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# Stretching Purchasing Power through Improved Escalation Methods

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# Abstract

Escalation methods ensure cost estimates adapt to economic changes and facilitate accuracy and reliability. The National Nuclear Security Administration (NNSA) chartered the Programmatic Recapitalization Working Group (PRWG) to track mission-critical equipment directly supporting weapons activities across the nuclear security enterprise. The PRWG maintains a comprehensive database of equipment above the NNSA capital acquisition threshold of $500,000, including currently active equipment and planned future procurements. The previous escalation methodology for equipment purchase price was limited to using a single equipment escalation index. Additional fidelity in price projections can be achieved by leveraging empirical price data and published indices to derive escalation rates specific to various equipment categories. This paper explores our approach to improving upon the previous escalation methodology to better inform planning and programming decisions. This approach can be leveraged when one broad escalation index is used to predict costs for many significantly differing data elements.


**Keywords**: *Data-Driven, Regression, Escalation*

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# 1. Introduction

## 1.1 National Nuclear Security Administration

Founded by Congress in 2000, the National Nuclear Security Administration (NNSA) is a semi-autonomous agency within the Department of Energy (DOE) with the mission to manage the United States' nuclear weapons stockpile, reduce global danger from weapons of mass destruction, and to promote international nuclear safety and nonproliferation.[1]

The NNSA is headquartered in Washington, D.C. with secondary headquarters in Albuquerque, New Mexico. Headquarters serve policy and administrative functions (e.g., Planning, Programming, Budgeting, Evaluation, (PPBE) etc.). Production, research and development, and testing and evaluation work for the NNSA's science-based stockpile stewardship and global security missions are carried out across the country at the NNSA's eight National Security Enterprise (NSE) sites. These sites consist of government-owned and contractor-operated labs, production plants, and test ranges. Labs are primarily responsible for the research, development, and evaluation of specialized nuclear and nonnuclear components. Production plants are responsible for large scale material and component production, nuclear weapon assembly and dismantlement, and maintaining the war reserve stockpile. The experimental test site at Nevada is a multi-mission test range with high-hazard experimentation capabilities delivering technical and service solutions in support of national security. To meet mission requirements and carry out all the types of work described above, the NSE sites need a multitude of various types of programmatic equipment.

## 1.2 Programmatic Recapitalization Working Group

Given the complicated and nuanced nature of the various missions of all eight sites, problems arose around recapitalizing programmatic equipment. It was difficult to determine the program responsible for funding these expensive purchases, and this

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[1] About NNSA | Department of Energy

resulted in duplicative efforts. The Programmatic Recapitalization Working Group (PRWG) is a collaborative body that seeks to address these programmatic equipment recapitalization challenges. Programmatic equipment is equipment that directly supports or is integral in weapon activity (WA) deliverables. Examples of NNSA WA programs include (but are not limited to): Plutonium Sustainment, High Explosives and Energetics Modernization, Capabilities Based Investments (CBI), individual stockpile systems sustainment (e.g., W76-1, B83), Life Extension Programs (LEPs), modernization, alternations (e.g., B61-12, W80-4, W87-1), etc. [2]

**Programmatic** equipment supporting these missions are mobile and directly support mission work, such as lathes, scanning electron microscopes, milling machines, lasers, advanced cameras, etc. Programmatic equipment can range from thousands of dollars to millions of dollars apiece.

**Non-programmatic** real property assets are generally immobile and permanently affixed to the building or land, and do not directly contribute to the NNSA's WA programs. Examples include HVAC, plumbing, electrical wiring, built-in cabinets, elevators, etc.

It is important to distinguish programmatic equipment from non-programmatic real property assets, as the PRWG addresses programmatic equipment.

The PRWG has been collecting programmatic equipment data from the eight NSE sites for the past five years through annual data calls. The PRWG's scope of work is confined to **programmatic** equipment for which the **purchase price** is equal to or exceeds the **capital acquisition threshold** of $500,000.[3] For each piece of equipment, the PRWG collects attributes related to age, cost, risk, and condition to determine the overall health and risk of the NNSA's programmatic equipment portfolio to *proactively* inform NNSA program offices of potential future equipment needs.

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[2] PRWG FY23 Data Call Guidance

[3] Capital Acquisition Threshold is a dollar amount that determines the proper financial reporting of an asset. It is currently $500,000 for the DOE. DOE Financial Management Handbook; Chapter 10, Accounting for Property, Plant and Equipment; Pg. 10-3.

The PRWG collects historical equipment purchase price information in “Then-Year” dollars ($TY) but provides future equipment recapitalization needs in “Base-Year” dollars ($BY) to better assist programs in their Planning, Programming, Budgeting, and Execution (PPBE) process. For this reason, the PRWG is responsible for calculating the price escalation of historical equipment to project future prices, which is the primary focus of this paper.

### 1.3 Inflation and Escalation

Inflation and escalation are sometimes used interchangeably but have very different meanings. Inflation refers to macro level price changes for a *broad* market basket of goods and services over time. The most frequently utilized measure of inflation is the Consumer Price Index (CPI). Inflation is typically cited in the news and makes for flashy headlines like – “Inflation rate highest since 1982” (a common theme during the height of the COVID-19 pandemic in 2022). When annual inflation is above zero, the value of money is worth less than it was the previous year and vice versa. For example, assuming positive inflation, $100 would buy *less* a year from now than it would today.

Since programmatic equipment are not a part of the consumer goods and services basket, the CPI is simply not a good fit for measuring inflation. This paper utilizes the Gross Domestic Product Price Index (GDPPI) as the measure of inflation because it considers the broadest measure of inflation in the economy (and includes programmatic equipment in its basket).

Escalation refers to the price changes of *specific* goods and services. For example, if someone were interested in seeing only how *nectarines* have changed in price over time, they should look at an escalation rate specific to nectarines. This rate would normally differ from the broader inflation (GDPPI) rate and could be higher, lower, or equal to inflation in any given year. Although inflation is a factor that affects escalation, there are other factors which also impact the real price change of a specific good or service over time. These factors include (but are not limited to) supply/demand conditions, technological advancements, environmental effects, and political/social effects.

Constant Price (CP) refers to costs that do not include escalation or inflation. Constant Year (CY) dollars do not include inflation but include real price change. Then year (TY) dollars include inflation and real price change. A graphical depiction from DoD's Cost Assessment and Program Evaluation, is shown in Figure 1.[4]

Escalation = Real Price Change + Inflation

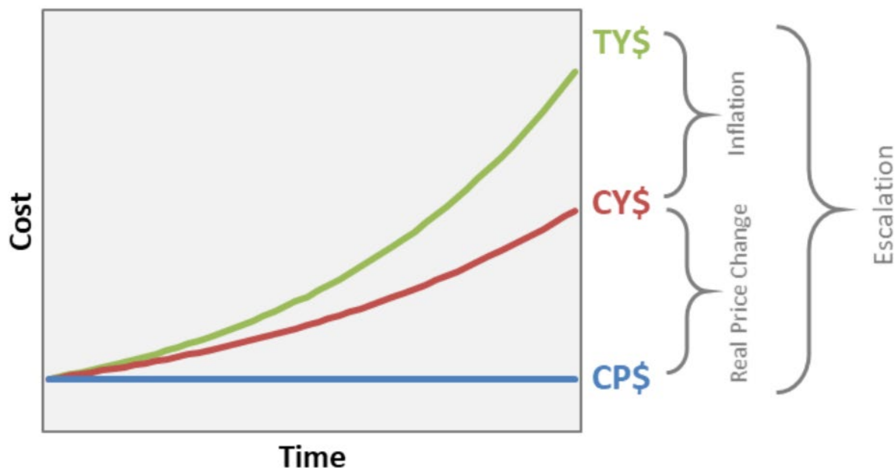


*Figure 1: DoD CAPE Escalation, Inflation, Real Price Change*

**Table 1** outlines an example of the real price change of a piece of metalworking machinery. Nominal value refers to how the value of money changes over time due to inflation. Using GDPPI, $50,000 in 1983 is equivalent to $128,000 in 2023. The equipment cost also changes over time, but at a different rate compared to inflation. Using an index specific to equipment (in this case the Producer Price Index for metalworking machinery, WPU113), a $50,000 piece of equipment in 1983 would cost $119,150 in 2023. The difference between nominal value change (inflation) and equipment cost change (escalation) is the real price change. The replacement cost of the equipment in 2023 is more than double the cost in 1983, but the *real cost* (in TY$) has decreased by over 6.9% compared to the nominal baseline value (CY$).

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[4] Office of the Secretary of Defense Cost Assessment and Program Evaluation (2021). Inflation and Escalation Best Practices for Costs Analysis (2021)

Understanding the impact of real price change on equipment is important when calculating escalation.

| | 1983 | 2023 |
|---|---|---|
| **Nominal Value – GDPPI (CY$)** | $50,000 | $128,000 |
| **Equipment Cost (TY$) – WPU113** | $50,000 | $119,150 |

| | |
|---|---|
| **Nominal Difference ($)** | -$8,850 |
| **Real Price Change (%)** | -6.9% |

*Table 1: Real Price Change*

As escalation can simply be defined as the rate of change in cost of a specific good over time, only two variables per data instance are needed to empirically determine the escalation rates. These variables are "cost" of the equipment (in actual $TY) and the year (i.e., "time") in which the equipment was purchased. The next section discusses data needs in detail.

# 2. Data Collection and Data Quality

## 2.1 Data Collection

Although the PRWG collects over 20 attributes for each piece of equipment. This paper will utilize the following three key attributes for analyzing escalation:

1. **Purchase Price** (the main cost input in PRWG's data call) is defined as the dollar amount spent solely for the equipment itself – typically found on the purchase order. This does *not* include the costs related to installation, facility modification, and/or shipping the equipment (to name just a few additional expenditures).
2. **First Day of Operation** is the date the equipment was entered into service.
3. **Lead Time to Procure** is the time between the date of the purchase order to the first day of operation (includes time related to shipping, installation, tooling, testing, etc.).

By subtracting the **Lead Time to Procure** from the **First Day of Operation**, the PRWG can determine the **Purchase Date** for all equipment. This information will be used for the "time" portion of the escalation analyses.

### 2.2 Data Quality

PRWG collects data from eight sites which operate equipment with vastly different missions, scopes, and processes. Therefore, maintaining complete, accurate, consistent, and reliable data across eight sites that are managed and operated by different contractors requires constant communication and a structured data governance. As data quality is crucial to any type of data analysis, the PRWG employs several key measures, both before and after the data calls, to ensure data quality.

**Pre-Data Call:** One of the most important aspects of any data call is clear and concise data guidance backed by a data dictionary and paired with a standardized data collection template. The PRWG has exerted significant effort in collaborating with NSE site representatives to remove ambiguity in the data collection instructions wherever possible. The PRWG regularly revises the data call to ensure it is only collecting data fields that add value to data users while minimizing data collection work for primary sources (i.e., equipment custodians).

**Post Data Call:** The PRWG has developed a standardized data validation and verification (V&V) process which involves an automated algorithm to run initial data checks on completeness and consistency, manual in-depth analysis on each version of the data collected from the eight sites (intra-site and inter-site), and one-on-one meetings with site representatives to discuss the data in detail. The V&V meetings give PRWG an opportunity to further understand specific data instances, investigate and correct potential data errors, and facilitate collaboration between headquarters and the NSE sites.

## 3. Methodologies and Results

### 3.1 Historical Escalation Methodology

Until recently, the PRWG employed the same escalation rate for *all* PRWG equipment. The previous methodology converted $TY to $BY ($BY2023 will be used for the purposes of this paper) by utilizing the Metalworking Machinery Equipment Producer Price

Escalation Index (WPU113) published by the Bureau of Labor Statistics (BLS).[5] WPU113 was determined the best fit for the majority of the PRWG data back in 2020. Gross Domestic Product Price Index (GDPPI) produced by the U.S. Bureau of Economic Analysis (BEA)[6] serves as the measure of inflation.

As of October 2023, the GDPPI is 256.0 and the WPU113 Index is 238.3, a 6.9% difference compared to 1983. This means that overall *inflation* (GDPPI) has been increasing faster compared to the *escalation* (WPU113) of metalworking machinery and equipment. See **Figure 2** below for the direct comparison from 1983 to 2023.

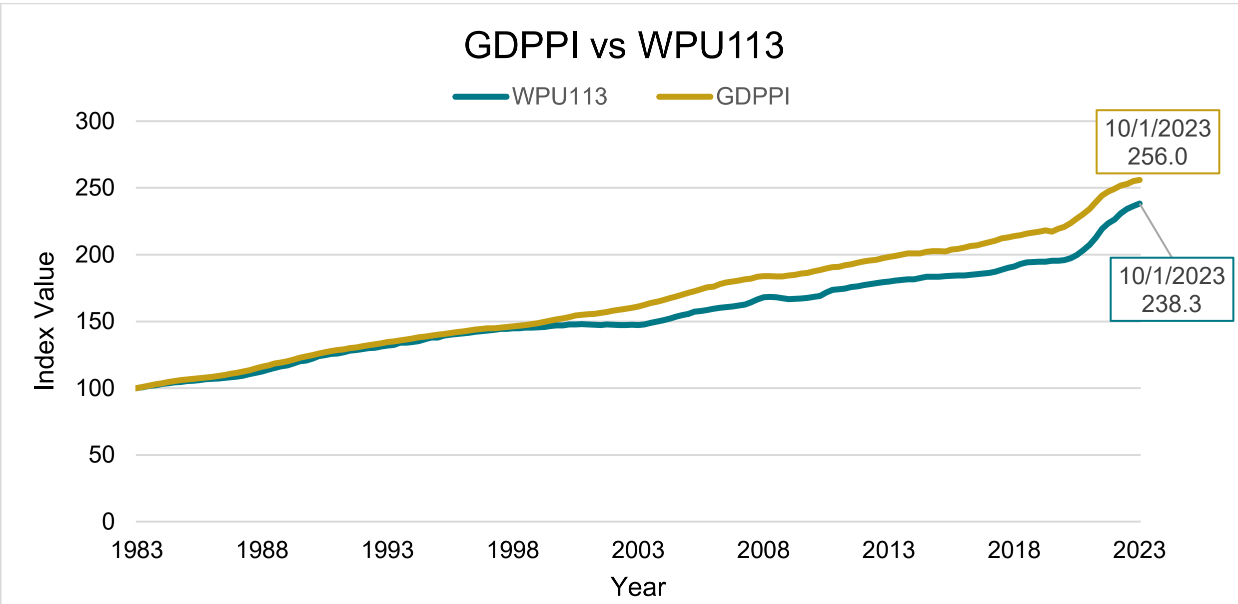


*Figure 2: GDPPI vs WPU113*

The distance between the WPU113 blue line and the GDPPI gold line represents *real price change* (discussed in detail in section 1.3). Given that the escalation line is below the inflation line, the WPU113 index shows that real price changes are *less* than inflationary changes. This could be due to several reasons, one of which is that the GDPPI and WPU113 differ in their scope and coverage.

GDPPI is a weighted index of all goods and services produced in the United States. GDPPI weights items by their proportion of total GDP. Non-machinery items (such as

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[5] Bureau of Labor Statistics Data (bls.gov)
[6] Bureau of Economic Analysis (bea.gov)

services, farm production, or employment[7]) have a large influence on inflation but are outside the scope of the WPU113 index. Other possible reasons for the difference include supplies of materials, labor rates, learning curves, increase in automation in production processes, etc.[8]

The two critical variables required to escalate price to base year dollars are: **First Day of Operation** and **Purchase Price ($TY)**. The BY2023 WPU113 price is calculated by taking the TY purchase price and dividing it by the WPU113 escalation factor associated with the year of the first day of operation. See **Table 2** for examples on the calculation.

| PRWG Collected Data | | | Calculated Cells | | | |
|---|---|---|---|---|---|---|
| **Equipment Name** | **First Day of Operation** | **Purchase Price ($TY)** | **Year** | **WPU113 Escalation Factor** | **Calculation** | **BY2023$ Purchase Price** |
| North Star Imaging X3000 | 11/30/2019 | $925,280 | 2019 | .888623 | $925,280/.888623 | $1,041,251 |
| North Star Imaging X3000 | 9/21/2022 | $856,229 | 2022 | .957258 | $856,229/.957258 | $894,460 |

*Table 2: North Star WPU113 Calculation Example*

Some limitations of this current methodology can quickly be gleaned from the example above. The x-ray equipment shown in the table are identical, both North Star Imaging X3000's. Yet, their calculated replacement prices reflect a 14% difference ($1.04M vs. $0.9M). This specific example shows that x-rays have gotten cheaper over time versus following the typical inflationary trend. This could be for several reasons: automation in producing x-rays, learning curves making the process cheaper over time, increased competition from other suppliers, etc.

The PRWG database has evolved over time; a significant portion of the portfolio includes equipment that do not fit into a metalworking and machinery index (shown in the example above). Due to the various economic trends that may apply to specific categories of

[7] NIPA Handbook; Chapter 3: Principal Source Data
[8] Office of the Secretary of Defense Cost Assessment and Program Evaluation (2021). Inflation and Escalation Best Practices for Costs Analysis (2021)

equipment, utilizing a ‘one size fits all’ escalation methodology for PRWG’s entire portfolio of equipment is resulting in inaccurately escalated equipment costs. The next section of the paper will explore and analyze two alternative escalation methods and show the importance of categorization within a portfolio.

## 3.2 Equipment Categorization

The PRWG was a pioneer in standardizing NNSA equipment categories for large and complex equipment types. This systematic process involves housing diverse arrays of equipment in the portfolio into logical groupings (i.e., equipment categories) based on equipment function, characteristics, and capabilities. The process originally employed a PRWG-developed natural language processing (NLP) model that evaluated equipment names and descriptions to determine raw equipment groupings. This list of categories is refined continuously through collaboration with the equipment custodians and Subject Matter Experts (SMEs). The list is currently composed of ~10 major categories, ~100 equipment categories, and ~300 sub-categories, resulting in a three-tiered categorization system to support various levels of analyses (see Appendix B).

Without this intermediate level of data organization, the PRWG would have been limited to analyzing equipment data at three levels – enterprise, site level, or individual equipment. Consider the following questions:

1. At what rate does the cost of all NNSA equipment change over time?
2. At what rate does the cost of equipment #ABC123 change over time?
3. At what rate does the cost of NNSA lathes change over time?

The first two questions are too broad considering the diversity of equipment in the portfolio. This leaves the last question, which suggests a useful balance of generality (multiple pieces of equipment per group) and specificity (only one type of equipment per group).

**Table 3** provides a few examples of equipment, their categories, and subcategories:

| Name | Major Category | Category | Sub-Category |
|---|---|---|---|
| NLX6000CY CNC Lathe | Metalworking Machinery | Lathe | Computer Numerical Control (CNC) |
| American Engine Lathe | Metalworking Machinery | Lathe | Engine |
| Makino Manual Lathe | Metalworking Machinery | Lathe | Manual |
| Dual Beam Electron | Measuring and Lenses | Microscope | Scanning Electron (SEM) |
| Transmission Electron | Measuring and Lenses | Microscope | Transmission Electron (TEM) |
| \ZEISS NUHV Orion Plus Helium Ion Microscope | Measuring and Lenses | Microscope | Focused Ion Beam (FIB) |

*Table 3: Equipment Categorization Example*

## 3.3 New Equipment Escalation Methodologies

Due to the limitations associated with a "one size fits all" historical escalation methodology, the PRWG decided to explore alternate escalation methodologies. The goal of these alternate methodologies is to provide NNSA program offices higher fidelity equipment price projections to better inform the PPBE process. This paper explores two alternate escalation methodologies – **data-based empirical escalation by equipment category** and **index-based empirical escalation by equipment category**.

### 3.3.1 Data-Based Empirical Escalation by Equipment Category

For the first alternative escalation methodology, the PRWG explored an empirical approach which leverages the data collected on equipment price and purchase year to derive escalation rates for categories of equipment through a regression methodology. The following paragraph will illustrate this methodology for lathes, which is one of the largest categories of equipment (by count) in the PRWG database.

Changes related to monetary values over time are typically referred to in terms of growth rates. Inflation is referred to as a percentage increase over a previous period. For this reason, an exponential regression is used to estimate cost growth. **Figure 3 indicates** the cost of lathes has increased 3.3% annually over the last ~50 years. Equipment with costs greater than two standard deviations from the average were considered outliers and excluded from this analysis. Prices were normalized on a scale of 0-100 to eliminate any price sensitivities.

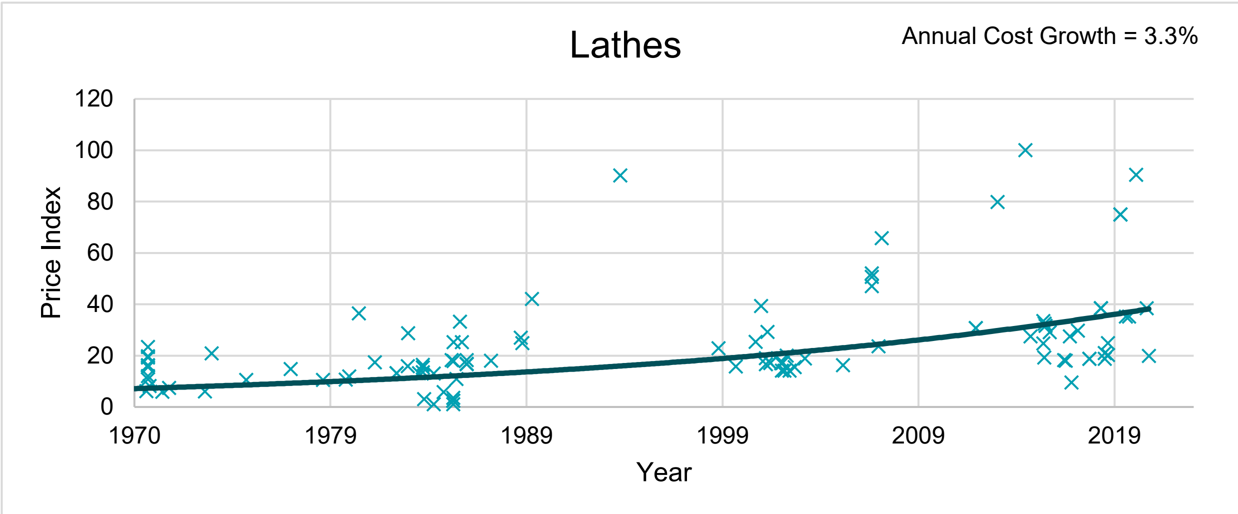


*Figure 3: Lathe Trends*

Using the empirical approach with the PRWG data is difficult because there are rarely exact one-for-one replacements for equipment. Equipment evolves and technologies drastically improve over time, often resulting in lower prices. It is difficult to determine which lathes are similar enough to create a cost estimating relationship (CER). This is by no means a new problem in the CER/escalation world; normalizing for changes in quality, efficiency, technological improvements (to name a few), is a considerable effort when quantifying price changes for a specific basket of goods over time.

**Figure 4** from lathes manufacturer Moore Tool shows the trend of increasing precision in their lathes over time[9]. To account for quality changes, spec information would be required that the PRWG does not currently collect such as: precision, chuck size, bar capacity, RPM's, spindle storage, etc. Even though the PRWG dataset does not have enough information to quantify the cost difference associated with improved precision, there are still valuable insights to be drawn from empirical analysis of equipment costs over time.

[9] Moore Tool Pamphlet https://mooretool.com/pdf/f_1600.pdf

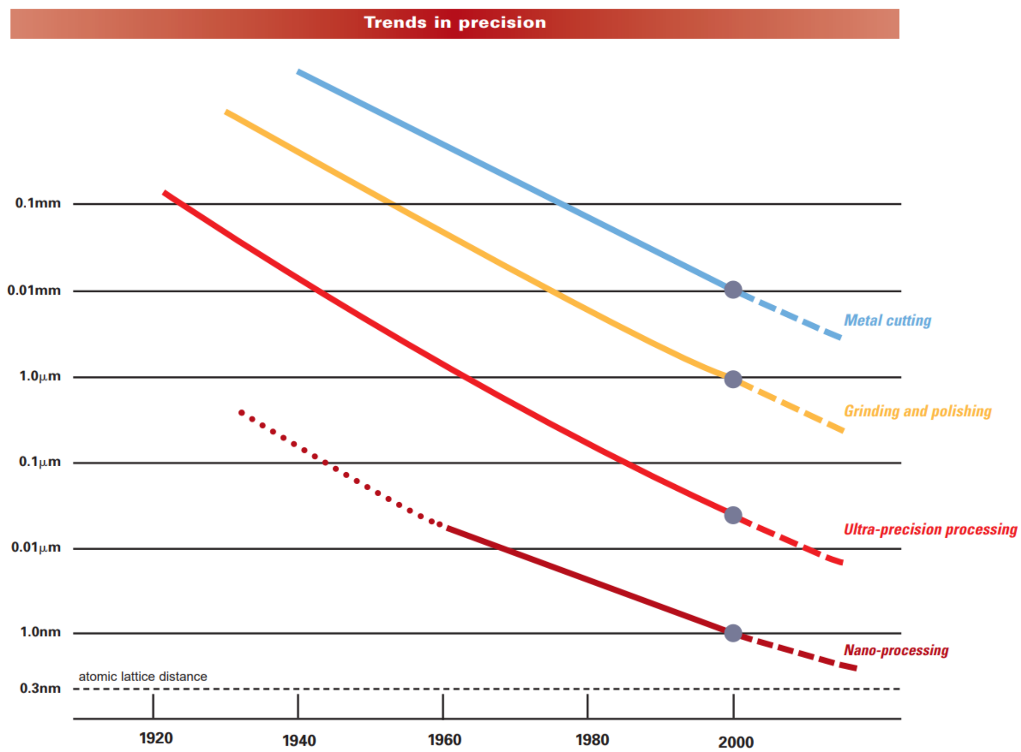


*Figure 4: Moore Tool Lathe Precision Trends*

Because the PRWG does not have enough data on equipment specifications to create custom escalation rates for each individual equipment make and model, the PRWG focused on a higher level of data. This was accomplished through aggregation of categories into larger groups (major categories) based on equipment function (see Appendix B).

**Figures 5 and 6** show the differences in cost escalation between two major categories: Metalworking Machinery (lathes, mills, welders, etc.) and Computer Equipment (high performance computers, data storage equipment, data collection equipment, etc.).

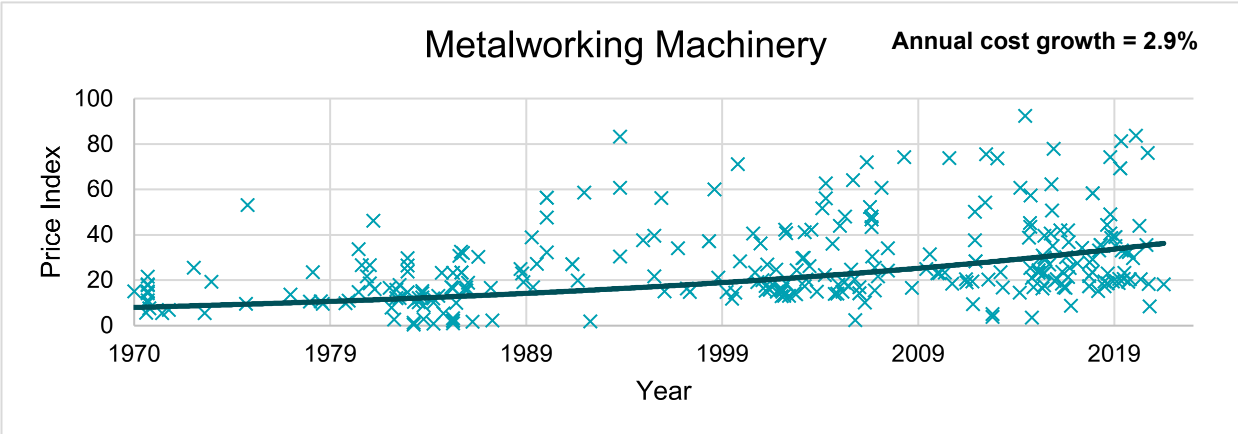


*Figure 5: Metalworking Machinery*

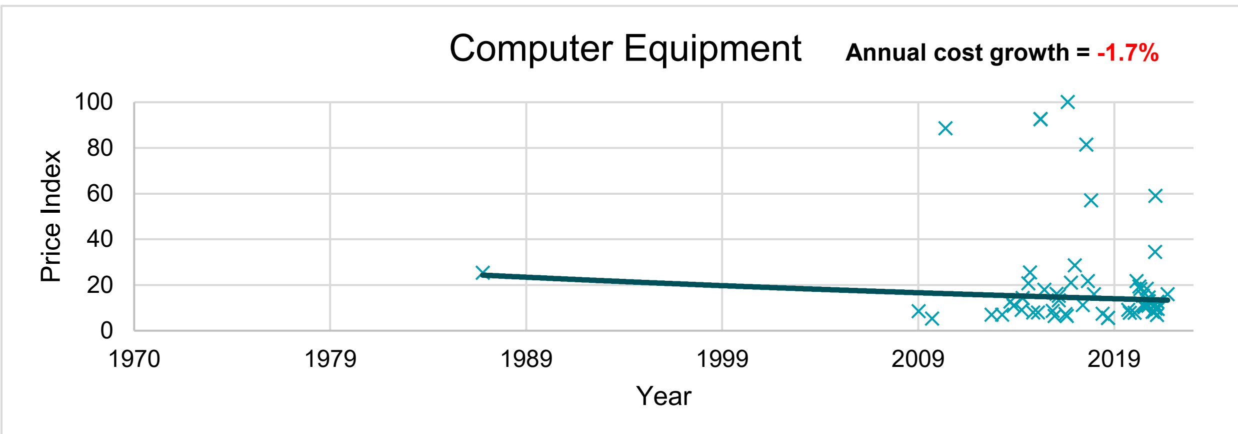


*Figure 6: Computer Trends*

The empirical analysis shows a divergence in escalation trends between metalworking machines and computer equipment. Computers have been getting cheaper over time while increasing their RAM, memory, and capabilities. Metalworking machinery has been trending upwards due to increased sophistication in technologies and supplies tracking with economy inflation. The historical escalation methodology using a single WPU113 index was not able to capture this difference and resulted in a significant over-escalation of computer equipment costs. Empirically derived escalation rates by major category may provide a better estimate of cost trends compared to the historical one-size-fits-all approach. However, the limited number of data points and the inability to address changes in quality make constant empirical growth rates an imperfect method for escalating equipment costs. A method to address those challenges is discussed in the next section.

### 3.3.1 Index-Based Empirical Escalation by Equipment Category

Now let's turn our attention to the second alternative escalation methodology. Indices provide a potential solution to the issues posed by empirically derived escalation rates. The Bureau of Labor Statistics (BLS) produces monthly price indices based on producers' listed prices for a select group of good and services. The indices are produced by weighting a collection of samples within a specific group and then adjusting the samples for changes in quality[10]. **Figure 7** shows an interesting example of the price differentiation for different BLS produced PPI indices.

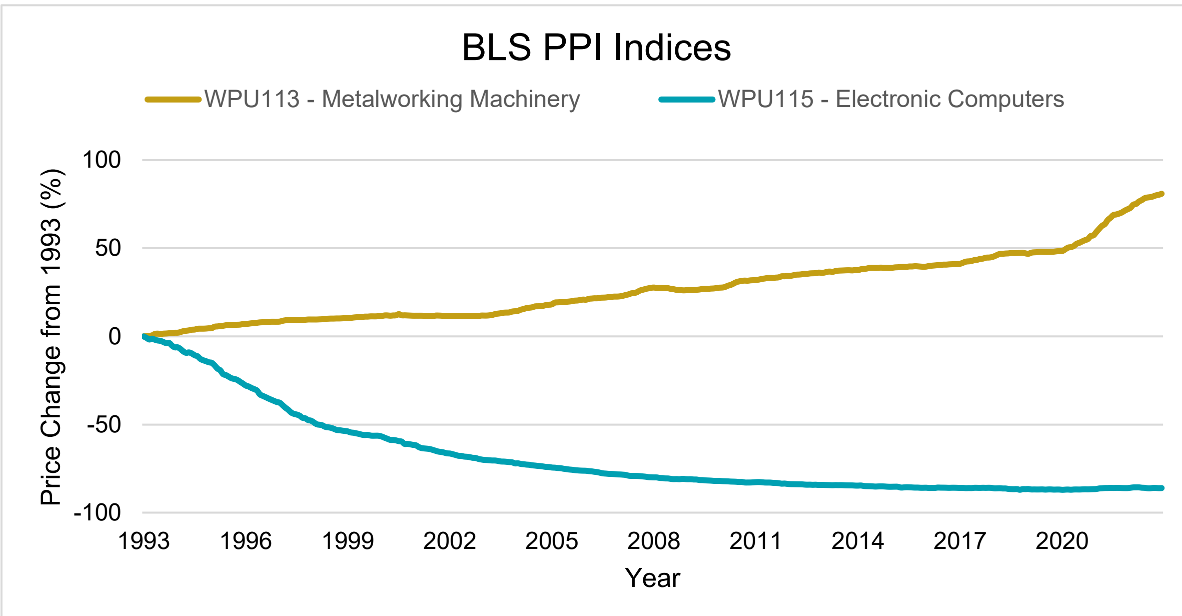


*Figure 7: BLS PPI Indices*

The indices for metalworking machinery and computers follow the same divergent pattern observed in the empirical data.

The first step in this approach is shown in **Figure 8** and involved taking the empirically derived rates from section 3.2.2 (Computer and Metalworking) and comparing them to the Computer and Metalworking PPI indices. The difference between the two methods highlights issues with constant annual growth rates derived from empirical data:

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[10] BLS Handbook of Methods

escalation is unlikely to be constant over time, and one shouldn't neglect the impact due to changes in equipment quality.

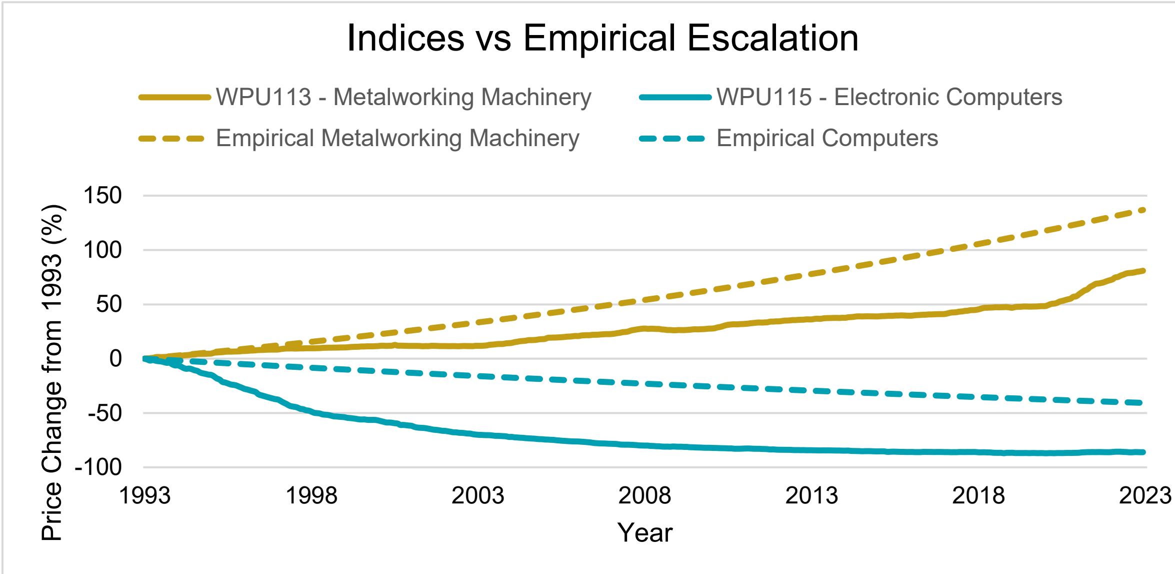


*Figure 8: Indices vs. Empirical Escalation*

The next step was to identify all the indicies from the BLS that fit the same functions as PRWG equipment. The indicies selected need to cover the same time span as the PRWG equipment, and need to be evaluated for their applicability to all the equipment listed in each category. **Table 4** lists the nine indices used in the analysis.

| PPI Series ID | Name | Date Range |
|---|---|---|
| WPU113 | Metalworking Equipment | 1947 to 2023 |
| WPU1134 | Industrial Furnaces | 1947 to 2023 |
| WPU114 | General Machinery | 1939 to 2023 |
| WPU1144 | Material Handling Equipment | 1947 to 2023 |
| WPU115 | Electronic Computers | 1990 to 2023 |
| WPU117 | Electrical Machinery | 1939 to 2023 |
| WPU1186 | Measuring Instruments and Lenses | 1985 to 2023 |
| WPU118602 | Optical Instruments and Lenses | 1985 to 2023 |
| WPU118603 | Laboratory Analytical Instruments | 1985 to 2023 |

*Table 4: Indices*

# 4. Comparative Analysis and Impact of New Escalation Methodologies

## 4.1 Comparative Analysis

The three methodologies outlined above (single escalation index for all equipment (previous methodology), empirical data-based escalation by equipment category, and index-based empirical escalation by equipment category) were compared relative to their ability to accurately escalate the programmatic equipment costs to observed instances of escalation.

**Observed instances of escalation** refers to the price differences of identical programmatic equipment purchased at different times. Identical equipment can be identified by using the name and description provided in the data call. For a specific equipment to qualify as an "observation of cost escalation" enough descriptive information must exist to reasonably assume that equipment is the same in terms of both quality and functionality to another equipment in the data call.

There were 99 pieces of equipment that could be paired to at least one other identical piece of equipment purchased after it. The observations spanned 20 of the 87 equipment categories, and 7 of the 10 major categories (see Appendix B for the full list). **Table 5** shows two examples of the same equipment purchased multiple times. Equipment prices were standardized to the cost of the most recent purchase to minimize bias across equipment types.

| Equipment Name/Description | Purchase Date | Relative Price |
|---|---|---|
| NORTH STAR IMAGING,X3000 | 12/5/2018 | 108.1 |
| CT Machine, 2D 3D,NSI,X3000 | 4/4/2020 | 105.2 |
| NORTH STAR IMAGING,X3000 | 4/9/2021 | 100.7 |
| NORTH STAR IMAGING,X3000 | 1/24/2022 | 100.0 |
| 5-axis motion stage DIW Printer | 8/7/2016 | 50.0 |
| 5-axis motion stage DIW Printer | 8/13/2017 | 31.9 |
| 5-axis motion stage DIW Printer | 11/18/2019 | 100.0 |

*Table 5: Identical Equipment Examples*

**Figure 9** below shows a plot of four identical x-ray equipment purchased between 2018 and 2021 compared to the three methodologies for cost escalation. The first instance of the identical equipment (2018) in the timeline was utilized as the benchmark.

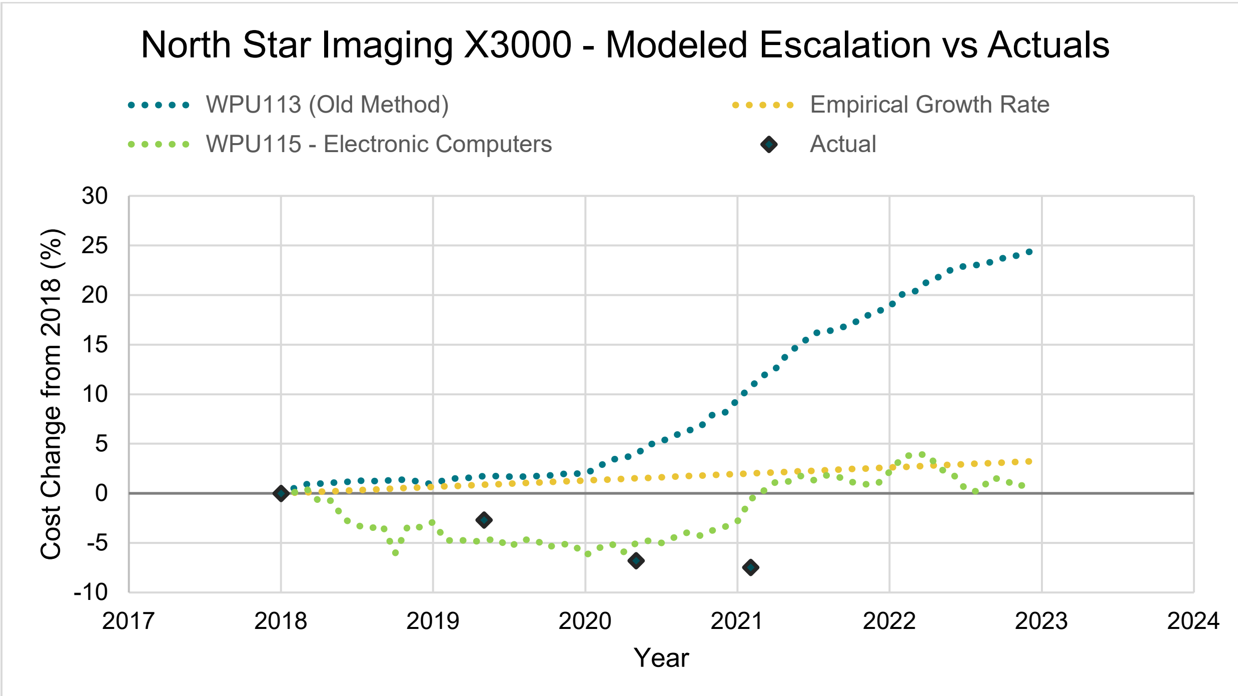


*Figure 9: X-Ray Escalation Methods vs. Actuals*

The difference between a methodology's predicted escalation and the observed (actual) escalation is defined as the error. **Table 6** lists the errors calculated for a specific X-ray. Keep in mind that the first data point in 2018 will have a zero error as it is the starting point and is therefore not shown.

To determine which PPI index serves as the best estimate for escalation, the squared errors were calculated for the eight selected BLS indices and summed by equipment category. The index (WPU115) with the lowest sum of squared errors (SSE) was considered the optimal index.

| Purchase Date | WPU113 Error | WPU113 SSE | Empirical Error | Empirical SSE | WPU115 Error | WPU115 SSE |
|---|---|---|---|---|---|---|
| 4/1/2020 | 4.4% | 19.48 | 3.5% | 12.54 | -2.1% | 4.43 |
| 4/1/2021 | 10.8% | 116.47 | 8.3% | 69.29 | 1.8% | 3.31 |
| 1/1/2022 | 18.2% | 331.11 | 9.5% | 89.73 | 6.9% | 47.34 |
| **All** | **11.1%** | **467.06** | **7.1%** | **171.55** | **2.2%** | **55.08** |

*Table 6: Standard Error Examples*

## 4.2 Accuracy Assessment (Comparison to Actuals)

The bias results are listed in **Table 7**. To normalize the positive and negative bias values, the absolute value weighted averages is listed in the final row. The category specific index method has the least bias compared to the previous method and the empirical method.

| | | Bias | | |
|---|---|---|---|---|
| Major Category | Count | Previous Methods (WPU113 escalation) | Empirical Methods | Category Specific Index Method |
| Electrical Equipment | 6 | -16.7 | -18.9 | -15.4 |
| Furnaces | 1 | -18.8 | -17.5 | -17.7 |
| Lab Equipment | 13 | 14.5 | 14.9 | 3.4 |
| Measuring and Lenses | 20 | 0.6 | -3.1 | -4.9 |
| Metalworking Machinery | 15 | 2.4 | 7.6 | 1.5 |
| Microelectronic Fabrication | 2 | -13.6 | -15.2 | 0.3 |
| Vehicles | 1 | -7.7 | -16.5 | -5.9 |
| Absolute Value (All) | 58 | 6.7 | 9.4 | 4.9 |

*Table 7: Bias by Major Equipment Category*

**Table 8** looks at the SSE's and shows similar results. The category-specific index method had the lowest SSE of the three methodologies. The results for equipment category and major category show the category-specific index method is a better approach to answering the question "what would a specific piece of equipment cost today?"

| Major Category | Equipment Category | Count | Sum of squared errors (SSE) | | |
|---|---|---|---|---|---|
| | | | Previous Method (WPU113) | Empirical Method | Category Specific Index Method |
| **Electrical Equipment** | | **6** | **7,024** | **7,429** | **6,821** |
| | Additive Manufacturing | 6 | 7,024 | 7,429 | 6,821 |
| **Furnaces** | | **1** | **353** | **305** | **312** |
| | Furnace | 1 | 353 | 305 | 312 |
| **Lab Equipment** | | **13** | **12,985** | **13,544** | **6,637** |
| | Controller | 1 | 841 | 1,027 | 153 |
| | Glovebox | 2 | 316 | 241 | 232 |
| | Shaker | 2 | 5,228 | 4,938 | 4,666 |
| | Xray | 8 | 6,600 | 7,337 | 1,586 |
| **Measuring and Lenses** | | **20** | **6,515** | **6,002** | **4,784** |
| | Camera | 5 | 2,280 | 1,843 | 1,092 |
| | Centrifuge | 1 | 1 | 5 | 0 |
| | Interferometer | 3 | 32 | 7 | 3 |
| | Measuring Machine | 2 | 637 | 761 | 513 |
| | Microscope | 7 | 2,759 | 2,479 | 2,497 |
| | Spectrometer | 2 | 807 | 906 | 679 |
| **Metalworking Machinery** | | **15** | **3,287** | **5,155** | **2,934** |
| | Boring Machine | 1 | 17 | 11 | 5 |
| | Finishing Machine | 4 | 88 | 74 | 38 |
| | Forming Machine | 1 | 22 | 54 | 11 |
| | Lathe | 3 | 42 | 1,231 | 42 |
| | Milling Machine | 2 | 725 | 806 | 725 |
| | Welder | 4 | 2,393 | 2,980 | 2,114 |
| **Microelectronic Fabrication** | | **2** | **854** | **960** | **666** |
| | Lithography | 2 | 854 | 960 | 666 |
| **Vehicles** | | **1** | **59** | **271** | **35** |
| | Vehicle | 1 | 59 | 271 | 35 |
| **Grand Total** | | **58** | **31,076** | **33,665** | **22,190** |

*Table 8: SSE by Equipment Category*

## 4.3 Impact

**Table 9** details the impact of the new escalation methodology on the total PRWG portfolio. Changing methodologies to a category-specific escalation index from the previous uniform methodology has a minor impact (-3.7%) on the total escalated price of the

PRWG equipment portfolio. However, there is a significant difference at the equipment category level, with some categories increasing or decreasing in escalated price by over 20%. The differences by category are due mainly to the age of equipment (escalation has a larger cumulative impact on older equipment) and the difference between the WPU113 index and the new index used.

| | Escalated Purchase Price BY23 $M | | Comparison (New - Old) | |
|---|---|---|---|---|
| **Major Category** | **Old Methodology WPU113** | **New Methodology - Index Specific** | **Difference $M** | **Difference %** |
| Alignment Equipment | 39.5 | 32.6 | -6.9 | -17.38% |
| Computers | 159.9 | 146.1 | -13.8 | -8.62% |
| Electrical Equipment | 418.9 | 512.3 | 93.4 | 22.30% |
| Furnaces | 119.3 | 111.4 | -7.8 | -6.57% |
| Lab Equipment | 642.2 | 519.4 | -122.9 | -19.13% |
| Measuring and Lenses | 524.0 | 484.4 | -39.6 | -7.57% |
| Metalworking Machinery | 573.2 | 585.8 | 12.6 | 2.20% |
| Microelectronics Fabrication | 301.6 | 372.2 | 70.6 | 23.41% |
| Misc Equipment | 349.3 | 237.3 | -112.0 | -32.06% |
| Vehicles | 57.2 | 63.5 | 6.3 | 11.05% |
| **All Equipment** | 3,185.1 | 3,065.0 | -120.1 | -3.77% |

*Table 9: Results by Major Equipment Category*

Accurately estimating equipment costs is critical to recapitalization planning. Underestimating costs results in unexpected cost growth which stresses budgets and may require changes in schedule or equipment quality. An overestimate of equipment costs may lead decision makers to believe that some recapitalization actions are not feasible, causing them to defer cost effective improvements. Ultimately, a reduction in cost escalation error results in increased efficiency in programmatic equipment funding decisions.

## 4.4 Implications and Limitations

While the new **index-based empirical escalation by equipment category** methodology discussed in the preceding sections has advantages, it also has its share of limitations. This section discusses several limitations and their implications.

1. A key limitation to the analysis is the PRWG's ability to identify identical pieces of equipment purchased in different years. Pieces of like equipment identified by the PRWG are assumed to be *identical*, with any change in purchase price due strictly to escalation (excluding changes to quality). However, there may be differences between the same equipment that affect the price. For example, the exact same make and model X-ray equipment could have optional manufacturer features or NNSA-required custom modifications (e.g., shielding or enclosures) which are included in the purchase price but not noted in the equipment description.
2. It is also important to note that the indices utilized in this paper are based solely on commercial-off-the-shelf equipment, which as explained above means that it is not representative of all the customized equipment that NNSA often requires to accomplish its mission.
3. Another limitation of all three methodologies is that the exact purchase date is estimated. The date used in the analysis is an estimate based on the equipment's first day of operation and the lead time required to procure it. For the more volatile indices, a difference of just one month can impact the accuracy of the escalated price estimate.
4. Also, the BLS producer price indices rely on listed prices for equipment, whereas PRWG estimates are based on the actual purchase price. Other studies have shown a difference between producers' listed prices and the actual prices paid by customers[11]. NNSA prices are generally greater due to the complicated nuances in the qualification process allowing vendors to sell to an agency supporting nuclear weapon safety and modernization.
5. Perhaps the greatest limitation in this research is the assumption that a piece of equipment will always be replaced with an *identical* piece of equipment. This is a necessary assumption to create escalation rates with minimum bias, but it is not realistic. As technology ages and scope evolves, new equipment will often incorporate significant upgrades and increased capabilities in comparison to the

[11] Betsock, T. & Newman I. (1993). The Problem of List Prices in the Producer Price Index: The Steel Mill Products Case. In M. Foss, et al (Ed.), *Price Measurements and Their Uses* (pp. 261 – 274).

legacy equipment it replaces. For example, a CNC 3-Axis Mill was capable of meeting mission needs in 1990 but a 5-Axis mill may be required in 2024 for an increased level of milling capabilities and angles. Adjusting or normalizing for these types of technological advancements requires more data collected over time than the PRWG currently has.

# 5. Future Analysis

## 5.1 Escalation by Equipment Supplier

The PRWG has exerted significant efforts collaborating with NSE site representatives to remove ambiguity wherever possible in the data call guidance. This also included making changes to ensure a level of granularity necessary for specific equipment supplier analyses.

Specifically, PRWG now collects “equipment make and model” in the **Equipment Name** field, which allows analysts to research the specific vendor that supplies the equipment. Due to this data field change, 303 suppliers were identified across the PRWG portfolio.

This will lead to opportunities in vendor sharing across the sites (getting qualified vendors to sell items in support of nuclear missions is difficult), opportunities for bulk buying, and (for the purposes of this paper) opportunities to see trends in vendor costs over time. Future research will investigate vendor-specific cost changes over time.

## 5.2 Escalation for Evolving Capability Needs

As mentioned in Section 4.4, one of the more unrealistic assumptions in this analysis is that a piece of equipment will always be replaced by an identical piece of equipment. Normalizing for technological advancements is a best practice in escalation analysis, but with the information the PRWG currently collects – it is not feasible. A natural progression of this research is to try to determine cost changes related to technological advancements by equipment category.

PRWG does collect linkages between ‘Active’ equipment and the ‘Future’ equipment that will replace the active equipment. These linkages can enable this type of analysis as it will start to paint a picture of the technological advancements taking place within each equipment category over time.

### 5.3 NNSA Equipment Cost Drivers

With an accurate escalation methodology employed, the PRWG can now start to look at NNSA internal cost drivers for equipment. For example, if two of the exact same type of equipment (or very similar equipment) significantly differ in cost after adjusting for price escalation, the PRWG can investigate potential drivers for the cost difference. NNSA facilities in which PRWG equipment reside can vary significantly in terms of their hazard characteristics (e.g., nuclear hazard vs. chemical hazard). Therefore, the cost to purchase and certify two identical pieces of equipment can vary significantly if the equipment differ in their intended use. Below is a non-exhaustive list of potential cost drivers which the PRWG can now explore:

- Domestic vs. foreign purchase
- Intended use (NNSA mission)
- Facility hazard category
- Purchasing M&O site
- Type of NNSA project/procurement

## 6. Conclusion

Accurate estimation of programmatic equipment cost escalation is a critical step in a proactive approach to NNSA recapitalization. Better estimates of escalated (base year) equipment costs provide the PRWG with the necessary context to inform its equipment sponsor programs and deliver data-driven analysis to decision makers. However, the varied nature of equipment collected by the PRWG represents a significant challenge to accurately escalating equipment costs.

The PRWG's previous approach to escalation using a single index (producer price index WPU113 for metalworking machinery) provided a fair approximation of programmatic equipment trends. Using a consistent, quality-adjusted index provided the benefit of simplicity but masked unique cost drivers associated with different equipment categories.

This paper explored two alternatives to the previous approach, specifically:

1. **Data-Based Empirical Escalation by Equipment Category** of programmatic equipment costs to create comprehensive escalation indices for each individual piece of equipment.
2. **Index-Based Empirical Escalation by Equipment Category,** assigning indices to equipment categories based on instances of observed cost escalation ensures the indices more accurately reflect the cost drivers impacting programmatic equipment cost changes.

Given the lack of data for the first approach to be feasible and to preserve the benefits of a consistent, quality-adjusted index and the inherent differences between equipment categories, our research indicates that the **Index-Based Empirical Escalation by Equipment Category** approach should be utilized moving forward.

Category-specific cost escalation provides the PRWG, and the NNSA, with new insights leading to a more data-driven, high-fidelity, and effective approach to cost estimation.

# Appendix A: Acronyms

| Acronym | Definition |
|---|---|
| ABQ | Albuquerque |
| BLS | Bureau of Labor Statistics |
| BY | Base Year |
| CBI | Capability Based Investments |
| CER | Cost Estimating Relationship |
| CNC | Computer Numerical Control |
| DC | District of Columbia |
| DOD | Department of Defense |
| DOE | Department of Energy |
| FYNSP | Future Years Nuclear Security Program |
| HPC | High Performance Computer |
| HQ | Headquarters |
| M&O | Management and Operating |
| NNSA | National Nuclear Security Administration |
| NSE | Nuclear Security Enterprise |
| PPBE | Planning, Programming, Budgeting, and Execution |
| PPI | Producer Price Index |
| PRWG | Programmatic Recapitalization Working Group |
| SME | Subject Matter Expert |
| SSE | Sum of Squared Error |
| TY | Then Year |
| V&V | Verification and Validation |
| WA | Weapons Activities |

# Appendix B: Equipment Categories Hierarchy

| Major Category | PRWG Equipment Categories | Sub-Category |
|---|---|---|
| Alignment Equipment | Aligner | |
| Alignment Equipment | Gimble | |
| Alignment Equipment | Positioner | |
| Computers | Data Collection Device | |
| Computers | Data Storage | |
| Computers | Diagnostic System | |
| Computers | High Performance Computer | |
| Computers | Other IT Equipment | |
| Electrical Equipment | Accelerator | Accelerator (Circular Particle Accelerator) |
| Electrical Equipment | Additive Manufacturing | Additive Manufacturing (3D Printer) |
| Electrical Equipment | Amplifier | |
| Electrical Equipment | Generator | |
| Electrical Equipment | Laser | |
| Electrical Equipment | Modulator | |
| Electrical Equipment | Other Power System Equipment | |
| Electrical Equipment | Power Control | |
| Electrical Equipment | Power Supply | |
| Electrical Equipment | Pulser | |
| Electrical Equipment | Reactor | |
| Furnaces | Fume Hood | |
| Furnaces | Furnace | Furnace (Blast) |
| Lab Equipment | Calibrator | |
| Lab Equipment | Controller | |
| Lab Equipment | Electron Beam Equipment | |
| Lab Equipment | Glovebox | |
| Lab Equipment | Mixer | |
| Lab Equipment | Other Lab Equipment | |
| Lab Equipment | Process Control | |
| Lab Equipment | Shaker | Shaker (Electromechanical) |
| Lab Equipment | Tester | Tester (Environmental) |
| Lab Equipment | Vacuum | |
| Lab Equipment | Wet Bench | |
| Lab Equipment | Xray | Xray (Accelerator) |
| Measuring and Lenses | Analyzer | |
| Measuring and Lenses | Calorimeter | |
| Measuring and Lenses | Camera | |
| Measuring and Lenses | Centrifuge | |
| Measuring and Lenses | Counter or Detector | Counter or Detector (Counter) |

| Major Category | PRWG Equipment Categories | Sub-Category |
|---|---|---|
| Measuring and Lenses | Inspection Machine | |
| Measuring and Lenses | Interferometer | |
| Measuring and Lenses | Measuring Machine | Measuring Machine (Coordinate Measuring Machine (CMM)) |
| Measuring and Lenses | Microscope | Microscope (Atomic Force) |
| Measuring and Lenses | Oscilloscope | |
| Measuring and Lenses | Recorder | |
| Measuring and Lenses | Reflectometer | |
| Measuring and Lenses | Spectrometer | Spectrometer (Mass Spectrometer) |
| Measuring and Lenses | Velocimeter | |
| Measuring and Lenses | Vibrometer | |
| Metalworking Machinery | Autoclave | |
| Metalworking Machinery | Boring Machine | |
| Metalworking Machinery | Cutting Machine | Cutting Machine (Gas Cutting) |
| Metalworking Machinery | Drilling and Tapping Machines | |
| Metalworking Machinery | Electric Discharge Machine | |
| Metalworking Machinery | Finishing Machine | Finishing Machine (Polishing) |
| Metalworking Machinery | Forming Machine | Forming Machine (Press) |
| Metalworking Machinery | Grinder | Grinder (Centerless) |
| Metalworking Machinery | Heat Transfer Equipment | |
| Metalworking Machinery | Lathe | Lathe (CNC) |
| Metalworking Machinery | Machining | |
| Metalworking Machinery | Machining Center | Machining Center (Single-Orientation) |
| Metalworking Machinery | Milling Machine | Milling Machine (CNC) |
| Metalworking Machinery | Other Shop Equipment (General) | |
| Metalworking Machinery | Welder | Welder (Electron Beam) |
| Microelectronic Fabrication | Bonding Machine | Bonding Machine (Selective Solder) |
| Microelectronic Fabrication | Cleaning Machine | |
| Microelectronic Fabrication | Coating System | Coating System (Chemical Vapor Deposition (CVD)) |
| Microelectronic Fabrication | Etching Machine | |
| Microelectronic Fabrication | Lithography | Lithography (Scanner) |
| Microelectronic Fabrication | Other Microelectronics Fabrication Equipment | |
| Misc Equipment | Chassis | |
| Misc Equipment | Communication | |
| Misc Equipment | Environmental Apparatus Indoor | |
| Misc Equipment | Environmental Apparatus Outdoor | |
| Misc Equipment | Environmental Test | |
| Misc Equipment | Intensifier | |

| Major Category | PRWG Equipment Categories | Sub-Category |
|---|---|---|
| Misc Equipment | Other Environmental Control Equipment | |
| Misc Equipment | Other General Storage Equipment | |
| Misc Equipment | Other Miscellaneous Equipment | |
| Misc Equipment | Pump | |
| Misc Equipment | Refrigerator | |
| Misc Equipment | Storage | Storage (Cabinets) |
| Misc Equipment | Surveillance | |
| Misc Equipment | Tank | |
| Misc Equipment | Trap | |
| Vehicles | Lift | Lift (Crane) |
| Vehicles | Trailer | |
| Vehicles | Vehicle | Vehicle (Truck) |

# Appendix C: References


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