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THE POLAR ICEBREAKER PROJECT: A FISCAL ANALYSIS

OFFICE OF THE PARLIAMENTARY BUDGET OFFICER
BUREAU DU DIRECTEUR PARLEMENTAIRE DU BUDGET

The Parliamentary Budget Officer (PBO) supports Parliament by providing economic and financial analysis for the purposes of raising the quality of parliamentary debate and promoting greater budget transparency and accountability.

This report provides an independent cost estimate of the Development and Acquisition phases of the Polar Icebreaker Project. The Polar Icebreaker Project aims to replace the Canadian Coast Guard's existing fleet of heavy icebreakers with two new heavy icebreakers built to modern specifications.

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Executive Summary

The Polar Icebreaker Project, initially launched by the Government of Canada in 2008, intends to replace the Canadian Coast Guard's current fleet of heavy icebreakers, namely the legacy Canadian Coast Guard Ship (CCGS) Louis S. St-Laurent with a new class of heavy icebreakers built to modern specifications. At present, the Polar Icebreaker Project calls for the acquisition of two new vessels, with one each being constructed at Vancouver Shipyards and Chantier Davie Canada Inc., the latter pending approval of the shipyard's inclusion as a partner in the federal government's National Shipbuilding Strategy.

Based on the recent experience of the Government of Canada's shipbuilding procurement initiatives to date, as well as competing priorities at the partner shipyards, PBO assumes that construction activities for the first of the two ships will begin within the 2023-2024 fiscal year, with the second beginning in the 2024-2025 fiscal year. Deliveries of these vessels are anticipated for 2029-2030 and 2030-2031, respectively.

The last announced Government estimate for the Polar Icebreaker Project dates to 2013, when the initial procurement cost for a single ship was estimated to be $1.3 billion.

This report provides an independent estimate of the cost of the Polar Icebreaker Project. We include all applicable costs associated with the Development and Acquisition phases and conduct a sensitivity analysis to determine the fiscal impact that would arise due to a one or two-year delay in the start of construction.

To develop estimates for each of these cost categories, we employ a combination of models. In particular, we adopt an analogue approach based on three procurement programs and combine this with the results of a parametric regression analysis.

Summary Table 1 presents the main results of the analysis. The total project cost estimate is approximately $7.25 billion, inclusive of project management costs of $346 million, design costs of $820 million, and acquisition costs of $6.1 billion. Delays of either one or two years would increase total project costs by $235 million or $472 million, respectively.

Summary Table 1 Polar Icebreaker Project Cost Estimates

millions $	Estimate	1-year delay	2-year delay
Project Management	346	376	405
Design	820	829	839
Acquisition	6,082	6,278	6,475
Total	**7,248**	**7,483**	**7,720**

Source: PBO Calculations.
Notes: Figures are in nominal dollars. All costs are exclusive of any applicable taxes.

1. Introduction

The Polar Icebreaker Project, initially launched by the Government of Canada in 2008, intends to replace the Canadian Coast Guard's current fleet of heavy icebreakers, namely the legacy CCGS Louis S. St-Laurent, with a new class of heavy icebreakers built to modern specifications. The project originally aimed to construct a single new polar icebreaker at an estimated cost of $720 million with operational status to be achieved in 2017[1]; it was subsequently delayed to allow the partner shipyard, Vancouver Shipyards (VSY), to complete work on the Royal Canadian Navy's Joint Support Ship program. With subsequent difficulties surrounding the procurement of the Joint Support Ships, the Polar Icebreaker Project was further delayed, necessitating a life extension program for the CCGS Louis S. St-Laurent.[2]

At present, the Polar Icebreaker Project calls for the acquisition of two new vessels, with a single vessel being constructed at each of VSY and Chantier Davie Canada Inc., the latter pending approval of the shipyard's inclusion as a partner in the federal government's National Shipbuilding Strategy.

Based on the recent experience of the Government of Canada's shipbuilding procurement initiatives to date, as well as competing priorities at the partner shipyards, PBO assumes that construction activities for the first of the two ships will begin within the 2023-2024 fiscal year, with the second beginning in the 2024-2025 fiscal year. Deliveries of these vessels are anticipated for 2029-2030 and 2030-2031, respectively.

The last announced estimate for the Polar Icebreaker Project dates to 2013, when the Government indicated that the initial procurement cost for one ship would be increased to $1.3 billion.

This report provides an independent estimate of the Polar Icebreaker Project. We include all applicable costs associated with the Development and Acquisition phases; in particular, we estimate costs for each of the following categories:

- Governmental project management costs for both the Development and Acquisition phases;
- Design costs;
- Studies, analysis, and engineering support costs;
- Acquisition costs, including the cost of initial spares; and,
- System test, trials, and evaluation costs.

To develop estimates for each of these cost categories, we employ an analogue approach based on the historical and contemporaneous experiences of multiple procurement programs, notably the Arctic and Offshore Patrol Ship (AOPS) program, the Joint Support Ship (JSS) program, and the United States Navy's Lewis and Clark-class Support Ship program.

These are combined with the results of a regression analysis to project the final costs of the program.

Box 1: Polar Icebreaker Characteristics

Weight, Full Load	23,500 tonnes
Length	150 m
Beam	28 m
Max speed	18+ knots
Crew	100 crew and personnel
Propulsion	Diesel Electric
Ice Class	Polar Class 2+
Helicopter Capacity	2

Source: Department of Fisheries and Oceans

2. Estimates

The Polar Icebreaker Project is currently in the Development phase, with construction activities on the first of the two planned vessels projected to begin in 2023-2024. As such, the assumed timelines, project specifications, and to a lesser extent, ship characteristics, are still subject to change. The estimates presented in this section are tailored to the specifications provided to the PBO by the Department of Fisheries and Oceans (DFO) and are current as of April 2021. Section 2.4 presents the results of a sensitivity analysis while Section 2.5 presents the results of a Monte Carlo simulation to account for modelling uncertainty inherent in the employed methodology.

Compared to naval vessels, estimating costs for large polar icebreakers presents an additional challenge as there are not many extant vessels of similar specifications and capacities. Those that are currently in service tend to be legacy vessels due to be replaced in the near future. For example, the construction of the CCGS Louis S. St-Laurent dates to the mid-to-late 1960s, whereas the United States' Polar-class icebreakers date to the mid-1970s. The United States Coast Guard is currently developing replacements for the aging Polar-class icebreakers as part of the Polar Security Cutter program.[3]

To properly account for the lack of directly comparable historical data on icebreakers of a similar size and capability profile as that which is intended to be produced in the Polar Icebreaker Project, we appeal to a mix of historical and contemporaneous procurement programs for vessels that have either a "right size, wrong mission" or "right mission, wrong size" specification profile as a basis of cost estimation.[4] Section 2.1 provides details concerning the source data used in this study as well as the methods used to produce a cost estimate for the Polar Icebreaker Project.

2.1. Data and Methodology

For the purposes of this analysis, the total project costs of the Polar Icebreaker Project are divided into two categories: ancillary project costs and acquisition costs. These are estimated separately.

A brief description of the data sources and methodology used in this study follows. A more thorough treatment of these topics is provided in Appendices A and B.

Ancillary Costs

Ancillary costs include all activities associated with the project that do not directly concern construction activities. These include governmental project management costs for the Development phase of the project, project management costs during the Acquisition phase, and Design costs.

We base our estimates of the government's project management costs on the realized and projected project management expenditures associated with the AOPS program, adjusting for the inclusion of an additional shipyard. Design costs are projected using the relationship between the AOPS' design costs and lightship weight.

Acquisition Costs

Acquisition costs are inclusive of all construction activities as well as outlays associated with initial studies, analysis, and engineering support, initial spares, and system tests, trials, and evaluation.

Our estimates of the construction costs of the Polar Icebreaker Project are based on three analogue procurement programs: the Royal Canadian Navy's AOPS and JSS programs, and the US Navy's Lewis and Clark-class underway replenishment vessel program. To generate an estimated acquisition cost for the Polar Icebreaker Project, we normalize the *first ship*[5] costs from each of the three analogue programs to a common base year, then apply an escalation factor to account for differences in lightship weight between the analogue vessels and the polar icebreaker. In the case of the United States analogue, the Lewis and Clark-class vessel, additional adjustments are undertaken to account for differences in labour productivity, labour costs, and exchange rates between the United States and Canada.

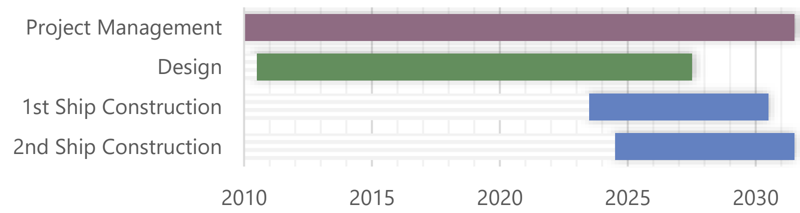
To supplement the estimates derived from the three analogue procurement programs, we generate a fourth estimate based on a study by *Arena et. al.*[6] that relates the acquisition costs of naval and auxiliary vessels to ship characteristics, notably lightship weight, class, and power density. The final acquisition cost estimate is calculated as the average cost across all four models.

2.2. Assumed Project Timelines

Figure 2-1 presents an estimated profile of the progression of the Polar Icebreaker Project based on PBO calculations and inputs provided from the Department of Fisheries and Oceans and accounting for the historical experience of the project thus far.

The project management phase is assumed to have begun incurring significant costs in the 2009-2010 fiscal year; these activities will continue through to the delivery of the final vessel in 2030-2031. Design activities are assumed to have begun shortly after the start of the program and close out by the 2026-2027 fiscal year. The construction of the first ship at VSY is assumed to commence in 2023-2024, with the second ship beginning construction at Chantier Davie Canada Inc. the following year. The deliveries of these vessels are assumed to occur in 2029-2030 and 2030-2031, respectively.

Figure 2-1 **Polar Icebreaker Project Timelines**



Sources: PBO Calculations, Department of Fisheries and Oceans.
Note: Horizontal axis represents fiscal years.

Costs pertaining to each category are not distributed uniformly over these periods. We distribute the estimated real costs over the assumed timelines according to the experience and projected expenditure profiles of the JSS program; these real costs are then adjusted for economywide inflation and, where necessary, shipbuilding-specific inflation to produce the final cost estimate of the program.

2.3. Total Project Costs

The estimated cost of the Polar Icebreaker Project is approximately $7.25 billion dollars. Table 2-1 presents a breakdown of the constituent elements of these costs. Project management costs for both the development and acquisition phases of the procurement total $346 million. Design costs are estimated at $820 million. Acquisition costs, including all costs associated with construction, are estimated at approximately $6.1 billion.

Table 2-1 **Total Project Costs**

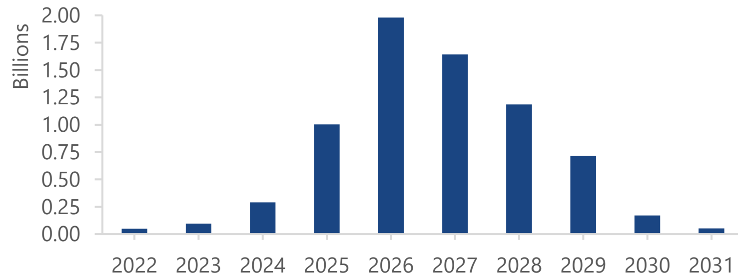
millions $	**Project Management†**	**Design**	**Acquisition**	**Total**
Point estimate	346	820	6,082	**7,248**

Sources: PBO and DFO.
Notes: † The Project Management category includes costs for both the Development and Acquisition phases of the Polar Icebreaker Project.
All costs are exclusive of any applicable taxes.

Figure 2-2 depicts the project's expenditure profile over time. Expenditures begin a rapid ascent beginning in the 2023-2024 and 2024-2025 fiscal years as construction activities begin for both vessels, reaching a peak in 2025-2026. Project expenditures taper off towards the end of the construction cycle, with the final delivery occurring in 2030-2031. While the expenditure profile in this report is presented on a cash basis, it will differ from what will appear in the Government's financial statements given these are presented on an accrual accounting basis.

Figure 2-2

Project Expenditures Over Time, 2022-2031



Source: PBO Calculations.
Notes: Horizontal axis represents fiscal years. Expenditures from previous years omitted.

2.4. Sensitivity Analysis

We conduct a sensitivity analysis to determine the fiscal impact of a one- and a two-year delay. These are assumed to represent delays in the start of construction for *both* vessels at each partner shipyard, with concurrent Design costs being similarly delayed. Project management costs are assumed to increase in real terms as a result of each delay scenario, with the government continuing to manage the program until its completion.

Table 2-2 displays the results of the sensitivity analysis. A one-year delay results in a total increase of $235 million, while a two-year delay increases costs by $472 million.

Table 2-2

Sensitivity Analysis: One and Two-Year Delays

millions $	**Estimate**	**1-year delay**	**2-year delay**
Project Management	346	376	405
Design	820	829	839
Acquisition	6,082	6,278	6,475
Total	**7,248**	**7,483**	**7,720**

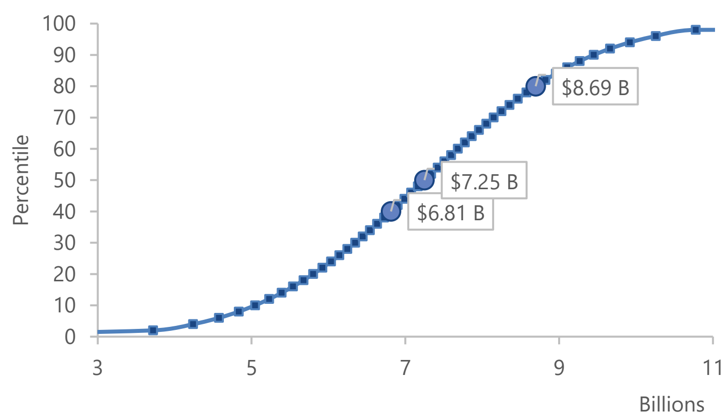
Source: PBO Calculations.
Notes: Figures are in nominal dollars. All costs are exclusive of any applicable taxes.

2.5. Modelling Uncertainty

The most substantial cost category of the total project cost estimate, acquisition costs, was calculated by employing a variety of differing approaches: three separate analogues, of which two are extant Canadian procurement programs and one a historical US Navy procurement, and a regression analysis based on historical US naval shipbuilding data. The average of these various estimates was then used as the point estimate of acquisition costs. To account for the inherent modelling uncertainty contained in this approach, we calculate a distribution of total project costs based on the variance of the constituent estimates.

Figure 2-2 displays the results of this calculation. The 50th percentile represents the "most-likely" price tag of the project, which is the estimate of the total project expenditures discussed earlier in this section. We estimate a low-end cost, evaluated at the 40th percentile of the total project cost distribution, of $6.81 billion, and a high-end cost, evaluated at the 80th percentile, of $8.69 billion. Thus, modelling imprecision may account for a decrease in total project expenditures of $0.4 billion, or an increase of $1.4 billion, as compared to the main point estimate of $7.25 billion.

Figure 2-3 Cumulative Distribution of Total Project Costs



Source: PBO Calculations.
Note: The 40th, 50th, and 80th percentiles are highlighted.

Appendix A: Modelling Ancillary Costs

Ancillary costs include design and project management costs. These cost categories are both based on the AOPS program. While the AOPS program is still underway, two vessels have already been delivered to the Royal Canadian Navy, and Design costs are fully known. We assume based on existing expenditures that projected costs for the government's project management activities are accurate.

We estimate project management and design costs separately. The following sections describe each model in turn. Where appropriate, all economic inflation projections are based on the PBO's projected Consumer Price Index (CPI).[7]

A.1 The Project Management Cost Model

We distribute the AOPS project management costs over the lifetime of the project, using a distribution based on that of the JSS program. We convert the distributed costs to the 2019-2020 fiscal year and sum them to obtain an estimate of the real costs valued in 2019-2020 dollars. We then derive a notional project management distribution for the icebreakers aligned with the JSS distribution and matching the actual spending profile of the AOPS project. Following this, we remove the already-incurred project management outlays of the polar icebreakers project from the total project management costs of the AOPS program. The resulting cost is then distributed over the projected lifetime of the polar icebreakers project. We then inflate the distributed costs using the PBO's projected CPI and shipbuilding-specific inflation and add them to the already incurred expenses of the icebreaker project. Finally, we apply an escalation factor of approximately 41.4 percent[8] in order to account for the inclusion of an additional shipyard.

A.2 The Design Cost Model

The Design cost model uses historical data on design costs from the AOPS program. To properly normalize these historical costs, we disperse the costs over an assumed 7-year period, matching the distribution of the JSS program. These expenditures are then inflated to the 2019-2020 fiscal year. To account for the difference in size in the AOPS and the polar icebreaker's specifications, we adjust design costs by taking the ratio of lightship weight for the polar icebreaker to that of the AOPS. The resulting estimates are then dispersed according to a notional distribution of design costs for the Polar Icebreaker Project.[9] These costs are then escalated according to the PBO CPI index to account for inflation.

Appendix B: Modelling Acquisition Costs

Acquisition costs are inclusive of all construction activities as well as expenditures associated with initial studies, analysis, and engineering support, initial spares, and system tests, trials, and evaluation. We employ two complementary approaches to modelling acquisition costs: one based on the analogue modelling concept and another based on a parametric model.

The analogue modelling concept is the principal method used by the United States Congressional Budget Office (CBO) in estimating ship costs.[10] It consists of identifying a historical procurement program for a ship class similar to the ships planned to be produced and for which costs are fully known. This approach uses the cost per metric tonne of the analogue ship, and then adjust for differences in weight, labour costs, productivity and other characteristics and capabilities, to estimate the cost of the icebreaker.

The parametric modelling approach is based on a study by *Arena et. al*. (2006) that relates the acquisition costs of naval and auxiliary vessels to ship characteristics, notably lightship weight, class, and power density. These cost estimating relationships are tailored to the specifications of the polar icebreaker to produce an out-of-sample estimate.

The final estimate of acquisition costs is then based on the average of each of the independent modelling estimates.

The specifics of each modelling approach are discussed in turn.

B.1 The Analogue Approach

As described previously, due to a lack of directly comparable analogue vessels, we appeal to a selection of historical and contemporaneous procurement programs to act as source data for our cost estimates. We therefore base our analogue approach on a set of vessels for which there is a mix of “right size, wrong mission” and “right mission, wrong size” characteristics such that the estimate is adequately informed. We identify three such analogues: the Royal Canadian Navy’s AOPS and JSS programs, and the US Navy’s Lewis and Clark-class underway replenishment vessel (designation T-AKE) program.

The Arctic and Offshore Patrol Ship

The AOPS, as its name suggests, is a class of armed patrol ships capable of conducting armed presence and surveillance throughout Canadian waters, notably including the Arctic. Compared to the polar icebreaker’s design specifications, it is smaller, with a differing mission profile aimed at conducting support, patrol, and sovereignty missions. However, it possesses the ability to operate in icy conditions with a reported Polar Class of 5.[11]

Box B.1: AOPS Characteristics

In-Service	2 vessels currently in service
Weight, Full Load	6,427 tonnes
Length	103 m
Beam	19 m
Max speed	17 knots
Crew	85 crew and personnel
Propulsion	Diesel Electric
Ice Class	Polar Class 5+
Helicopter Capacity	1

Source: Department of National Defence

The Joint Support Ship

The Joint Support Ships are multi-role vessels capable of supporting the Royal Canadian Navy's warships at sea, including the underway replenishment of fuel, munitions, and stores. The ships are equally capable of providing support to forces ashore through its sealift capabilities. While its mission set differs from the polar icebreaker, it is of comparable size and can operate in minimal ice conditions. Once operational, the JSS will possess a Polar Code certification to operate in Arctic waters above 60 degrees latitude.

Box B.2: JSS Characteristics

In-service	Anticipated 2025
Weight, Full Load	20,933 tonnes
Length	174 m
Beam	24 m
Max speed	20 knots
Crew	239 crew and personnel
Propulsion	Diesel Electric
Ice Class	N/A, Polar Code anticipated.
Helicopter Capacity	6

Source: Department of National Defence

The Lewis and Clark-class Underway Replenishment Vessel

The Lewis and Clark-class cargo ship is a replenishment vessel with a mission profile similar to that of the JSS. Built in the United States, the vessel operates globally, supporting US military operations in theatre and at sea. Compared to the polar icebreaker, it is significantly heavier.

Box B.3: T-AKE Characteristics

In-service	14 ships of class in service
Weight, Full Load	41,700 tonnes
Length	210 m
Beam	32 m
Max speed	20 knots
Crew	135 crew and personnel
Propulsion	Diesel Electric
Ice Class	N/A
Helicopter Capacity	2

Source: United States Congressional Budget Office

Analogue Methodology

For each of the three analogue vessels, the first step in developing an acquisition cost estimate is to normalize the costs of *first ship of each procurement program* to a common base year. In the case of the AOPS, we select the 2nd ship of class, using a reverse learning curve approach to obtain a notional 1st ship cost. We normalize all costs to the fiscal year ending 2020,[12] accounting for economic inflation,[13] shipbuilding inflation,[14] and as necessary, intergenerational capability-improvement inflation.[15]

The next step requires the adjustment of the associated normalized costs for differences in ship characteristics, notably the difference in lightship weight. These figures are divided by the ship's light tonnage, producing a value representing cost-per-ton. This is then multiplied by the polar icebreaker's anticipated lightship weight to produce an intermediate estimate of the acquisition phase cost.

Adjustments are then carried out to correct for differences in the respective shipyard's jurisdictions. In particular, the T-AKE was constructed in the United States. This requires adjustments for labour cost, productivity, and exchange rates.

We measure the difference in labour costs between the two countries using the total compensation per hour, which includes wages, salaries and employer social contributions.[16] To better reflect industry-specific differences, we calculate total compensation per hour for the US-termed "Other transportation equipment" industry, classified as the North American Industry Classification System (NAICS) 3364OT.[17] We estimate the average total compensation for US workers in this industry to be $57.02/hour USD over the 2015 to 2019 calendar years compared to $51.62/hour CAD for Canadian workers. We therefore adjust the labour portion of the icebreaker cost downwards using a factor of 0.91.

Productivity is measured as real gross domestic product (GDP) per hour.[18] Consistent with our labour costs approach, we estimate the average productivity for the NAICS 3364OT over the 2015 to 2019 calendar years and use it as a proxy for labour productivity in 2020. We estimate the productivity for Canadian workers over the same period. Canadian workers were less productive than their US counterparts in the "Other transportation equipment" industry by a factor of 0.59. Therefore, we adjust the labour portion of the icebreaker cost upwards by a factor of 1.70.[19]

These calculations result in a "unit labour cost" factor. We use this factor to adjust the labour cost proportion of acquisition costs. The total labour and material figures are then adjusted by the USDCAD exchange rate. For this purpose, we use the yearly average exchange rate for the fiscal year ending 2020 of 1.33.[20]

The final step in the analogue estimation process is the plotting of the costs according to the projected acquisition cost distribution spanning the assumed project timelines for the construction of the two polar icebreakers and inflating the resulting costs accordingly, using the PBO projected CPI and shipbuilding-specific inflation indices.

Parametric Methodology

The parametric modelling approach relies on a model developed by *Arena et. al.* (2006) that estimates the construction costs of a ship based on its system characteristics.[21] Using the cost estimating relationships of this regression, we estimate the cost of the icebreaker based on its lightship weight, power density, and class.

The equation is as follows:

$$\ln(C_9) = \beta_0 + \beta_1 \ln(LSW) + \beta_2 \ln(PowerDensity) + \beta_3 Auxiliary$$

where Auxiliary is a binary variable, used to identify whether the vessel is an auxiliary vessel, and the subscript ‘9’ refers to the 9th ship built. The cost estimating relationships in the equation were computed for the 2005 U.S. fiscal year dollars (October to September).

Since the model is designed to estimate the cost of the 9th ship – where the shipyard has finished going through the steeper part of the learning curve and the remaining cost reductions are much smaller – we adjust the cost assuming a standard learning curve of 85 per cent.[22]

As in the case of the analogue approach, the resulting estimated cost for the first ship is then inflated to the 2019-2020 Canadian fiscal year, using economic and shipbuilding-specific inflation. We then adjust for differences in labour costs and productivity in the same way as the T-AKE, the US Navy ship used in the analogue approach. As a final step, we distribute the estimated construction costs for both icebreakers over their construction schedules and inflate them using PBO’s projected CPI and shipbuilding industry-specific inflation to estimate the total construction costs for both icebreakers.

Notes

1. Nunatsiaq News, 2008. “Feds to replace old icebreaker”. https://web.archive.org/web/20080303122736/http://www.nunatsiaq.com/news/nunavut/80229_964.html. Accessed 11/23/2021.
2. The CCGS Louis S. St-Laurent is projected to undergo three five-month maintenance and life extension periods throughout the 2020s.
3. Polar Security Cutter Program Description, United States Coast Guard. https://www.dcms.uscg.mil/Portals/10/CG-9/Acquisition%20PDFs/Factsheets/POLAR.pdf?ver=2017-10-10-125654-090. Accessed 11/26/2021.
4. This practice follows the approach of NATO studies on the topic of cost estimation for shipbuilding procurement. See, for instance, “NATO Independent Cost Estimating and the Role of Life Cycle Cost Analysis in Managing the Defence Enterprise”, NATO SAS-076, 2012.
5. That is, the first completed ship of the procurement program. In the case of the AOPS, the data for the second ship was used to estimate a first ship cost by applying an inverse learning curve factor of 85%.
6. Arena, M.V., Blickstein, I., Younossi, O., and Grammich, C.A. (2006). Why Have Navy Ship Costs Risen?. https://www.rand.org/content/dam/rand/pubs/monographs/2006/RAND_MG484.pdf
7. Projected CPI is consistent with PBO’s Economic and Fiscal Outlook model, as at August 12, 2021.
8. This calculation is based on taking the square root of the number of participating shipyards as a means to adjust the estimated cost. Hartley, K. and Braddon, D. (2014), Collaborative Projects and the Number of Nations, DPE, 25, 6, December.
9. The design cost distribution is based on the historical experience of the Joint Support Ship and the Canada Surface Combatant. Design phase costs generally lead costs in the construction phase by 3 to 4 years.
10. Congressional Budget Office, “How CBO Estimates the Cost of New Ships”, April 2018. url: https://www.cbo.gov/system/files/115th-congress-2017-2018/reports/53785-cost-estimates-new-ships.pdf and “An Analysis of the Navy’s Fiscal Year 2017 Shipbuilding Plan”, February 2017. url: https://www.cbo.gov/sites/default/files/115th-congress-2017-2018/reports/52324-shipbuildingreport.pdf. Accessed 11/16/2021.
11. See: https://www.naval-technology.com/projects/harry-dewolf-class-arcticoffshore-patrol-ships-aops/. Accessed 11.26/2021.
12. This aspect is only relevant for the intermediate calculation steps of the model, as the final costs are plotted over a construction schedule cost distribution and inflated accordingly.
13. Economic inflation estimates follow the PBO’s Economic and Fiscal Outlook, as at August 12, 2021.

14. Shipbuilding inflation is, following United States Congressional Budget Office estimates, evaluated at 1.2% per year from 2000 to 2016, 0.9% from 2016 to 2020, and 1.2% per year thereafter.

15. Intergenerational inflation adjusts for the improvement of capabilities between generations of naval vessels. In this analysis, it is only applied in the case of the T-AKE as the AOPS and the JSS are both contemporary procurement programs.

16. We use the total compensation by industry provided by Statistics Canada tables which are more up to date data than the supply-use tables.

17. The Other Transportation Equipment industry classification is comprised of NAICS 3364XX (Aerospace product and parts manufacturing), 3354XX (Railroad rolling stock manufacturing), 3366XX (Ship and boat building) and 3369XX (Other transportation equipment manufacturing) where 'X' indicates all industry codes within this 4-digit code.

    PBO attempted to estimate the labour cost for NAICS 3366XX (Ship and boat building) explicitly, however several factors made this option less reliable. For one, US data for this NAICS was only available for 2007 and 2012, making any projections or comparisons for more recent years problematic. Second, corresponding data for Canada in 2012 coincided with the beginning of significant investment in shipbuilding. We believe the Canadian data for this year would not be representative of a typical year of labour costs, productivity or shipbuilding learning. For this reason, we opted to use the next-highest level of aggregated to approximate the data for the shipbuilding industry.

    We used data from 2015 to 2019, the most recent period for which regular data were available in both the US and Canada and exclude 2020 data because of the pandemic.

18. Canadian GDP by Industry is presented at basic prices, whereas the US reports market prices. PBO used the gap between Canada's total GDP (market prices) and Canada's total GDP for all Industries (basic prices) to adjust the industry-specific GDP to reflect market prices. Chained (2012) GDP were used for both nations, with Canadian GDP converted to USD purchasing power parity (PPP) using a PPP index. The index is available here: OECD (2021), Purchasing power parities (PPP) (indicator). doi: 10.1787/1290ee5a-en (Accessed on 25 October 2021)

19. This is calculated as 1 / 0.59.

20. Calculated using the PBO's Economic and Fiscal Outlook.

21. Arena, M.V., Blickstein, I., Younossi, O., and Grammich, C.A. (2006). Why Have Navy Ship Costs Risen?. https://www.rand.org/content/dam/rand/pubs/monographs/2006/RAND_MG484.pdf

22. Mislick, G.K. and Nussbaum, D.A. (2015). Cost Estimation: Methods and Tools.