between the reports for different contract years create difficulties.

For example, early contract years for the F456 display the cost information in the same format as shown in figure 10.1. Later years show fire control equipment without the added breakdown. If we had priced fire control equipment in two sections (software and other), then an adjustment would be needed when the detailed information is no longer available. We can avoid the need for an adjustment without losing much accuracy by pricing these components at a higher level of detail.

Another situation involves the weapons delivery and armament elements. Table 10.2 shows a price for the combination of these two components. The F456 reports (fig. 10.1) show them as separate items; however, the F123 reports exhibit them as a single element without additional detail. Because of this, we have chosen to combine the F456 elements to resemble the component classifications used for the F123 more closely. A more consistent time series for the weapons/armament component results. The prices displayed in table 10.2 represent the data included under the Air Vehicle element code.

As seen in tables 10.1 and 10.2, the navigation equipment components procured under both contractor-furnished equipment (CFE) and government-furnished equipment (GFE) are combined to make a single pricing series. In 1981, the majority of the CFE navigation equipment switched to GFE navigation equipment; however, the total composition of navigation equipment remains the same. Owing to the method by which BEA processes quality adjustments, switches between priced series can cause some calculation problems. To avoid these problems, we combine these two very similar series and process at the total navigation equipment level. A detailed discussion of price series switches appears later in this paper.

Problems arise when attempting to develop consistent price series for the remaining elements, such as project management or technical publications. No quantities are associated with these elements, thus making it difficult to develop per-unit prices. The contract quantity for the air vehicle could be used as a proxy quantity; however, the composition of these elements changes, so any series developed in this manner would be inconsistent over time. For example, both the 1981 and the 1982 F456 contracts have air vehicle quantities of fifty-five; however, more than fifty-five technical publications were bought in the 1982 contract. Using air vehicles as a proxy quantity in this case causes an apparent price increase for technical publications when in fact the price might be stable. Also, because the share of these items to the total value of the contract varies over time, we cannot allocate them over the Air Vehicle elements.

As mentioned earlier, current dollars equal the sum of the products of prices and quantities delivered in a given time period. Constant dollars equal the sum of the products of the quantities delivered in the given time period and the corresponding base prices. Any adjustments needed for differences in quality over time for a given product are made in the base price. As a result, constant dollars reflect purchases of a varying mix of consistent product series.

Although BEA maintains price and quantity estimates for a large number of defense purchases, insufficient data on prices, quantities, or both require us to use an alternative approach when developing current and constant dollars for some items. The unpriced items such as data and project management, as well as the costs classified as nonrecurring, must be included in current- and constant-dollar defense purchases. As mentioned earlier, data are available for disbursements by class of aircraft. Progress payments, however, are not available. The method by which estimated progress payments are removed from disbursements is referred to as the "ratio method."

The "ratio method" uses disbursements data from financial reports to approximate purchases, in any given time period, for those items not specifically priced. For example, an aircraft contract represents purchases of $1,000 over a five-year period. Of the $1,000, only $750 appears in the data base of priced items. The remaining $250 is spread over the five years of the program by assigning 25 percent of all disbursements to current dollars in the time period when the disbursement is made. If disbursements in the first year are $200, the current-dollar unpriced items are $50 ($200 × .25). To calculate purchases, the $50 is then added to any current dollars that result from deliveries of aircraft in that year. This procedure assures that all appropriate DOD expenditures appear as defense purchases. To obtain constant dollars, the current dollars for unpriced items are deflated using the priced items as a proxy. Constant-dollar purchases then equal the sum of constant dollars for priced and unpriced items.

10.2.2 Price Series Splicing

A common problem in developing current- and constant-dollar defense purchases occurs with the introduction of new products. The case study example illustrates this problem with the F123 that ends in 1978 and the F456 that begins in 1977. A common method used to deal with this problem is to treat the new product as a quality adjustment to the old product. An evaluation of the physical differences between the old and the new systems in this case shows that quality improved for all components except engines. (The previously upgraded engines for the F123 are used without modification for the first four contracts of the F456.)

The procedure to calculate the quality adjustment for the new product is similar to the method used to calculate the value of quality change for a model change in a single system. Prices at comparable levels of production efficiency for both systems are estimated in prices of a single time period. The technique for choosing a comparison time period varies with the circumstances of the product series.

In the case study example, both the F123 and the F456 were produced in 1977. We need to estimate the value of quality change in 1977 dollars, so it is logical to choose 1977 as the comparison time period. This eliminates the need to adjust the calculated value of quality change to dollars of another time period and, therefore, reduces the amount of the estimation error in the calculations.

Although prices already exist for the F456 in 1977 dollars, they reflect costs at the top of the learning curve and represent an inefficient level of production. If the actual 1977 F456 prices are used in the quality-adjustment calculations, the value of quality change between the two aircraft would be grossly overstated. To eliminate this problem, prices at the bottom of the learning curve for the new system are chosen—1980 F456—as the starting point for the estimation procedure. These prices represent the point where labor efficiency in the new system is comparable to that in the old system. Once the new 1977 prices for the 1980 F456 have been estimated by removing a value for price change between these two time periods, they can be directly compared with the prices for the F123. The difference between the adjusted F456 prices and the F123 prices equals the value of quality change for the new system in 1977 dollars.

For example, the price of the F123 airframe in 1977 (contract 10 in table 10.1) is 1,652.8. The price of the F456 airframe at the bottom of the learning curve is 3,407.7 (contract 4 in table 10.2). Estimating and removing price change between 1977 and 1980 gives a price for the F456 airframe in 1977 dollars. The value of the price change must be based on a relevant price series that reflects a pure price change. The BEA has a limited choice of proxies for this purpose. The price series for another aircraft can provide a good source of price change if production of the other aircraft remains steady in the relevant time period. If such a source is unavailable, then we have to use a general price index for aircraft or aircraft components to estimate price change. For the purposes of this case study, a historical DOD procurement index series was used to estimate price change between contracts. In this case, the value of price change between 1977 and 1980 for the airframe is 888.7, and the resulting price estimate for the airframe in 1977 dollars is 2,519.0. Taking the difference between the prices for the two systems gives a quality adjustment of 866.2 (2,519.0 − 1,652.8) in 1977 dollars.

Often, the time period chosen for the splice represents the time when the decision was made to proceed with the procurement of the new product. This is generally the case when the two products do not have an actual overlap time period. For example, the government decides to procure the F456 in 1976 and deliveries start in 1977. If we assume that the F123 was last delivered in 1975, then we would estimate the F123 in 1976 prices and compare it with the estimates for an efficiently produced F456 in 1976 prices. The resulting values of quality change must then be adjusted to reflect prices comparable to the first delivery prices of the F456.

As the table 10.2 notes to contract 4 mention, the 1980 F456 represents the bottom of the learning curve for all components except the weapons and armament systems, which have no apparent learning curve. Because there is no need to adjust the 1977 F456 price for weapons and armament systems in order to derive a comparable level of production efficiency with the F123, the two systems can be linked without adjustments. The price of the F456 weapons and armament systems is 512.0 in 1977, and the price for similar F123 systems is 322.0 in 1977. If we assume that the entire difference in price is due to quality improvement, then the value of the quality change is 190.0 (512.0 − 322.0). Table 10.3 displays the quality adjustments by component for the entire F456 program.

A splicing technique must also be used when data sources for a single system change to the extent that the component prices no longer represent the same items. For example, contractor data exist for a substantial portion of a program, but budget documents provide the only available information for current and future contracts. The contractor information details cost data by component. The budget documents provide a single price for the combination of airframe and all other contractor-furnished equipment. Obviously, the contractor-furnished airframe price and the budget document airframe price represent different levels of detail and cannot be used in the same price series without adjustments.

One way in which we can handle this situation is to make a quality adjustment to the existing series. For example, on the basis of the last available contractor information, the price of the airframe could be quality adjusted using the sum of the prices of the other components as the value of the quality improvement. This estimate could then be used with the price derived from the budget documents. This procedure may sound acceptable, but it has many problems in practical application. For example, the budget documents include not only the same components extracted from contractor reports but also an unspecified and variable mix of other items. An estimate could be developed to account for this problem; however, the value developed for the quality adjustment in such a case becomes very judgmental.

The preferred way in which to handle the problems associated with changing data sources is to develop an alternative price series composed strictly of budget data. This series would then be used to move the primary pricing components, which are derived from contractor reports, in the relevant time periods. For those time periods in which the contractor data are available, the budget data series remains inactive and does not influence the derivation of current- and constant-dollar defense purchases. This procedure holds an advantage because it requires no arbitrary decisions about the composition of the budget aggregation.

10.2.3 Quality Valuation

Once component prices have been established for the systems and the two weapons systems have been spliced, the next major step in constructing a

Table 10.3 **Value of Quality Adjustments for the F456 ($thousands)**

Contract number	1	2	3	4	5	6	7	8	9	10	11	12
Contract quantity (units)	10	30	40	40	55	55	55	60	60	60	60	65
Delivery year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)												
Airframe	866.2							530.2				
Flight controls	118.6							17.3	0.0			
Penetration aids	6.0											
Communications equipment	5.0											
Radar equipment	146.7					235.1		511.3				
Fire control equipment	57.4		0.0					97.6			400.0	
Weapons and armament systems	190.0											
Navigation equipment	51.2				0.0			127.5				
Navigation equipment (CFE)	46.9				−235.0			.2				
Navigation equipment (GFE)	4.4				235.0			127.3				
Government-furnished equipment (GFE)												
Engines (2 per aircraft)					710.5					640.1		
Other GFE	414.7					−300.0	319.0	736.1			−444.9	
Total												

current- and constant-dollar series is the valuation of quality change within a particular system. For simplicity, we assume that the quality for each of the components of the F123 remains the same for the four contracts shown. We can then concentrate on the quality adjustments needed for the F456.

The first quality issue listed in the addendum to table 10.2 appears in 1979 (contract 3) when the contractor updates the fire control software. In the F456 program, the fire control software update incorporates new processing technology that increases the speed of calculations. The important point in this case is that the price of the improved software is less than the price of the original software—335.5 in 1978 and 298.5 in 1979. Given the performance/cost-of-production method of adjusting for quality change and the rule that the cost of producing the physical change is the value of the quality improvement, we would not make any adjustments for the software update (see sec. 10.1.2 above).

The next quality issue appears in 1981 (contract 5) when the government purchases upgraded engines. The new engines increase the performance of the aircraft and, therefore, qualify as a quality adjustment. The value of the quality change equals the difference in prices between 1980 and 1981 less an adjustment for price change. In the example, quality change is 710.5 (3,059.8 − 2,125.7 − 223.6), where 223.6 is the estimate of price change based on a relevant price indicator series. The engine upgrade shown in 1986 (contract 10) is processed in the same manner.

The 1981 contract also includes another type of quality adjustment. In the example, contractor-furnished equipment and government-furnished equipment both include purchases of navigation equipment. In this contract year, the majority of the navigation equipment formerly procured from the prime contractor switched from CFE to GFE. The price for this equipment in 1981 is 235; therefore, the value of quality change for CFE navigation equipment is −235, and the value of quality change for GFE navigation equipment is 235. As mentioned earlier, switches such as this can cause problems in later calculations. In this case study, these two subcomponents never influence the final results. All processing is done at the level of total navigation equipment, where the quality-adjustment effect is zero.

The next quality adjustment occurs in 1982 (contract 6) when the radar is improved to offset advances in enemy missile technology. This quality adjustment is similar to the engine upgrade mentioned before. In this case, the value of the quality change is 235.1 (1,048.5 − 749.3 − 64.1), where 64.1 is the estimate of price change between 1981 and 1982.

The contracts for 1982 and 1983 (contracts 6 and 7) show the effects of changes in the mix of equipment for other GFE. For simplicity in this case study, we assume that the other GFE component contains a consistent mix of equipment in most contracts. Typically, the other GFE components of an aircraft system can vary substantially from one contract to the next. In these two contracts, the number of repair kits purchased falls in 1982 and resumes in

1983. The value of the repair kits not purchased in 1982 is 300, so the value of the quality adjustment for this component is −300. In 1983, we assume that the price of repair kits has increased by the same amount as the remaining components within other GFE; therefore, the value of the repair kits purchased and, thus, the quality adjustment is 319.0.

A model change usually requires some additional considerations when calculating the value of quality adjustment. In many instances, the price series will exhibit learning-curve characteristics, and additional steps must be taken so as not to overstate the value of the quality adjustment.

In 1984 (contract 8), deliveries for the new B model of the F456 begin. The data show evidence of a learning curve for some components of the new model, including the airframe, radar equipment, fire control equipment, navigation equipment, and other GFE. Quality improves for flight controls, but no learning curve is evident. The remaining components (penetration aids, communications equipment, weapons, and engines) do not have significant quality changes. In the example, the bottom of the learning curve for the new model is reached in 1985 for all components except radar equipment. The bottom of the learning curve for the radar equipment appears in 1986.

To calculate the correct value of the quality adjustment, we estimate the price of the A model in 1984 prices. Then we estimate the price of the B model at the bottom of the learning curve (1985 for all items except radar) in 1984 prices. The difference between the estimated prices for the B model and the estimated prices for the A model equals the value of quality adjustment for the new model.

For example, we estimate the price of the airframe for the A model in 1984 dollars as 4,507.2 (4,306.9 × 1.0465), where 1.0465 is the factor used to adjust for price change between 1983 and 1984. As mentioned earlier, for the case study, the value or factor used to adjust for price change between two time periods comes from a DOD procurement price indicator series. The price of the B model in 1984 dollars, derived from prices at the bottom of the learning curve, is 5,037.4 (5,204.6/1.0332), where 1.0332 is the factor used to adjust for price change between 1984 and 1985. The value of the quality adjustment for the new model airframe equals the difference between 5,037.4 and 4,507.2, or 530.2. The same procedure is used for all components; however, for radar equipment, the factor accounts for price change between 1984 and 1986. Also, because flight controls do not have a learning curve, no adjustment was necessary. The calculation of the quality adjustment for this component is identical to that for the engine upgrades explained earlier.

The next quality issue appears in 1985 (contract 9). A minor problem was discovered in the flight controls for the new B model. An engineering change order was instituted to correct the production deficiency responsible for the flaw in the flight controls, and the cost of the correction is $7,000 per aircraft. Although such a case, by its very nature, indicates a quality improvement, BEA would not make any adjustment in the constant-dollar purchases series.

In other words, the cost of the correction of a deficiency on a production aircraft will appear as a price change. As mentioned earlier, it is assumed that, when a system starts into production, it fits together and works.

The last quality-adjustment issue mentioned in the notes to table 10.2 concerns a GFE-CFE switch in 1987 (contract 11). Some fire control equipment previously included in the other GFE component is now being purchased as CFE. This case shows the opposite of the situation explained earlier for navigation equipment, but, in this situation, the two pricing series remain separate. On the basis of contractor cost information, the price of the fire control equipment is 400.0. Thus, the value of quality improvement for CFE radar equipment is 400.

Previously, we alluded to calculation problems when making quality adjustments for switches between pricing series. Assuming no other quality adjustments, the net effect on the total quality for the aircraft after a price series switch should be zero. In order to achieve this result, the quality adjustment for one series must equal a value that will offset the constant-dollar implications of the quality adjustment in the other series. The technique by which this is done involves some concepts not yet discussed in this case study; therefore, at this time, we will say only that the value of the quality adjustment for other GFE is −444.9. Appendix B discusses the problems of switches and quality valuation in detail.

10.2.4 Quality Factors

To account for quality adjustment in constant-dollar defense purchases, BEA adjusts the base price of a series to reflect the change in quality. Each current price reflects a certain level of quality in the product series, so we derive a quality-adjusted base price for every current price. The technique by which this is done involves the derivation of quality factors and cumulative quality factors. Quality factors are a way of expressing the value of quality change as a percentage change. Cumulative quality factors allow us to compare levels of quality over a sequence of contracts. Each current or contract price in a price series has a quality factor and a cumulative quality factor.

For example, a product originally costs $500 and a quality improvement occurs that is valued at $50. Quality improves by 10 percent; therefore, the quality factor is 1.100. Subsequently, the price of the product rises to $700, and another quality adjustment occurs that is valued at $35. This new quality adjustment is a 5 percent improvement over the already improved product, and the quality factor is 1.050. The two values of quality improvement are not comparable, given the price changes, and cannot be added; however, using quality factors, the difference in the levels of quality between the first and the latest observations can be expressed as another percentage change. This cumulative quality factor for the newest version of the product equals the product of the quality factors, or 1.155 (1.100 × 1.050).

In general, the quality factor equals a quality-adjusted price divided by a non-quality-adjusted price. In practice, we use two variations of this equation to derive quality factors. The method used depends on the situation and the assumptions made about the price and quality values available for use in the equation. The two methods are shown below (U.S. Department of Commerce 1975, 65). Equation (5) shows method 1, the adjusted current price link method, and equation (6) shows method 2, the back link method:

$$F_s = \frac{P_s}{P_s - V_s}, \tag{5}$$

$$F_s = \frac{P_{s-1} + V_s}{P_{s-1}} \tag{6}$$

where F = quality factor, V = value of quality change, P = price, and s = contract sequence.

Although the above equations can be expressed in notations indicating time, quality factors really represent changes in quality over a sequence of contracts or purchases. Often, this loosely corresponds to time; however, that is not always the case. Because contracts may overlap in a real time series, the boundaries of time with regard to quality are not clear. Also, a quality factor may represent the change in quality between two different systems in the same time period. In that case, s represents the new system and $s - 1$ represents the previous or older system. For example, to splice the F456 to the F123, we develop a quality adjustment in 1977 based on prices for each system in 1977.

The adjusted current price link method, which is the most commonly used technique, uses the current product price as the quality-adjusted price in the numerator. The denominator is an estimate of the non-quality-adjusted price, which is derived by subtracting the value of quality change from the current price. This equation generates a legitimate quality factor only when the price and quality values are expressed in terms of the same level of production efficiency.

The back link method uses product prices from the previous contract in the equation. The quality-adjusted price in the numerator is the price of the previous contract plus the value of the quality adjustment between the two contracts in question. The denominator is the price of the previous contract. The implications of this technique require that the price and quality values used in the equation are expressed in terms of the same price level as well as the same level of production efficiency.

For example, if P_{s-1} and Q_s are expressed in dollars of different time periods, then a quality adjustment based on the sum of these two values (P_{s-1} and V_s) ignores any price change evident between the two time periods represented by the contracts $s - 1$ and s. If P_{s-1} is $100, P_s is $200, and V_s is $90, then, using the back link method, the resulting quality factor is 1.9, or

(100 + 90)/100. Prices between contract $s-1$ and contract s increase 10 percent, so $s-1$ and s dollars are not equivalent. But, by using the back link method to calculate the quality factor, an assumption of equivalence is made. As a result, the quality factor in this example would be overstated.

We generally use the back link method when the value of the quality change and the two prices are all expressed in comparable dollars but the levels of production efficiency differ. This is the case when splicing two price series or when changing models. The value of quality change incorporated in the new product is based on an estimate of an efficiently produced item in that time period. In other words, the price is adjusted for the learning curve before the quality calculation is done. During the procedure, a price for the older product is also generated for that time period if a price does not already exist. The back link method allows us to estimate a meaningful value in the numerator, namely, the price of the previous product if a quality adjustment had occurred. For example, the 1977 F123 airframe price of 1,652.8 plus the value of quality change of 866.2 for the 1977 F456 airframe is a realistic estimate of a quality-improved airframe in 1977 dollars.

On the other hand, in a case where the learning curve is a factor, the adjusted current price link method generates a meaningless denominator because the price and quality values represent different levels of production efficiency. For example, in 1977, the price of the F456 airframe is 8,321.5, and the value of the quality change is again 866.2. Using the adjusted current price link method, the quality factor is 1.116, or 8,321.5/(8,321.5 − 866.2). The quality factor is meaningless because the denominator has no economic meaning. The price of 8,321.5 is abnormally high because of the learning-curve considerations, but the quality change value of 866.2 already includes adjustments to remove the learning-curve effect. Therefore, using this method to calculate the quality factor understates the value of quality change. It should be noted that, if a price that had been adjusted for the learning curve were used in place of 8,321.5, then this equation would generate a legitimate quality factor equal to that generated by the back link method.

Given comparable prices and quality values, either the back link or the adjusted current price link technique can be used to obtain the correct quality factor. In practice, we find it easier to calculate quality factors by making a distinction between these two methods. In the case study, the back link method was used to calculate component quality factors in those time periods when prices are at the top of the learning curve—1977 and 1984. The adjusted current price link method was used in all other time periods.

For example, for the 1977 (contract 1) F456 airframe, the price is 8,321.5, and the value of quality change is 866.2. The price for the previous observation is 1,652.8, or the price of the F123 in 1977. Using the back link method, the quality factor is 1.5241, or (1,652.8 + 866.2)/1,652.8. In 1986, the quality factor for the engines using the adjusted current price link method is 1.1593, or 4,658.9/(4,658.9 − 640.1).

Once the quality factors have been calculated, cumulative quality factors for the product series must be derived. The cumulative quality factor is 1.000 for the first observation of a pricing component, and subsequent cumulative quality factors accumulate multiplicatively from this point. The choice of the base year has no relevance in the equation. As in equations (5) and (6), the cumulative quality factor is derived for each product series by contract sequence:

$$M_s = M_{s-1} \times F_s, \tag{7}$$

where M = cumulative quality factor, F = component quality factor, and s = contract sequence.

In the case example, as mentioned earlier, we are assuming that quality is unchanged for the F123. As a result of this assumption, the quality factors for each of the F123 components for contracts 8–11 must equal 1.000. The cumulative quality factors for these contracts also equal 1.000.

Cumulative quality factors change when the new system is introduced. For the 1977 F456 airframe, the quality factor is 1.5241. When multiplied by the cumulative quality factor for the previous contract (1.000), the cumulative quality factor for the airframe in 1977 is also 1.5241. The next available airframe quality adjustment occurs in 1984 when the B model is introduced. The quality factor for the 1984 airframe is 1.1176, and, when multiplied by the cumulative quality factor for 1983, the cumulative quality factor for 1984 is 1.7034, or (1.5241 × 1.1176). In other words, the quality of the B model of the F456 is 70.3 percent greater than that of the F123.

Tables 10.4 and 10.5 show the component quality factors and cumulative quality factors for each contract.

10.2.5 Base Price Derivation

Cumulative quality factors allow us to calculate base prices for any base year with little difficulty. We do this by calculating what we call a *non-quality-adjusted base price* for each component series for the base year in question. The non-quality-adjusted base price equals the base period current dollars divided by the product of the base period quantity and base period cumulative quality factor. In other words, for a given base year, the non-quality-adjusted base price is the base price for the first observation of a component series.

$$N = \frac{P_b}{M_b}, \tag{8}$$

where N = non-quality-adjusted base price, M = cumulative quality factor, P = price, and b = base period.

This simple equation illustrates the procedure when only one contract is delivered in the base year. If different contract values exist in the base period, then each of the contract quantities must be multiplied by its respective price in the numerator and its cumulative quality factor in the denominator.

Table 10.4 F456 Quality Factors by Contract

Contract number	1	2	3	4	5	6	7	8	9	10	11	12
Contract quantity (units)	10	30	40	40	55	55	55	60	60	60	60	65
Delivery year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)												
Airframe	1.5241	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.1176	1.0000	1.0000	1.0000	1.0000
Flight controls	1.4808	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0232	1.0000	1.0000	1.0000	1.0000
Penetration aids	1.4681	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Communications equipment	1.4186	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Radar equipment	1.4148	1.0000	1.0000	1.0000	1.0000	1.2891	1.0000	1.4432	1.0000	1.0000	1.0000	1.0000
Fire control equipment	1.4073	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.2830	1.0000	1.0000	1.8085	1.0000
Weapons and armament systems	1.5899	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
Navigation equipment	1.3838	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.4030	1.0000	1.0000	1.0000	1.0000
Navigation equipment (CFE)	1.3795	1.0000	1.0000	1.0000	0.0089	1.0000	1.0000	1.0636	1.0000	1.0000	1.0000	1.0000
Navigation equipment (GFE)	1.4368	1.0000	1.0000	1.0000	12.7500	1.0000	1.0000	1.4062	1.0000	1.0000	1.0000	1.0000
Government-furnished equipment (GFE)												
Engines (2 per aircraft)	1.0000	1.0000	1.0000	1.0000	1.3025	1.0000	1.0000	1.0000	1.0000	1.1593	1.0000	1.0000
Other GFE	1.4885	1.0000	1.0000	1.0000	1.0000	0.8537	1.1735	1.3260	1.0000	1.0000	0.8706	1.0000

Table 10.5 **F456 Cumulative Quality Factors by Contract**

Contract number	1	2	3	4	5	6	7	8	9	10	11	12
Contract quantity (units)	10	30	40	40	55	55	55	60	60	60	60	65
Delivery year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)												
Airframe	1.5241	1.5241	1.5241	1.5241	1.5241	1.5241	1.5241	1.7034	1.7034	1.7034	1.7034	1.7034
Flight controls	1.4808	1.4808	1.4808	1.4808	1.4808	1.4808	1.4808	1.5151	1.5151	1.5151	1.5151	1.5151
Penetration aids	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681	1.4681
Communications equipment	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186	1.4186
Radar equipment	1.4148	1.4148	1.4148	1.4148	1.4148	1.8238	1.8238	2.6321	2.6321	2.6321	2.6321	2.6321
Fire control equipment	1.4073	1.4073	1.4073	1.4073	1.4073	1.4073	1.4073	1.8056	1.8056	1.8056	3.2655	3.2655
Weapons and armament systems	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899	1.5899
Navigation equipment	1.3838	1.3838	1.3838	1.3838	1.3838	1.3838	1.3838	1.9415	1.9415	1.9415	1.9415	1.9415
Navigation equipment (CFE)	1.3795	1.3795	1.3795	1.3795	0.0122	0.0122	0.0122	0.0130	0.0130	0.0130	0.0130	0.0130
Navigation equipment (GFE)	1.4368	1.4368	1.4368	1.4368	18.3197	18.3197	18.3197	25.7612	25.7612	25.7612	25.7612	25.7612
Government-furnished equipment (GFE)												
Engines (2 per aircraft)	1.0000	1.0000	1.0000	1.0000	1.3025	1.3025	1.3025	1.3025	1.3025	1.5099	1.5099	1.5099
Other GFE	1.4885	1.4885	1.4885	1.4885	1.4885	1.2708	1.4912	1.9773	1.9773	1.9773	1.7214	1.7214

Once the non-quality-adjusted base price has been derived, the base price for any individual contract within the component series can be calculated. The base price equals the non-quality-adjusted base price multiplied by the cumulative quality factor:

$$B_s = N \times M_s, \tag{9}$$

where N = non-quality-adjusted base price, M = cumulative quality factor, B = base price, and s = contract sequence.

For example, the base year for consideration is 1975 = 100. The F123 engines have a price of 1,459.7, a quantity of 70, and a cumulative quality factor of 1.000 in the base year. Using equation 8, the non-quality-adjusted base price for engines is 1,459.7, or (1,459.7 × 70)/(70 × 1.000).

The cumulative quality factor for engines changes for the 1981 contract of the F456. Using equation (9), the base price for the 1981 engines is 1,901.2, or (1,459.7 × 1.3025).

Table 10.6 displays the 1975 = 100 base prices for each of the component contract values. Table 10.7 displays the resulting price indexes using the price, quantity, and base price information. Table 10.8 shows purchases in constant 1975 prices.

10.3 Conclusions

This case study has examined many issues and procedures common to the work done at the Bureau of Economic Analysis for the derivation of the constant-dollar defense purchases series for military equipment. Aircraft, which is the largest of the durable goods aggregations, accounted for 8.7 percent of defense purchases in 1982. Since 1982, the portion of defense purchases attributable to aircraft has fluctuated between 8.3 and 11.9 percent. Since the 1987 high of 11.9 percent of defense purchases, aircraft's share of the total has gradually declined to 10.5 percent in 1989. The aircraft series detailed in this case study is typical of most of the major equipment purchases included in defense current and constant dollars. Some additional observations might prove useful.

10.3.1 Highlights

The base year presented in the case study is 1975. During that time, the F123 is a mature program with efficient production quantities, and the F456 has not yet appeared. Base prices represent prices at efficient production levels. Consider another base year. In 1984, the deliveries of a new model F456 begin, and, as explained earlier, many of the components such as the airframe and radar equipment have learning curves. As a result, a time series using 1984 base prices would reflect inefficient production levels for many of the components. Given multiple aircraft series in a 1984 = 100 base, the case study aircraft will have a relatively higher importance solely because of the location of the base period in relation to this aircraft's learning curve.

Table 10.6 **Base Prices, CY 1975 = 100 ($thousands)**

													Non-Quality-Adjusted Base Price
Contract number	1	2	3	4	5	6	7	8	9	10	11	12	
Contract quantity (units)	10	30	40	40	55	55	55	60	60	60	60	65	
Delivery year	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	
Contractor-furnished equipment (CFE)	3,325.3	3,325.3	3,325.3	3,325.3	3,325.3	3,437.0	3,437.0	3,952.9	3,952.9	3,952.9	4,116.1	4,116.1	2,205.8
Airframe	2,071.9	2,071.9	2,071.9	2,071.9	2,071.9	2,071.9	2,071.9	2,315.6	2,315.6	2,315.6	2,315.6	2,315.6	1,359.4
Flight controls	288.3	288.3	288.3	288.3	288.3	288.3	288.3	295.0	295.0	295.0	295.0	295.0	194.7
Penetration aids	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	10.1
Communications equipment	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	12.6	8.9
Radar equipment	386.6	386.6	386.6	386.6	386.6	498.4	498.4	719.3	719.3	719.3	719.3	719.3	273.3
Fire control equipment	157.3	157.3	157.3	157.3	157.3	157.3	157.3	201.8	201.8	201.8	365.0	365.0	111.8
Weapons and armament systems	393.6	393.6	393.6	393.6	393.6	393.6	393.6	393.6	393.6	393.6	393.6	393.6	247.6
Navigation equipment	135.4	135.4	135.4	135.4	135.4	135.4	135.4	190.0	190.0	190.0	190.0	190.0	97.9
Navigation equipment (CFE)													
Navigation equipment (GFE)													
Government-furnished equipment (GFE)	2,408.8	2,408.8	2,408.8	2,408.8	2,850.3	2,711.5	2,852.0	3,162.0	3,162.0	3,464.8	3,301.6	3,301.6	2,097.3
Engines (2 per aircraft)	1,459.7	1,459.7	1,459.7	1,459.7	1,901.2	1,901.2	1,901.2	1,901.2	1,901.2	2,204.0	2,204.0	2,204.0	1,459.7
Other GFE	949.1	949.1	949.1	949.1	949.1	810.2	950.8	1,260.7	1,260.7	1,260.7	1,097.5	1,097.5	637.6
Total	5,869.5	5,869.5	5,869.5	5,869.5	6,311.0	6,283.9	6,424.5	7,304.8	7,304.8	7,607.6	7,607.6	7,607.6	4,400.9

Table 10.7 **Implicit Price Deflators** (CY 1975 = 100)

	Delivery Year													
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)	100.000	111.688	168.561	169.782	192.190	166.264	183.889	198.546	209.797	278.167	236.952	238.266	247.428	252.733
Airframe	100.000	110.797	168.882	168.908	191.387	164.476	178.405	195.837	207.872	247.592	224.763	237.843	249.402	254.318
Flight controls	100.000	111.939	143.126	156.078	180.753	171.419	238.258	236.619	251.514	259.050	276.268	284.835	295.960	304.281
Penetration aids	100.000	116.754	153.853	170.513	214.798	171.568	177.647	181.700	183.726	183.051	184.402	189.130	189.806	195.209
Communications equipment	100.000	114.296	222.983	216.984	282.126	182.721	187.176	198.823	221.897	234.577	238.539	248.842	267.069	301.146
Radar equipment	100.000	111.939	227.142	215.235	241.072	175.105	193.794	210.362	221.156	432.766	291.457	246.291	250.551	256.362
Fire control equipment	100.000	113.698	149.933	161.252	189.743	170.522	178.301	191.523	209.385	289.936	226.398	240.540	245.120	247.409
Weapons and armament systems	100.000	114.901	130.067	138.998	154.026	160.784	165.560	173.385	175.747	188.780	186.925	191.523	197.417	203.692
Navigation equipment	100.000	115.936	180.560	191.371	230.601	184.435	189.851	206.023	223.190	281.346	241.325	247.326	249.769	263.270
Navigation equipment (CFE)														
Navigation equipment (GFE)														
Government-furnished equipment (GFE)	100.000	111.340	123.199	131.216	154.571	159.215	173.629	188.235	199.533	214.854	218.227	231.014	233.064	247.520
Engines (2 per aircraft)	100.000	109.678	112.393	116.833	131.888	145.623	160.935	176.369	185.816	194.210	200.206	211.381	213.372	222.846
Other GFE	100.000	115.144	146.593	160.111	189.458	180.119	199.058	216.077	226.962	245.986	245.404	265.339	272.607	297.069
Total	100.000	111.617	147.665	152.777	177.637	163.790	179.383	194.258	205.523	250.844	228.961	235.189	241.253	250.734

Table 10.8 **Constant Dollars (CY 1975 = 100)**

	Delivery Year													
	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
Contractor-furnished equipment (CFE)	154,404	165,432	198,685	265,190	133,010	133,010	182,889	189,037	189,037	237,172	237,172	237,172	246,963	267,544
Airframe	95,158	101,955	122,674	164,111	82,875	82,875	113,953	113,953	113,953	138,936	138,936	138,936	138,936	150,514
Flight controls	13,631	14,605	17,488	23,255	11,534	11,534	15,859	15,859	15,859	17,702	17,702	17,702	17,702	19,178
Penetration aids	706	756	904	1,200	592	592	814	814	814	888	888	888	888	962
Communications equipment	623	667	793	1,046	505	505	694	694	694	757	757	757	757	820
Radar equipment	19,131	20,497	24,364	32,097	15,466	15,466	21,266	27,413	27,413	43,160	43,160	43,160	43,160	46,757
Fire control equipment	7,825	8,384	9,957	13,103	6,293	6,293	8,652	8,652	8,652	12,110	12,110	12,110	21,901	23,727
Weapons and armament systems	17,331	18,568	22,505	30,378	15,745	15,745	21,650	21,650	21,650	23,618	23,618	23,618	23,618	25,586
Navigation equipment	6,850	7,340	8,694	11,402	5,417	5,417	7,448	7,448	7,448	11,400	11,400	11,400	11,400	12,350
Navigation equipment (CFE)														
Navigation equipment (GFE)														
Government-furnished equipment (GFE)	146,812	157,299	181,387	229,563	96,352	96,352	156,767	149,131	156,861	189,717	189,717	207,885	198,094	214,602
Engines (2 per aircraft)	102,181	109,480	124,077	153,271	58,389	58,389	104,568	104,568	104,568	114,074	114,074	132,242	132,242	143,262
Other GFE	44,631	47,819	57,310	76,291	37,963	37,963	52,199	44,563	52,293	75,643	75,643	75,643	65,852	71,340
Total	308,066	330,071	388,765	506,155	234,779	234,779	347,104	345,616	353,346	438,290	438,290	456,458	456,458	494,496

In both 1985 and 1986, the actual number of F456 aircraft remains the same; however, purchases measured in constant dollars change because the engine was upgraded in 1986.

In the notes to table 10.2, the second item indicates that the buy size, or the contracted quantity, for the engines falls because of the discontinued production of the F123. This issue raises an important point that has not yet been addressed in the case study. Buy size does not affect the definition of a specification. When the engine quantities fall from 210 (105 aircraft × 2 engines each) in 1978 to 80 in 1979, the price for a set of engines increases from 1,705.4 to 1,925.2. This translates to a substantial increase in the implicit price deflator for engines.

The base price derivation and quality-adjustment methods described in the case study offer us considerable flexibility. BEA can easily calculate defense purchases on any base because much of the preliminary work done for the published series need not be repeated for another base. Given prices, quantities, and quality factors, the derivation of base prices for any year can be completely automated.

10.3.2 Actual Data

Table 10.9 displays the implicit price deflators (IPD) and fixed-weighted price indexes for new aircraft implicit in the published defense purchases series. Table 10.10 shows the price indexes for various aircraft from which the published fixed-weighted index was calculated.

The differences between the two published series in table 10.9 indicate the effects of quantity shifts. For example, in 1986, the fixed index declines 7.4 percent, while the IPD increases 4.5 percent. Much of the difference can be attributed to the B-1. The B-1 price declines because of the learning curve, so the fixed-weighted index falls. The B-1 quantities increase 800 percent between 1985 and 1986. The large shift in the relative importance of the B-1 causes the IPD to increase. In addition, higher deliveries of C-5 aircraft in 1986 also help increase the IPD; the C-5 has no effect on the fixed-weighted index because it was not delivered in the base year.

The price indexes shown in table 10.10 exhibit many of the qualities highlighted earlier in this paper. For example, learning curves can be seen for many of these systems. The B-1 has a short life in which the prices drop dramatically as the buy sizes increase. The TR-1 prices drop steadily for many years because of the relatively small quantities purchased in each contract. In 1988, the F-14 index rises dramatically owing to deliveries of a new model that is moving down a learning curve.

Generally, when a learning curve is evident, indexes start very high and drop to a level similar to the other systems in that time period. The B-1 starts above 300 and drops to almost 130 at the bottom of its learning curve. The exception to this is when a system is high on its learning curve in the base

Table 10.9 **Implicit Price Deflator and Fixed-Weighted Price Indexes for Defense Purchases (CY 1982 = 100)**

	Fixed	IPD	% Change Fixed	% Change IPD	Difference in Change, Fixed − IPD
1972	39.1	46.7			
1973	43.2	48.7	10.3	4.2	6.0
1974	46.4	54.1	7.5	11.2	−3.7
1975	52.5	55.7	13.1	2.9	10.1
1976	53.5	58.4	2.0	4.8	−2.7
1977	57.1	62.5	6.8	7.1	−0.4
1978	64.4	67.9	12.7	8.6	4.1
1979	75.1	73.2	16.6	7.9	8.8
1980	79.8	78.8	6.3	7.6	−1.3
1981	89.3	87.2	11.8	10.7	1.1
1982	100.0	100.0	12.0	14.6	−2.6
1983	110.8	108.6	10.8	8.6	2.2
1984	129.8	125.6	17.2	15.6	1.6
1985	131.3	117.8	1.1	−6.2	7.3
1986	121.6	123.1	−7.4	4.5	−11.9
1987	113.4	108.5	−6.7	−11.9	5.2
1988	110.5	99.9	−2.5	−7.9	5.4
1989	112.7	99.5	2.0	−0.4	2.4

year. By rule, the index in the base year must be 100; therefore, these systems usually have very low indexes; the TR-1 is an example.

Changes in buy size produce interesting results in the price indexes for individual systems. The stretch-out in the A-10 program best illustrates the effect of buy size on prices. The price index increases 34.8 percent in 1982, 48.2 percent in 1983, and 8.5 percent in 1984. Four contracts were delivered during that time period, during which quantities fell from 142 to 60 to 20 in each of the last two buys.

Table 10.10 **System-Level Price Indexes for Military Aircraft (CY 1982 = 100)**

	A-7	A-10	C-130	KC-10	E-3	TR-1	F-15	F-16	B-1	F-14	F-18	A-6	E-2	EA-6	P-3	CH-53	AH-1	C-12	UH-60
1972	19.5	31.2	26.5	16.4	40.1	16.9	45.6	34.8	0.0	57.3	0.0	36.2	59.5	49.1	43.5	30.2	29.3	23.5	19.6
1973	20.4	32.6	28.6	17.9	46.1	18.2	54.4	44.3	0.0	57.6	0.0	37.5	59.4	41.8	42.5	37.3	35.1	28.9	23.3
1974	23.8	38.6	32.3	20.7	47.0	19.8	64.0	56.8	0.0	51.4	0.0	41.3	56.2	41.4	41.5	37.1	36.9	30.7	25.1
1975	24.8	49.6	37.5	23.7	62.4	23.5	76.0	64.9	0.0	55.6	0.0	49.9	51.8	42.1	47.3	35.2	37.1	33.0	26.9
1976	27.8	80.3	38.5	24.8	62.4	23.5	61.2	50.4	0.0	58.4	0.0	55.9	59.9	52.5	57.2	47.6	47.2	39.8	35.2
1977	31.3	74.4	46.8	29.8	64.9	28.7	62.9	54.2	0.0	58.9	0.0	50.9	73.5	61.4	72.9	49.7	52.9	44.3	53.5
1978	43.7	69.6	49.8	31.8	64.3	28.7	64.4	77.8	0.0	64.1	0.0	57.1	70.0	60.7	70.4	57.2	49.3	53.4	67.1
1979	54.0	66.6	62.2	39.4	78.2	30.5	70.5	102.2	0.0	68.3	0.0	69.8	87.5	65.4	70.9	65.2	51.3	58.3	90.7
1980	55.9	67.0	80.7	51.0	95.6	37.6	77.7	87.7	0.0	74.2	75.1	78.6	92.4	75.4	87.2	79.1	59.0	77.4	77.7
1981	65.4	74.2	91.0	103.5	98.3	63.6	85.0	90.9	0.0	87.6	101.3	82.0	98.9	85.0	90.6	94.3	71.0	86.7	83.8
1982	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1983	126.7	148.2	106.5	110.4	102.4	100.2	116.4	108.2	360.5	96.6	103.1	81.3	103.6	100.2	108.4	125.0	126.9	104.4	101.1
1984	118.5	160.8	118.2	114.1	102.3	87.1	121.5	126.0	331.7	99.3	111.0	98.1	104.3	97.3	117.7	120.6	168.4	104.4	98.7
1985	0.0	0.0	125.9	119.2	104.7	59.2	136.5	117.0	349.7	104.3	107.5	116.9	106.3	92.7	118.3	108.7	109.2	104.4	98.3
1986	0.0	0.0	122.6	116.5	98.8	54.0	146.6	116.4	190.8	106.1	118.2	147.1	115.7	86.0	120.4	116.5	103.0	104.4	100.8
1987	0.0	0.0	113.1	106.3	104.2	50.7	140.6	105.4	133.6	103.6	117.3	136.7	118.4	91.9	121.5	114.6	95.9	104.4	105.1
1988	0.0	0.0	120.0	114.4	123.5	51.7	144.1	100.8	131.9	161.7	114.8	151.9	115.7	101.6	121.3	111.2	93.5	105.4	110.2
1989	0.0	0.0	120.0	114.4	128.7	54.9	140.7	103.9	135.8	159.3	116.0	148.6	118.4	117.7	121.5	117.9	96.2	106.4	114.1

Appendix A
Learning Curves

Cost analysts have observed that, as more units of a complex item are produced, the labor hours required for producing successive units falls. This relation is called the organizational learning (or progress) curve. The earliest publication on a learning curve for aircraft was Wright (1936). Since that time, a considerable amount of research on this phenomenon has been undertaken by cost analysts and economists. A recent nonmathematical review of learning-curve research is contained in Argote and Epple (1990).

Most common forms of the learning curve are represented by a smoothly decreasing function for labor hours per unit of output as the number of units produced increases. The simple form of the curve is the "unit" or "Boeing" curve, in which the learning rate is defined as the percentage that labor hours decline as the quantities produced double. The following example depicts a learning rate of 10 percent:

Unit No.	Labor Hours
4	100
8	90
16	81
32	73

The labor hours saved per unit decrease by 10 percent as the number of units produced doubles. Learning curves are usually expressed in terms of the slope, which is 100 minus the learning rate. The example above represents a 90 percent learning curve.

The learning curve is important in deriving the appropriate price for splicing in a new weapons system. The splice price should represent the quality difference between the two systems at a comparable phase in the production cycle. Because of learning, prices of initial units of the new system will be overstated relative to the old weapons system where significant learning has already taken place. Splicing with the price for the first unit would result in the value of the resources saved in learning being treated as additional quality in the new system. The initial splice price would be very high, prices would drop after the splice period, and overall price change for the new system would be understated.

It is assumed that, by the hundredth unit of production of a new fighter aircraft, additional learning is relatively minor. Therefore, the price of the hundredth unit, expressed in dollars of the time period when the first production contract is signed, represents the best estimate of the actual resource cost difference between the two systems. Note that this estimate does not account for changed technologies between the two aircraft.

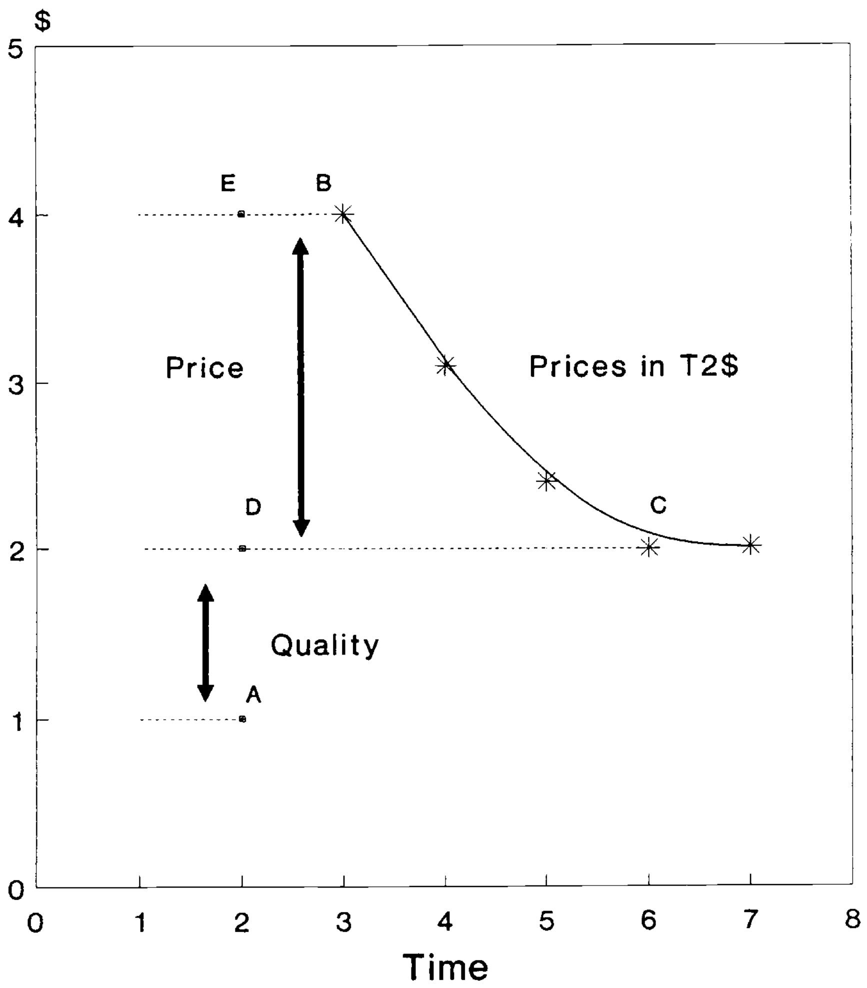

Fig. 10A.1 Splicing weapons systems with learning

Table 10A.1 Alternative Splicing for Price Indexes

	Price Per Unit			Price Indexes				
		F-II				Combined		
Time Period	F-I	$ of T	Actual	F-I	F-II	P1	P2	P3
Base = −1	2,000	3,200	3,200					
−1	2,000			100.0		100.0	100.0	100.0
0	2,500			125.0		125.0	125.0	125.0
1	3,000			150.0		150.0	150.0	150.0
2	3,000	8,500	9,000	150.0	281.3	230.8	150.0	450.0
3		6,500	8,000		250.0	250.0	133.3	400.0
4		5,000	7,000		218.8	218.8	116.7	350.0
5		4,000	7,500		234.4	234.4	125.0	375.0
6		3,500	8,000		250.0	250.0	133.3	400.0

Figure 10A.1 illustrates the procedure. Point *A* represents the price of the old system at time period 2, when the decision is made to purchase a new system. The curve *BC* represents the estimated resources needed to produce the new system in factor prices of time period 2. Point *C* is the hundredth unit of the new system. The difference in price of this unit, when compared to the old system, represents the difference in quality between the two systems $(D - A)$. The remaining difference in the expected price of the new system $(E - D)$ is recorded as a change in price.

A numerical example of how the learning curve is used to create an adjusted price and splice two series together may help clarify the procedure. Figure 10A.2 and table 10A.1 present data to splice the aircraft F-II to the aircraft F-I. In order to simplify the illustration, we have assumed that there are no quality changes to the aircraft during this period.

The initial production contract for the F-II was signed in time period 0, when the F-I was being delivered at a price of $2,500 (*A* on fig. 10A.2). In dollars of time period 0, the F-II is expected to have a price of $8,500 (*B*) for the first lot purchased and drop to $3,500 (*C*) for the fifth lot. These prices are derived by estimating the unit resource requirements (labor, materials, etc.) and expressing them in terms of time period 0 dollars. These estimates represent the expected savings in resources due to learning. Adjusting these prices for expected price change yields the price to be paid.

The hundredth F-II will be delivered from the fourth lot at a price of $4,000 (*D*) in time period 0 dollars. When compared to the F-I price of $2,500 (*A*) in time period 0, this price yields a quality difference (or, more specifically, a resource cost difference) of $1,500 $(D' - A)$. In short, one F-II is the equivalent of 1.6 F-Is in period 0 dollars. The F-I, however, has increased in price by 25 percent from the base period price of $2,000 (*E*). Therefore, the base price for the F-II must be adjusted to maintain the ratio of 1:1.6. This yields a F-II base price of $3,200 (*F*).

Using the derived base price for the F-II, a price index can be constructed for the spliced series (table 10A.1). The actual prices paid for the F-II are used to calculate the index; the quality link is carried in the new base price. The constant period 0 estimates are used only to estimate the resource-cost difference between the two systems. This procedure yields a high splice price for the F-II, thereby causing the price index to jump dramatically and then decline (index P1).

P2 shows the price index that would result if the same price data were used for the two aircraft, but the direct link procedure was used to splice the price series. This assumes that the entire difference in price between the two aircraft is due to a difference in quality. P3 shows the price index that would result if the direct comparison method were used to splice the two series. This method assumes that there is no difference in quality between the two aircraft.

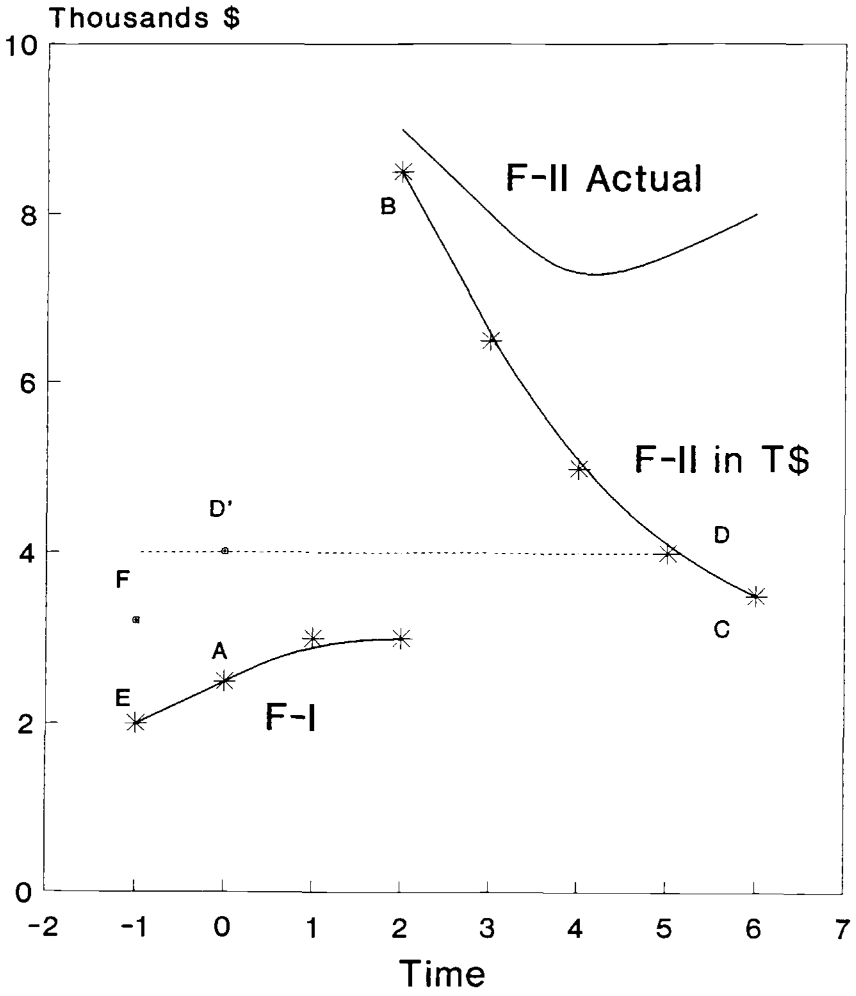

Fig. 10A.2 F-I/F-II splice

Appendix B
Analysis of Price Series Switches

Quality factors and the level of detail at which BEA derives prices lead to some problems for a few situations. Although the pricing series appear fairly detailed, they generally refer to a group of items. At times, BEA has sufficient information to subdivide these groups; however, details for many groups remain vague. A problem arises when an element of one pricing group shifts to another pricing group. In the case study, this situation can be observed in 1981 when some contractor-furnished (CFE) navigation equipment shifts to government-furnished (GFE) navigation equipment. Also, in 1987, some fire control equipment embedded in the other GFE series shifts to the CFE fire control series. Because the quality implied by the sum of these components remains the same, the sum of the base prices should also remain unchanged.

The way in which we derive quality factors implies that the percentage change in the price due to a quality adjustment translates to the same percentage change in the base price. But the relative importance of a product in the shift time period seldom equates to the same relative importance in constant prices. As a result, in most product shift cases, the quality factor technique produces a discrepancy between the changes in value of the two base prices in question.

For example, in 1987 some fire control equipment previously bought as GFE is now bought as CFE. Based on the contractor cost report, the value of this equipment equals 400. Using the adjusted current price link method, the quality factor for the CFE component is 1.8085, or 894.7/(894.7 − 400). Using the same technique and −400 as the value of the quality change for the GFE equipment, the quality factor is 0.8821, or 2,992/[2,992 −(−400)]. On a 1975 = 100 base, the effect on the CFE fire control base price is +163.2, and the effect on the other GFE base price is −148.7. The technique calculates a discrepancy in the base price in this example because prices have changed by different amounts in the two series. In other words, the relative importance of the two series has not remained constant.

When attempting to solve this problem, the detail contained in the price source documents often prohibits a simple solution. For example, the best way in which to solve the product switch problem is to group together over the life of the series those products that are involved in the switch. This, in fact, was done for the CFE-GFE switch of navigation equipment in 1981.

Unfortunately, switches usually involve nonspecific GFE data and more detailed CFE data such as the fire control equipment switch mentioned above. In the case study, the 1987 switch is valued at 400. This value most likely was obvious from the contractor price report. Assuming no quality adjustments due to a shift in contractor, we then estimate the current effect on the GFE series as being −400. In other words, no information was actually available about the price of the product when it was procured under GFE. In fact, it is only an assumption based on an odd GFE price change that the newly observed fire control product on the contractor cost report was once included under the GFE series. Therefore, it would be impossible to group the GFE fire control equipment with the CFE fire control equipment over the life of the aircraft.

The only way to solve the base price discrepancy problem in this case is to calculate a quality-adjustment value that will force the changes in the two base prices to offset. The calculation of the quality adjustment is explained best as a two-step procedure. First, the desired quality factor is derived by setting the base prices prior to the product switch equal to the base prices after the product switch. The quality valuation for one of the products must be available in order to solve the equation.

The following list defines the variables used in the subsequent equations:

a = first product;
b = second product;
M = cumulative quality factor before the switch;
F = quality factor for the switch;
N = non-quality-adjusted base price;
B = current price of product$_b$ in the base year;
R = product of any quality factors after the switch year up to and including the base year;
P = price of product$_b$ at the time of the switch; and
V = value of quality for product$_b$.

(B1)
$$M_aN_a + M_bN_b = M_aF_aN_a + M_bF_bN_b,$$

or, solving for F_b,

(B2)
$$F_b = \frac{M_aN_a + M_bN_b - M_aF_aN_a}{M_bN_b}.$$

F_a is known because the quality valuation for product$_a$ was determined beforehand. N_a is also known for the same reason. If the product switch happens after the base year, then N_b is known. If the product switch happens before the base year, then the following should be substituted for N_b in the above equation:

(B3)
$$N_b = \frac{B}{M_bF_bR_b}.$$

Solving for F_b, the equation becomes

(B4)
$$F_b = \frac{B}{M_aN_aF_aR_b + B - M_aN_aR_b}.$$

Then, for the second step, the quality factor equation is solved for the value of the quality change. In this case, the adjusted current price link equation is used:

(B5)
$$F_b = \frac{P}{P - V},$$

or, solving for V,

(B6)
$$V = \frac{-P + PF_b}{F_b}.$$

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Comment

Arthur J. Alexander

The goal of defense price estimates, according to Ziemer and Kelly, is to develop measures of constant-dollar defense purchases within the framework of the national income and product accounts. What is not stated is that constant-dollar purchases are proxies for physical items and quantities: a fundamental principle governing the conceptual basis for estimating constant-dollar purchases is that, if the number of identical items purchased in two periods does not change, then the index of constant-dollar purchases should not change. This principle provides the rationale for many of the assumptions and procedures described in the paper.

Defense deflators and price indexes for individual products, while useful for many purposes in their own right, are produced here as means to achieve the main goal. However, it is in the calculation of the price indexes that the central problem arises. This problem is the "performance/cost-of-production"

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method of quality adjustment. According to this method, products are examined to determine whether they have changed from one period to another; if a change is determined to be associated with an increase in quality, "the cost of producing that physical change is taken as the value of the quality change, and the price is adjusted accordingly" (Ziemer and Kelly, chap. 10 in this volume, p. 310). Product characteristics and performance are used only to determine if there has been a quality improvement; they are not used to evaluate the size of the improvement.

The use of cost as a measure of quality change ignores the possibility of improvements in technology and productivity and can severely overestimate price changes and underestimate output. Productivity in the design and production of military products can be substantial. Because of such productivity gains, newer and better products can actually be less costly to produce than older products. Under such conditions, the "performance/cost-of-production" method would measure no change in quality.

One example of an improved product costing less to produce was the F100 turbojet engine used in the F-16 and F-15 aircraft. More than eighty design changes were incorporated in this engine over the four-year period 1984–87, resulting in significant improvements in reliability and maintainability: maintenance manhours per flight hour were cut by 15 percent; unscheduled engine removals were reduced by 43 percent; support costs fell by one-third (Alexander 1988, 68). Yet the cost of these changes when introduced into production was actually negative—the engine was less costly to produce. Indeed, in six case studies of reliability improvement, there were no examples of cost increases. According to the Bureau of Economic Analysis (BEA) approach, these improvements in quality would not have been captured.

The reason that the F100 engine could be improved and quality increased with no increase in production cost was that the manufacturer, Pratt and Whitney, had become smarter over the years—smarter because of additional experience and because of the $120 million in design and test expenditures that the U.S. Air Force invested in these design changes. These payoffs to research and development (R&D) are biased downward by the BEA approach.

The problem faced by defense product price estimators is that price changes can arise from three sources: (1) changes in input factor costs; (2) changes in the productivity of producing goods of a given quality; and (3) changes in the quality of the good. These changes are illustrated in figure 10C.1, where the solid lines represent time period 1 input factor costs (W1) and the dashed lines are for period 2 factor costs (W2). The observed points are *A* and *B; A* is on the line showing the nominal cost-quality relation at period 1 values of factor costs and productivity levels. In period 2, the whole curve shifts downward because of productivity improvements. The distance C4–C1 represents the shift in productivity; inflation in factor costs is captured by C2–C1 or C5–C3 (these need not be the same); the cost of quality improvement is C5–C2 or C3–C1. Note that the BEA would measure the value of quality change as C4–

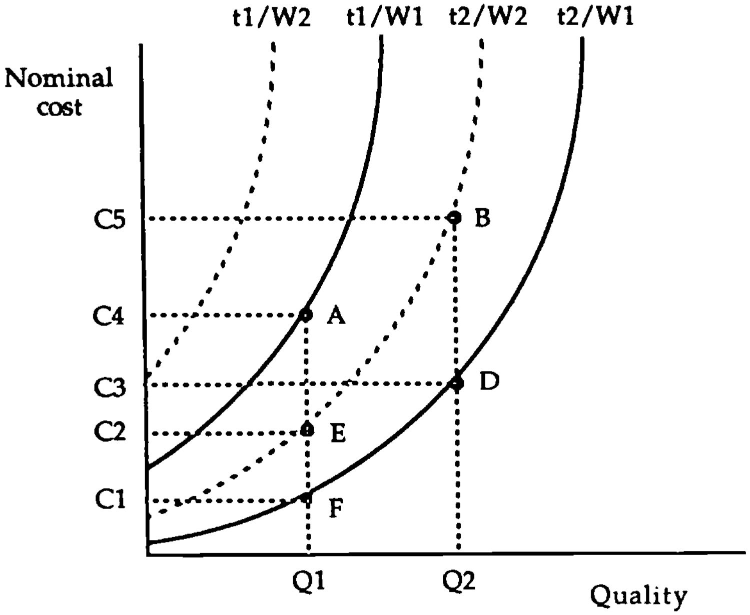

Fig. 10C.1 Cost-quality relations with changing levels of productivity and input factor costs

C3; if this value were negative because of strong productivity growth, it would record no quality change at all. The approach therefore generates the paradoxical outcome that, the larger the amount of productivity growth, the smaller the measured value of quality improvement. Price deflators are therefore too high and the estimated quality of output and calculated productivity growth too low.

Does this actually occur? In order to test the possibility of biased estimates, I calculated the productivity change implicit in the fixed-weighted price index for aircraft (Ziemer and Kelly, chap. 10 in this volume, table 10.9); productivity change was estimated by dividing an input factor cost index for aircraft by the fixed-weighted price index. From 1972 to 1982 (the years for which I happened to have a common set of data), input costs rose by 8.5 percent annually, while the aircraft price index (presumably, holding quality constant) increased at a 9.9 percent rate—implying that military aircraft production productivity actually fell by about 1.3 percent per year. Given the billions of R&D dollars devoted to military aircraft in each year's defense budget, this outcome is unlikely. Indeed, independent estimates of productivity for transport aircraft and jet engines showed annual productivity increases of 5.0 and 2.0 percent (Alexander and Mitchell 1985, 186, 190).

Unfortunately, dealing with the problem of measuring quality change is far more difficult than simply describing it. Hedonic price indexes are probably not feasible because of the sparse time series of most types of military equipment and because of the restricted market for defense equipment, where outliers may persist for longer periods than in more competitive markets. Some practitioners have used combat models to evaluate quality-quantity trade-offs for military aircraft, but these are applicable only to the gross characteristics of equipment. One technique that may be useful has been adopted in price surveys for the producer price index; this method requires manufacturers to estimate what it would have cost to produce the last-period model in the current period. The answer to this question is a measure of the distance C4–C2 in figure 10C.1. Equivalently, the producer could also be asked what it would have cost to produce the current model in the last period; this question, however, is more problematic since often a change is feasible only because of new technological knowledge—it could not have been produced earlier. These kinds of questions are feasible for small product improvements of a basic model. They become hypothetical when making comparisons across models, for example, from the F-4 to the F-16.

For nonincremental changes in military products, it may be necessary to look at their several missions. For a highly simplified example, if one mission of an attack aircraft is to drop bombs on targets, its effectiveness could be evaluated as the number of bombs on target per day, at a given range, per dollar of aircraft capital cost and support cost. Calculation of this measure would draw on such characteristics as payload, sensors, flight control systems, ordnance delivery computers, reliability, maintainability, and all the other design features and components that enable the aircraft to perform this mission. A weighted sum of all the missions would yield a quality index for the aircraft. Just setting out such a simplified approach to mission analysis gives a sense of the difficulty in implementing it, but it is the performance of the mission that ultimately lends value to the military equipment and to the notion of quality. Ultimately, analysts will ignore mission performance only at their peril.

Introducing the concept of mission in evaluating the quality of military products forces one to consider the existence of enemies. If an enemy develops a better air-defense system that reduces the effectiveness of an aircraft system, the quality of the aircraft declines; it becomes economically obsolete. If sold on secondhand markets, the price of the aircraft would fall to reflect its lower mission effectiveness. A similar effect would also be found for an antibiotic whose quality is measured as the lethality against a certain strain of bacteria; if a resistant strain evolved, the measured quality of the antibiotic would fall, as would its price.

It would be theoretically correct to show that military products have value only in performing specified missions and that we may be spending more but getting less because of enemy reaction. In a broader sense, the value of defense is a matter not only of constant-dollar purchases and productivity but also of the reactions of others. Correct and accurate measures of defense expenditures that properly account for such reactions may reveal surprising pictures of the value of defense.

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