Congressional Budget Office

APRIL 2018

How CBO Estimates the Cost of New Ships

At the direction of the Congress, the Department of Defense generally issues annual reports that describe the Navy's plan for building new ships over the next 30 years. To assist the Congress, the Congressional Budget Office evaluates the Navy's plan and produces its own estimates of those costs.[1] The estimates, which are expressed in constant dollars, can also be found in CBO's cost estimates as well as in other reports related to the construction of naval warships.[2]

In developing its estimates for the costs of the Navy's ships, CBO relies on a method that has four stages:

- CBO first projects the size of a future ship, using existing ship classes as guides for the size and capabilities of the new ship.
- The agency then uses historical data from an analogous class of ship (or analogous classes) to calculate the new ship's cost per thousand tons, multiplying that cost by the size that was determined in the first step.
- As a third step, CBO adjusts the cost of the ship by factors associated with *rate* (the production efficiencies that are made possible when several ships of the same type are built simultaneously or in close succession at a given shipyard), *learning* (the gains in efficiency that accrue over the duration of a ship's production as shipyard workers gain familiarity with a particular ship model), and *acquisition strategy* (such as whether ship contracts are granted directly to a company or awarded as the result of a competitive process).
- In the final step, CBO adjusts the estimated cost of the ship to account for the fact that inflation in the shipbuilding industry has been growing, and is projected to continue growing, faster than inflation in the economy as a whole. The difference between the naval shipbuilding index and the gross domestic product (GDP) price index is added to CBO's constant-dollar estimates to reflect real (inflation-adjusted) growth in costs.

To illustrate its analytic method, CBO shows in this report how it estimated the cost of building Virginia class submarines when analyzing the Navy's 2017 shipbuilding plan.

Projecting the Size of Future Ships

To estimate the cost of a future ship, CBO first uses data from the Navy to estimate the ship's size, which is traditionally measured as displacement—the weight of the water it displaces. At this stage, CBO determines the size by *full-load displacement* for surface ships and by *submerged displacement* for submarines, both of which measure the weight displaced by the ships with their contents—crew, stores, ammunition, and fuel and other liquids. If such data are not available (perhaps because the ship is projected to be built in 20 years and the Navy does not specify ship designs that far in advance), CBO makes its estimate based on the sizes of existing ships of the same type that perform the same missions.

For example, the Navy has described the DDG(X), a guided missile destroyer, as a future "midsized" surface combatant, although it has not yet designed the ship. The Navy estimates that the cost of a DDG(X)

1. See, for example, CBO's most recent assessment of the Navy's 30-year shipbuilding plan: Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan* (February 2017), www.cbo.gov/publication/52324.

2. For examples of related reports, see Congressional Budget Office, *Comparing a 355-Ship Fleet With Smaller Naval Forces* (March 2018), www.cbo.gov/publication/53637, and *Costs of Building a 355-Ship Navy* (April 2017), www.cbo.gov/publication/52632.

will be close to that of a large surface combatant—in this case, a modified version of the DDG-51 Flight III destroyer. A fully loaded midsized surface combatant displaces between 6,000 and 9,000 tons of water; the Navy's current large surface combatants displace 9,000 to 10,000 tons each. (The new Zumwalt class DDG-1000 destroyer, which is currently in production, displaces 15,000 tons.) CBO's estimate of the cost of the DDG(X) incorporates the assumption that, like the current DDG-51 Flight III, the new ship would displace 10,000 tons.

Once the size of the ship when fully loaded is determined, CBO estimates the weight of the ship when it is mostly empty—the *lightship displacement* for surface ships or the *Condition A-1 weight* for submarines, both of which are reasonable measures of the weight of a vessel without a crew, stores, ammunition, or fuel or other liquids.

The Relationship Between Weight and Cost

After estimating a ship's size, CBO uses historical data from an analogous class of ship (or analogous classes) to calculate the ship's cost per thousand tons (see Table 1). A primary advantage of CBO's using analogous ships and cost-to-weight comparisons to develop its estimates is that doing so is more straightforward than projecting costs on the basis of supposition; similar ships have already been built and their cost-to-weight ratios are already documented. The primary disadvantage of that approach is that, because the data are historical, they will not capture potential improvements in manufacturing or other efficiencies that come with new approaches to ship construction or changes in technology that could lower a ship's cost per thousand tons. (However, that disadvantage may not have much practical effect: CBO has not identified any examples of new-generation ships that cost less per ton than earlier ships of the same type.) Another disadvantage is that sometimes there is no good historical analogue, recent or distant, to use as the basis of a cost projection for a new ship with an innovative design. In rare instances, CBO may start with the Navy's estimate and then apply a more generic factor to account for the likely increase in cost above the amount in the Navy's current plan. The objective of applying such factors, which are derived empirically from historical data, is to estimate cost growth as the shipbuilding program evolves.[3]

As a rule, CBO tries to find the most recent comparable ship as a model for its cost-to-weight estimates. It would not be appropriate or useful to use an aircraft carrier as the analogue for a submarine: They are different vessels with different missions and designs, so their cost-to-weight ratios are not comparable.

For example, CBO identified the current Virginia class attack submarine as the most logical analogue for the new Columbia class ballistic missile submarine. Specifically, CBO used the cost per thousand tons of A-1 weight of the Virginia class submarine to estimate the cost of the Columbia class submarine as though it would be built in 2018. On the basis of the Navy's estimate that the new submarine would be about two and a half times the size of the current Virginia class submarine, CBO estimated that the total cost of the new vessel would be about two and a half times that of a Virginia class submarine at this point in the cost-estimating process. The agency did not use the historical cost of the original Ohio class ballistic missile submarine as the basis for its estimate because the Ohio was first built in the 1970s, too long ago to be useful. Even if adjusted for shipbuilding inflation, that basis would yield a cost for the Columbia that is only slightly higher than the cost of the Virginia today, despite the large difference in size.

Adjusting for Rate, Learning, and Acquisition Strategy

After establishing its preliminary estimate of how much a new ship would cost in 2018, CBO applies factors associated with rate, learning, and, as appropriate, the Navy's acquisition strategy to the entire proposed shipbuilding program. Although described here separately, those factors are applied simultaneously in the cost-estimating process. The result is an estimate of the cost of building new ships without any adjustment to account for future economic conditions in the industry.

3. Several researchers have examined the historical cost growth of weapon systems. See, for example, David L. McNicol and Linda Wu, *Evidence on the Effect of DoD Acquisition Policy and Process on Cost Growth of Major Defense Acquisition Programs*, IDA Paper P5126 (Institute for Defense Analyses, September 2014), www.acq.osd.mil/parca/docs/ida-p5126.pdf (826 KB); Obaid Younossi and others, *Is Weapon System Cost Growth Increasing? A Quantitative Assessment of Completed and Ongoing Programs* (prepared by the RAND Corporation for the United States Air Force, 2007), www.rand.org/pubs/monographs/MG588.html; and Mark V. Arena and others, *Historical Cost Growth of Completed Weapon System Programs* (prepared by the RAND Corporation for the United States Air Force, 2006), www.rand.org/pubs/technical_reports/TR343.html.

Table 1.

Ship Analogues for Estimating Cost-to-Weight Ratios

Ship Type	Analogous Ship Class
Aircraft Carriers	Ford (CVN-78)
Ballistic Missile Submarines	Virginia (SSN-774)
Attack Submarines	Virginia (SSN-774)
Large Surface Combatants	Arleigh Burke (DDG-51)
Small Surface Combatants	Freedom (LCS-1) Independence (LCS-2)
Large Amphibious Warfare Ships	America (LHA-6)
Small Amphibious Warfare Ships	San Antonio (LPD-17)

Source: Congressional Budget Office.

When more than one ship is purchased in a given year, the cost per ship is less than it would be for a single ship, largely because the fixed overhead costs of ship construction at a shipyard are shared by more ships. That difference is the rate effect: It is less expensive per ship to produce two ships than it is to produce one, and cheaper still to build four ships than to build two—as long as the shipyard has the production facilities and workforce to accommodate the larger volume of work. Historically, the rate effect varies by type of ship. For example, building 2 attack submarines rather than 1 in a year reduces the cost of both by 10 percent; for surface combatants, the rate effect is closer to 20 percent.

Occurring simultaneously with the rate effect is the learning effect. As more ships of the same type are built in sequence, the shipyard learns how to build those ships more and more efficiently. The second ship in a production run is expected to cost less than the first; the fifth ship is less expensive than the second; and the ninth ship is even cheaper to build than the fifth. That effect represents the learning curve in production and, based on historical evidence, the slope of that learning curve varies by ship type. Whereas the rate effect continues to reduce costs as the number of ships built simultaneously in the same shipyard increases, the reduction in cost that comes from learning tapers off as more and more ships are built. Eventually, learning becomes effectively exhausted. Generally, the effects of the learning curve have the smallest influence of all factors in CBO's method for estimating shipbuilding costs.

CBO's cost estimates also incorporate the effects of the ship acquisition strategy, when applicable. For example, DDG-51 Arleigh Burke class destroyers are usually purchased under a multiyear procurement contract. Such a contract commits the government to purchase a certain number of ships in exchange for a price that is less than it would be if those ships were purchased under a series of individual contracts because the shipyard can better plan its labor force and its purchases of inputs over a longer period. If the government does not purchase the agreed number of ships in the multiyear contract, it must pay a substantial penalty to the shipbuilder.

Adjusting for Cost Growth in the Naval Shipbuilding Industry

In the final step of the process, CBO adjusts the estimate to account for the consistently faster growth in prices paid for labor and materials in the shipbuilding industry than in the rest of the U.S. economy. The earlier part of the process establishes how much a ship would cost to build today, given current economic conditions and including adjustments for rate, learning, and acquisition strategy. But because the ship will be built in the future, CBO adjusts its constant-dollar estimates of the costs of new ships by applying a factor that is derived from the difference between historical inflation in the shipbuilding industry and general inflation in the economy as a whole. CBO regards that difference as real cost growth in the shipbuilding industry—that is, the cost growth in the industry after the effects of inflation in the general economy have been removed.

The costs of building ships in the future will depend not just on their size and capabilities but also on the evolution of production costs. The differences between the Navy's and CBO's estimates of the cost of the Navy's shipbuilding plans arise in part from their different methods of estimating production costs that will be incurred years or decades from now in constant dollars (that is, the amounts have been adjusted to remove the effects of inflation).

When estimating the cost of building a ship in the future that is identical to a ship that has already been produced, the Navy reports the future cost of capabilities purchased as being the same as the cost today. By contrast, CBO projects the cost to build the same ship in the future by accounting for the rising cost of shipbuilding labor and materials relative to the rising costs of other goods and services in the economy. CBO regards that difference between shipbuilding inflation and overall inflation as growth in the constant-dollar cost of building naval ships. The agency's constant-dollar estimates incorporate the increased costs of a future ship of any given size and capability relative to the average increase in costs for other goods and services that might be purchased with the same funds.

For its fiscal year 2017 shipbuilding plan, which was issued in 2016, the Navy provided CBO with a naval shipbuilding cost index that measures growth in the costs of labor and materials from 1960 to 2015.[4] To project increases for 2016 through 2020, the Navy constructed a shipbuilding cost index by extrapolating from the historical cost data and incorporating other information—derived from advance-pricing agreements, vendor surveys, and forecasts of the labor market—into its projections. For the 2016–2020 period, the Navy projected, shipbuilding costs would rise at an average annual rate of 2.8 percent (see Figure 1).

The Navy incorporated that projection into its budget request for 2017 and into the associated Future Years Defense Program; both documents express costs in nominal dollars (that is, without an adjustment to remove the effects of inflation). In projecting the constant-dollar costs for its 2017 shipbuilding plan, the Navy converted nominal dollars to constant 2016 dollars by discounting the nominal dollar amounts; it used the same shipbuilding cost index that it used to construct the future-year estimates. Thus, the Navy's constant-dollar estimates are essentially a measure of the amount of ship capability purchased: If a ship costs $2.5 billion to build in 2018, the Navy's projected cost (in 2016 dollars) of building an identical ship in 2037 will be the same amount—$2.5 billion.

In contrast, CBO used the gross domestic product price index, which measures the prices of all final goods and services produced in the economy, to convert shipbuilding costs from nominal to constant dollars. In 2017, CBO anticipated an average annual rate of increase in that measure of 1.9 percent for the 2016–2020 period. In its analysis of the Navy's 2017 plan, CBO's estimates of the cost of building a given ship (as projected from the Navy's shipbuilding cost index) showed a rate of increase over the period that was an average of 0.9 percentage points faster per year than the rate of inflation it projected at the time for the overall economy.[5]

Between 1986 and 2016, the average difference between the rate of increase in the Navy's shipbuilding cost index and that in the GDP price index was about 1.2 percentage points per year. Cost growth in the shipbuilding industry exceeded general inflation for most of that period, and CBO lacks an analytical basis for determining when or to what extent the difference between the two growth rates might narrow. The agency therefore projected that shipbuilding inflation would outpace GDP price inflation by 0.9 percentage points per year between 2016 and 2020 and by about 1.2 percentage points per year—matching the 30-year historical average—thereafter. As a result, CBO estimated that a ship that costs $2.5 billion to build in 2018 would cost $3.2 billion (in 2016 dollars) in 2037. (However, shipbuilding costs cannot continue to grow faster than the costs of goods and services in the economy as a whole indefinitely. If that occurred, the price of ships would eventually outstrip the Navy's ability to pay for even a small number of them.)

An Example: Projecting the Cost of Virginia Class Attack Submarines

In its fiscal year 2017 shipbuilding plan, between 2017 and 2033, the Navy planned to purchase 24 Virginia class attack submarines at a rate of 2 per year in most years through 2025 and then at a rate of 1 per year for the rest of the period. Using the methods described above, CBO estimated that those submarines would cost a total of $74 billion (in 2016 dollars), or about $3.1 billion each. (The Navy's estimate was slightly lower: a total cost of $70 billion, or about $2.9 billion each.)

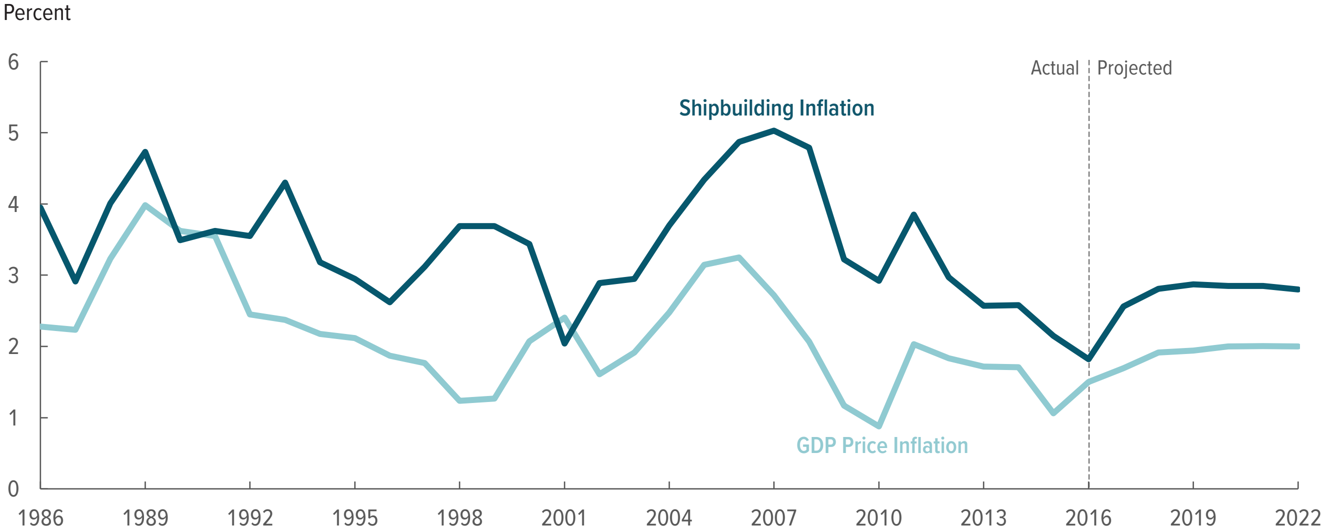
To estimate the cost of those future submarines, CBO used data for the ships' closest analogue—the Virginia class submarines that had already been built. From 1998, when production of the class began, to early 2017, when CBO performed its analysis, the Navy had purchased 22 Virginia submarines: 12 were serving in the fleet, and 10 more were in various stages of construction. To arrive at its cost projections, CBO started with the actual cost

4. See Department of the Navy, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for Fiscal Year 2017* (July 2016), https://news.usni.org/2016/07/12/20627. The Navy did not issue a 30-year plan for fiscal year 2018.

5. See Congressional Budget Office, *An Analysis of the Navy's Fiscal Year 2017 Shipbuilding Plan* (February 2017), www.cbo.gov/publication/52324.

Figure 1.

Annual Rates of Shipbuilding Inflation and GDP Price Inflation



Sources: Congressional Budget Office; Department of the Navy.

Inflation projections are as estimated under the Navy's 2017 shipbuilding plan.

GDP = gross domestic product.

of $6.0 billion for the first Virginia class submarine. The agency then subtracted from that total the $2.3 billion that the Navy spent for nonrecurring engineering and detailed design—onetime expenses that are reflected solely in the cost of building the first submarine and that do not carry over to subsequent vessels.

On the basis of cost data for that lead ship and for 21 additional submarines that have been completed or authorized thus far, CBO estimated a learning effect of 95 percent: As successive ships are built, the cost of a ship twice as far in the production sequence is 95 percent of that of the ship to which it is being compared. So, for example, costs drop by 5 percent from the second ship to the fourth, by another 5 percent from the fourth to the eighth, and so on. Learning tends to level out because the distance to the next doubling is always increasing: 8 more ships must be built to reach the 16th ship and thus to achieve an additional 5 percent decline in costs. CBO applied the 95 percent learning effect going forward from the 24th submarine (which was authorized in 2016) so that the next 5 percent reduction would occur when the Navy purchased the 24th submarine in its shipbuilding plan—the 48th in the Virginia class. CBO estimated the cost of that submarine, without an adjustment to account for the rate effect, to be $2.8 billion.

At the same time that CBO applied the learning effect to the estimates for Virginia class submarines, it applied the rate effect where appropriate. When submarines are purchased at a rate of 2 per year (a practice that began in 2011 and that was anticipated to continue in most years through 2025 under the Navy's 2017 plan), the cost per submarine is reduced by 10 percent; that reduction is added to the reduction attributable to the learning effect.

In addition, in 2019 the Navy will start including what is called the Virginia payload module in most of its new Virginia class submarines. (The payload module is a new section designed to carry additional missiles or unmanned systems.) To account for the cost of redesign, CBO added about 10 percent, starting in 2019, to the estimated cost of most submarines. The 2 ships planned for 2025 would be the 39th and 40th in the class, and both would include the new payload module. The 40th ship's position in the production sequence is not quite double that of the 24th, so the learning effect was set at 3.7 percent rather than a full 5 percent.[6] Applying a 3.7 percent learning effect, a 10 percent rate effect, and a 10 percent add-on for the payload module to the 40th submarine, CBO arrived at an estimate of $2.8 billion in constant 2016 dollars for that ship.

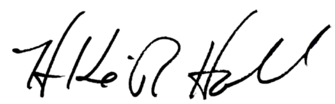
In the final step, CBO applied a factor to account for the difference between general inflation in the U.S. economy and inflation specific to the shipbuilding industry. That real growth would have increased the cost of submarines purchased in 2025 by 12 percent. After making all of those adjustments, CBO estimated that the 40th Virginia class submarine would cost $3.2 billion.

6. For more on procedures for estimating and applying learning curves, see Matthew S. Goldberg and Anduin E. Touw, *Statistical Methods for Learning Curves and Cost Analysis* (Institute for Operations Research and the Management Sciences, 2003).

This report was prepared to enhance the transparency of the work of the Congressional Budget Office. In keeping with CBO's mandate to provide objective, impartial analysis, the document makes no recommendations.

Eric J. Labs prepared the report with guidance from David Mosher and Edward G. Keating.

Jeffrey Kling reviewed the report, Loretta Lettner edited it, and Jorge Salazar prepared it for publication. An electronic version is available on CBO's website (www.cbo.gov/publication/53785).



Keith Hall
Director