# Cost estimation

MAE 4160, 4161, 5160

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# Today’s topics:

- Overview of NASA cost estimation process
- Lifecycle cost estimation
- Approaches to cost estimation
  - Bottom-up (Work Breakdown Structure)
  - Top-down (Cost Estimation Relationships)
  - Analogy
- Learning curves
- Cash flow
- Net present value

# The NASA cost estimation process

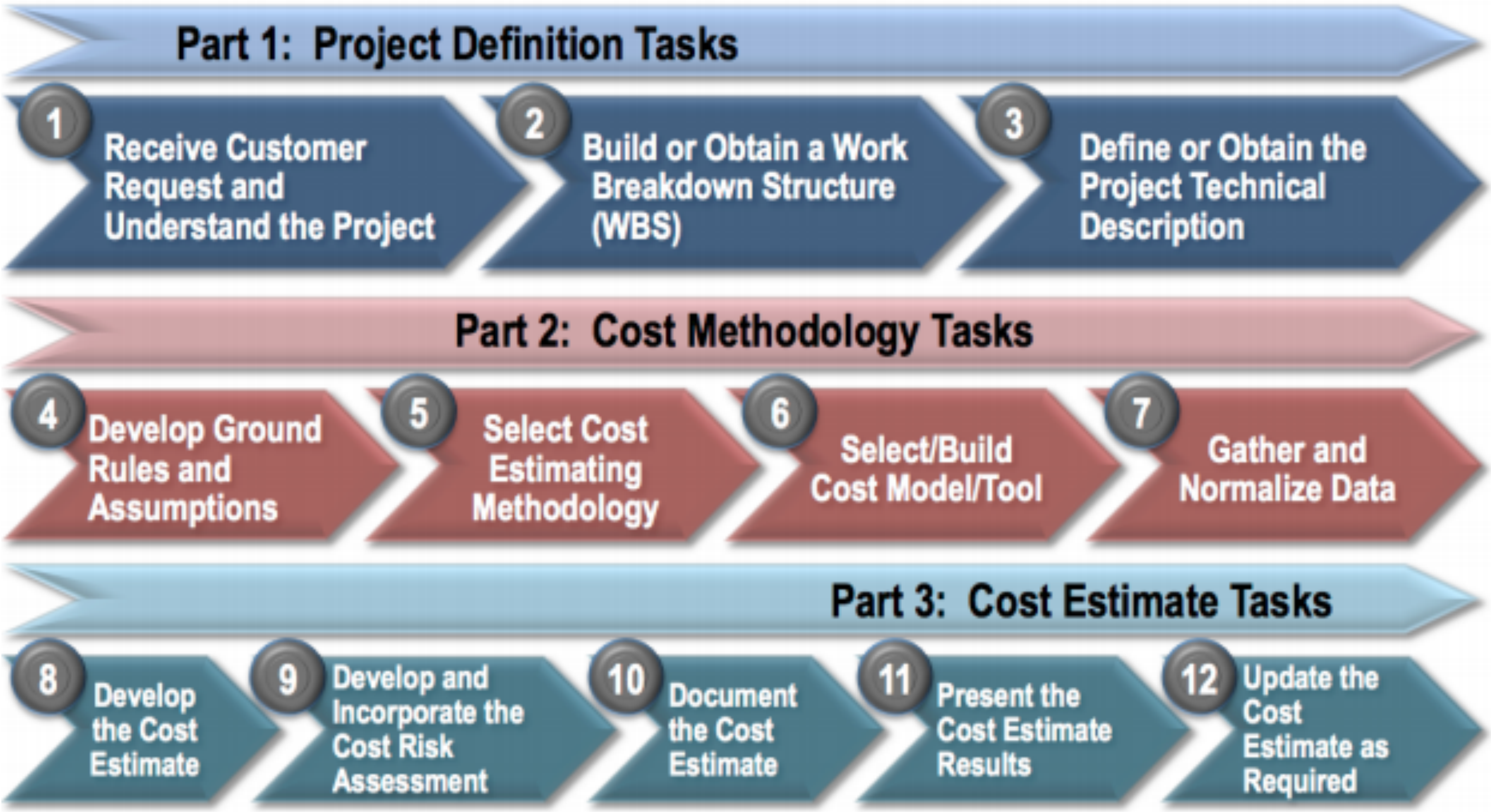


Figure 2. The NASA Cost Estimating Process

https://www.nasa.gov/offices/ocfo/nasa-cost-estimating-handbook-ceh

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# Lifecycle cost estimation

To estimate the cost of a mission, you must think holistically about cost throughout the system's lifecycle ⟶ **lifecycle cost**

- Development cost (including any technologies)
- Implementation/fabrication cost
- Testing cost
- Launch cost
- Operations cost
- Disposal cost

Separate-out **non-recurring** (one-time costs to develop, fabricate, and test a qualification unit) from **recurring cost** (incurred for every unit produced, e.g. fabrication, launch, operations)

When appropriate, consider the effects of **inflation**, **learning**, and **economies of scale**.

# Approaches to cost estimation

## Bottom-up

- Uses Work Breakdown Structure (WBS)

## Top-down

- Uses parametric Cost Estimation Relationships (CER)

## Analogy

- Uses nearest-neighbor estimation + correction factors

# Approaches to cost estimation

## Bottom-up

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**In practice, expect to use a mix of these approaches. Some high-level decomposition of cost into different activities (WBS) and then estimates based on historical data and/or models (CER or analogy) for the individual activities.**

# Approaches to cost estimation

**We'll start with this**

## Bottom-up

- Uses Work Breakdown Structure (WBS)

**In practice, expect to use a mix of these approaches. Some high-level decomposition of cost into different activities (WBS) and then estimates based on historical data and/or models (CER or analogy) for the individual activities.**

## Top-down

- Uses parametric Cost Estimation Relationships (CER)

## Analogy

- Uses nearest-neighbor estimation + correction factors

# Work Breakdown Structure (Bottom-up)

A **list** of the **components** and **activities** required to develop a system.

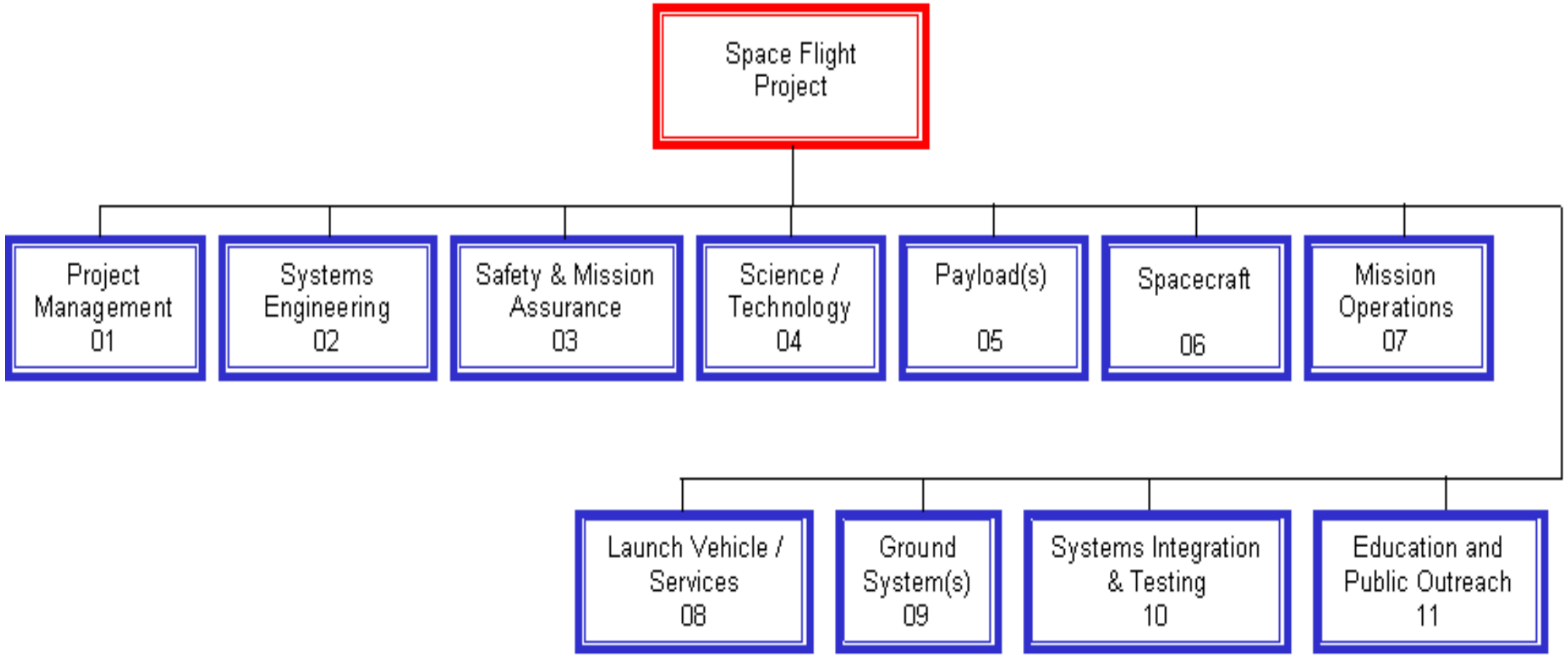


**Figure B-2. NASA Standard Space Flight Project WBS**

- Start with the NASA standard WBS, as shown above
- Expand appropriately to the step in the development process. See the CADRe standard for suggested lower-level breakouts

# CADRe (Cost Analysis Document Requirement)

- Describes a NASA project at each milestone
- Captures estimated and actual costs in a WBS structure
- Provides a historical record of cost, schedule, and technical project attributes so that estimators can better estimate future analogous projects

## CADRe WBS

The NASA Standard WBS required by NPR 7120.5E only proceeds to level 2. This increases the degrees of freedom for the Program/Project Manager to construct a WBS that best facilitates project accomplishment. However, the cost estimator and project lead must be aware that there are managerial data demands that must map from the project's WBS. Construction of a WBS that considers these requirements may alleviate significant PM level of effort at stages of the project beyond initial WBS formulation.

For each Agency project, the WBS established by the project must use the NSM numbering scheme and also must correlate exactly through level seven to the corresponding financial accounting structure utilized for each project within the NASA Core Financial System.

In addition to the NASA Core Financial System requirements, projects must submit data into the CADRe system under the CADRe WBS format, shown at right. These data are used by the Agency for reference in future cost estimates. Construction of a project WBS that mirrors or easily maps to the CADRe structure will achieve savings in future level of effort and is considered a "best practice."

| NASA WBS Elements | Level |
|---|---|
| System Name | 1 |
| Project Management | 2 |
| Systems Engineering | 2 |
| Safety and Mission Assurance | 2 |
| Science/Technology | 2 |
| Payload(s) | 2 |
| Payload Management | 3 |
| System Engineering | 3 |
| Payload Product Assurance | 3 |
| Instrument *n* | 3 |
| Instrument *n* Management | 4 |
| Instrument *n* Systems Engineering | 4 |
| Instrument *n* Assurance | 4 |
| Antenna | 4 |
| Optics | 4 |
| Sensors/Detectors | 4 |
| Structures & Mechanisms | 4 |
| Thermal Control | 4 |
| Electronics | 4 |
| Power | 4 |
| Pointing Subsystem | 4 |
| Harness & Cabling | 4 |
| C&DH | 4 |
| Ground Support Equip | 4 |
| Integration, Assembly Test & Check out | 3 |
| Flight System \ Spacecraft | 2 |
| Flight System Project Management | 3 |
| Flight System Systems Engineering | 3 |
| Flight System Product Assurance | 3 |
| Spacecraft | 3 |
| Spacecraft Management | 4 |
| Spacecraft Systems Engineering | 4 |
| Spacecraft Product Assurance | 4 |
| Spacecraft Structures & Mechanisms | 4 |
| Spacecraft Thermal Control | 4 |
| Spacecraft Electrical Power & | 4 |
| Spacecraft GN&C | 4 |
| Spacecraft Propulsion | 4 |
| Spacecraft Communications | 4 |
| Spacecraft C&DH | 4 |
| Spacecraft Software | 4 |
| CSCI Name 1 | 5 |
| CSCI Name 2 | 5 |
| Software Subsystem I&T | 5 |
| Spacecraft I&T | 4 |
| Entry/Decent/Lander | 3 |
| Rover | 3 |
| Spacecraft Retirement & Disposal | 3 |
| Launch Vehicle/Services | 2 |
| Mission Operations System (MOS) | 2 |
| MOS Management | 3 |
| MOS Systems Engineering | 3 |
| Mission Operations Center | 3 |
| Science/Data Operations Center | 3 |
| Data Distribution & Archival | 3 |
| Communications/Network Infrastructure | 3 |
| Training | 3 |
| Ground Data System (GDS) | 2 |
| GDS Management | 3 |
| GDS Systems Engineering | 3 |
| Mission Operations Center | 3 |
| Science/Data Operations Center | 3 |
| Data Distribution & Archival | 3 |
| Ground Stations | 3 |
| Communications/Network Infrastructure | 3 |
| GDS Integration & Test | 3 |
| System Integration, Assembly, Test & Check | 2 |
| Education & Public Outreach | 2 |
| Reserves | 1 |
| CM&O | 1 |
| G&A | 1 |

# Bottom-up cost estimation with a WBS

## In principle

- Estimate the cost of each WBS line item
- Add up all line items

## How do you estimate the cost of each line item?

- Cost of materials + (# of people hours) x salaries

## How do you capture uncertainty?

- Estimate may include a point estimate and a standard dev, or pessimistic/ optimistic estimates
- Other methods (CER/analogy) may be used to estimate cost of certain line items

| | B | C | D |
|---|---|---|---|
| 2 | | Point Estimate | Std Dev |
| 3 | Missile System | $696,344 | $231,798 |
| 4 | Sys Dev & Demo Phase | $164,898 | $81,542 |
| 5 | Air Vehicle | $111,549 | $54,857 |
| 6 | Design & Development | $25,000 | $6,509 |
| 7 | Prototypes | $9,749 | $6,044 |
| 8 | Software | $76,800 | $50,709 |
| 9 | Sys Engineering/Program Mgmt | $21,000 | $4,958 |
| 10 | System Test and Evaluation | $22,310 | $21,091 |
| 11 | Training | $5,577 | $3,680 |
| 12 | Data | $2,231 | $1,480 |
| 13 | Support Equipment | $2,231 | $1,097 |
| 14 | | | |
| 15 | Production Phase | $531,212 | $181,997 |
| 16 | Air Vehicle | $333,396 | $74,435 |
| 17 | Propulsion | $11,416 | $3,006 |
| 18 | Payload | $16,271 | $4,499 |
| 19 | Airframe | $112,250 | $26,776 |
| 20 | Guidance and Control | $186,979 | $61,745 |
| 21 | Integration, Assy, Test & Checkout | $6,480 | $2,163 |
| 22 | Engineering Changes | $16,670 | $9,092 |
| 23 | Sys Engineering/Program Mgmt | $93,351 | $94,298 |
| 24 | System Test and Evaluation | $1,000 | $135 |
| 25 | Training | $33,340 | $16,003 |
| 26 | Data | $6,668 | $2,400 |
| 27 | Peculiar Support Equipment | $6,668 | $2,424 |
| 28 | Common Support Equipment | $113 | $47 |
| 29 | Initial Spares and Repair Parts | $40,007 | $14,520 |

# Approaches to cost estimation

## Bottom-up

- Uses Work Breakdown Structure (WBS)

## Top-down

- Uses parametric Cost Estimation Relationships (CER)

Now this

## Analogy

- Uses nearest-neighbor estimation + correction factors

# Cost estimating relationships (CER)

## Top-down cost estimation is based on **parametric models** (CER's)

- CER is an estimate of cost (or a component of cost) **as a function of** a small subset of driving parameters (independent variables)
  - Mass, complexity, TRL, schedule, . . .
- Typically uses **power laws** which become linear regressions in log-space
  - 1 parameter: $cost = C_0 x^{\beta}$
  - 2 parameter:

$$cost = C_0 \cdot \left(\frac{x_1}{x_1 ref}\right)^{\beta_1} \cdot \left(\frac{x_2}{x_{2ref}}\right)^{\beta_2}$$

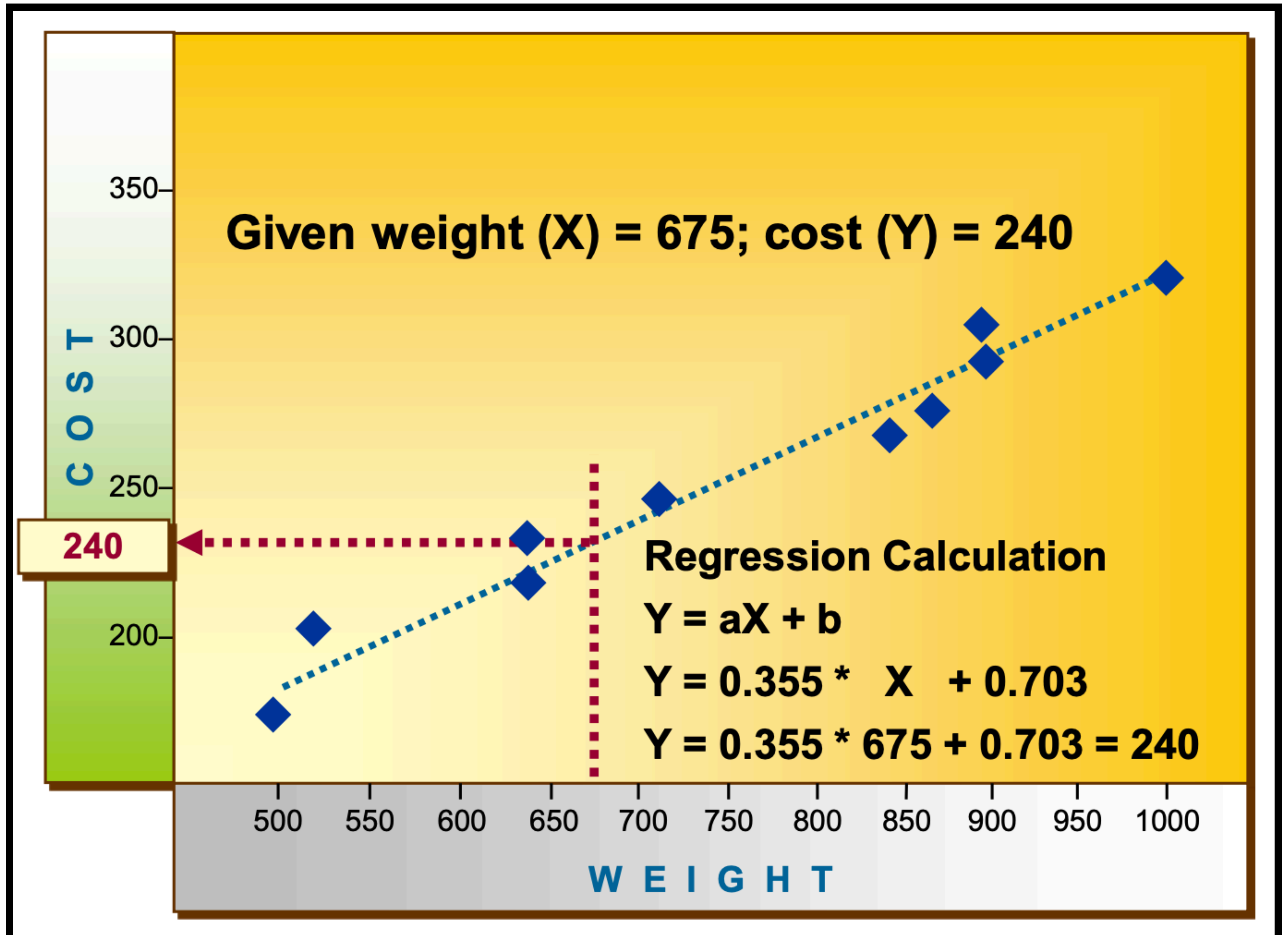

Figure C-3. Scatterplot and Regression Line of Cost (Y) Versus Weight (X)

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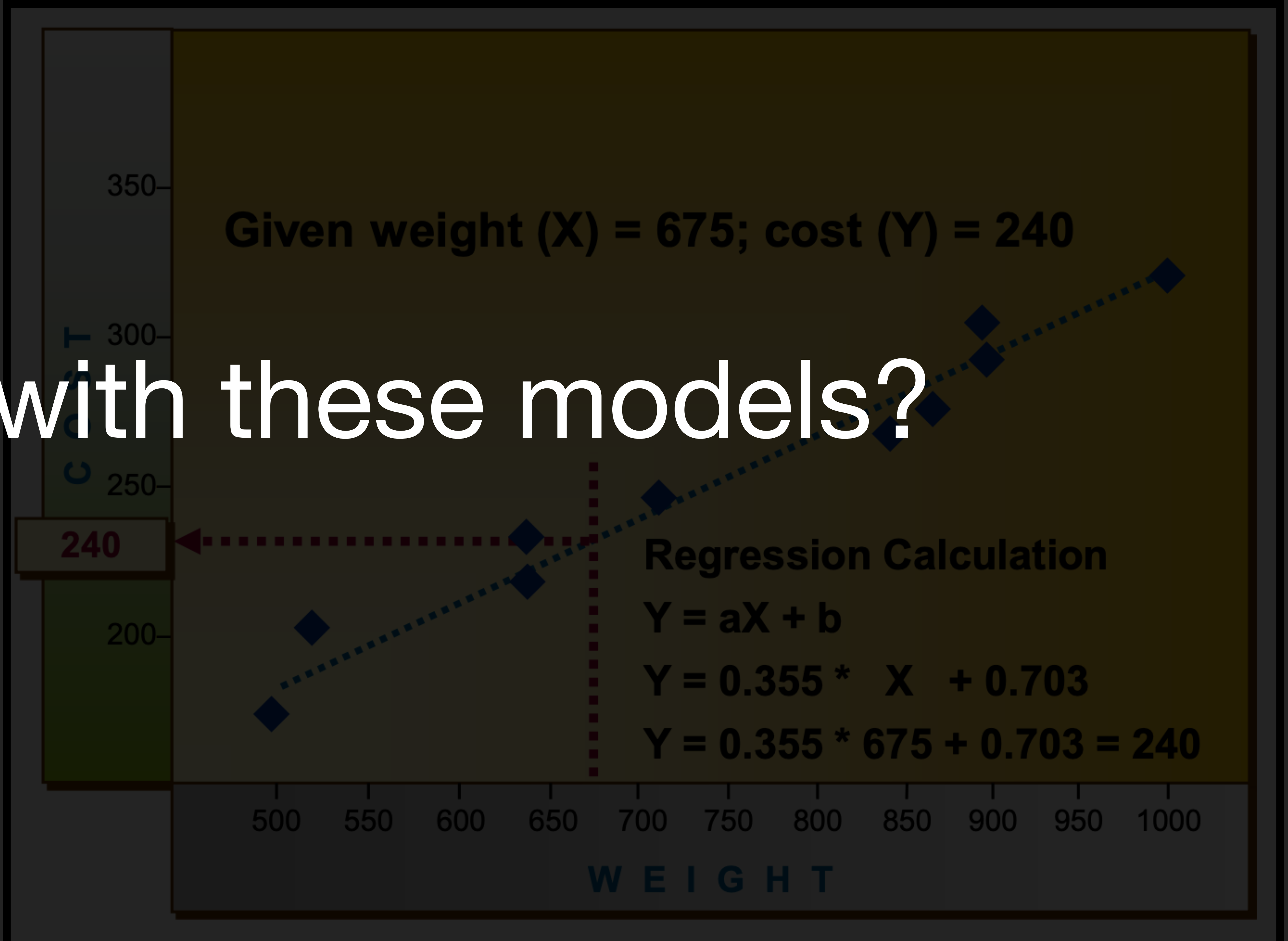


Figure C-3. Scatterplot and Regression Line of Cost (Y) Versus Weight (X)

How do we come up with these models?

# How are CER developed?

## Top-down cost estimation is based on **parametric models** (CER's)

1. Gather **data** of past examples of relevant systems and their costs (you need substantial data!)
   - Remember to write down which year's dollars the data is in! Inflation matters and will need to be corrected for

2. Formulate one or more cost models $C = f(x_1, x_2, \ldots, x_N)$
   - Choose the independent variables $x_i$
   - Choose the shape of the parametric curve (i.e. power law)

3. Fit the cost models
   - Find values of parameters that minimize error on the training data set
   - Assess model performance (e.g. mean square error) on test data set

**Iterate until satisfied.**

# Incorporating error and range of validity in CER's

**In addition to the parametric expression, a CER must also report:**

- A range of validity
- A measure of the error in the model (e.g. standard error of the estimate, SEE)

$$SEE(\%) = \sqrt{\frac{1}{N-p}\sum_i \left(\frac{C_i - \hat{C}_i}{\hat{C}_i}\right)^2}$$

where $C_i$ is the real cost, $\hat{C}_i$ is the estimated cost, $N$ is the number of examples in the data set, and $p$ is the number of parameters in the CER

**TABLE 20-1. Inflation Factors Relative to the Year 2000 Based on Projections by the Office of the Secretary of Defense (January 1998).** See text for discussion.

| Fiscal Year (FY) | Inflation Factor to Base Year 2000 | Fiscal Year (FY) | Inflation Factor to Base Year 2000 |
|---|---|---|---|
| 1980 | 0.456 | 2001 | 1.017 |
| 1981 | 0.510 | 2002 | 1.034 |
| 1982 | 0.559 | 2003 | 1.052 |
| 1983 | 0.610 | 2004 | 1.075 |
| 1984 | 0.658 | 2005 | 1.099 |
| 1985 | 0.681 | 2006 | 1.123 |
| 1986 | 0.700 | 2007 | 1.148 |
| 1987 | 0.719 | 2008 | 1.173 |
| 1988 | 0.740 | 2009 | 1.199 |
| 1989 | 0.771 | 2010 | 1.225 |
| 1990 | 0.802 | 2011 | 1.252 |
| 1991 | 0.837 | 2012 | 1.279 |
| 1992 | 0.860 | 2013 | 1.308 |
| 1993 | 0.883 | 2014 | 1.336 |
| 1994 | 0.901 | 2015 | 1.366 |
| 1995 | 0.918 | 2016 | 1.396 |
| 1996 | 0.937 | 2017 | 1.427 |
| 1997 | 0.958 | 2018 | 1.458 |
| 1998 | 0.970 | 2019 | 1.490 |
| 1999 | 0.984 | 2020 | 1.523 |
| 2000 | 1.000 | | |

**TABLE 20-5. CERs for Estimating Subsystem Theoretical First Unit (TFU) Cost.**

| Cost Component | Parameter, X (Unit) | Input Data Range | TFU CER* (FY00$K) | SE (%) |
|---|---|---|---|---|
| 1. Payload | | | | |
| 1.1 IR Sensor | aperture dia. (m) | 0.2–1.2 | $142{,}742\ X^{0.562}$ | 21,424† |
| 1.2 Visible Light Sensor | aperture dia. (m) | 0.2–1.2 | $51{,}469\ X^{0.562}$ | 7,734† |
| 1.3 Communications | comm. subsystem wt. (kg) | 65–395 | 140 X | 43 |
| 2. Spacecraft | spacecraft dry wt. (kg) | 154–1,389 | 43 X | 36 |
| 2.1 Structure | structure wt. (kg) | 54–560 | 13.1 X | 39 |
| 2.2 Thermal | thermal wt. (kg) | 3–87 | $50.6\ X^{0.707}$ | 61 |
| 2.3 Electrical Power System (EPS) | EPS wt. (kg) | 31–573 | $112\ X^{0.763}$ | 44 |
| 2.4 Telemetry, Tracking & Command (TT&C)/DH‡ | TT&C/DH wt. (kg) | 13–79 | $635\ X^{0.568}$ | 41 |
| 2.5 Attitude Determination & Control Sys. (ADCS) | ADCS wt. (kg) | 20–192 | $293\ X^{0.777}$ | 34 |
| 2.6 Apogee Kick Motor (AKM) | AKM wt. (kg) | 81–966 | $4.97\ X^{0.823}$ | 20 |
| 3. Integration, Assembly & Test (IA&T) | spacecraft bus wt. payload wt. (kg) | 155–1,390 | 10.4 X | 44 |
| 4. Program Level | spacecraft + payload total recurring cost (FY00$K) | 15,929 – 1,148,084 | 0.341 X | 39 |
| 5. Ground Support Equipment (GSE) | N/A | | | |
| 6. Launch & Orbital Operations Support (LOOS) | spacecraft bus + payload wt. (kg) | 348–1,537 | 4.9 X | 42 |

* Taken from USCM, 7th edition (1994) using minimum, unbiased percentage error CERs.
† Absolute error (FY00$K), not percentage error.
‡ Includes spacecraft computer. If separate CERs for TT&C and C&DH are desired, use a 0.45/0.55 split.

**TABLE 20-4. CERs for Estimating Subsystem RDT&E Cost (FY00$K).** Applicable range for a good estimate is 25% above and below this data range. CER represents contractor cost without fee.

| Cost Component | Parameter, X (Unit) | Input Data Range | RDT&E CER* (FY00$K) | SE (%) |
|---|---|---|---|---|
| 1. Payload | | | | |
| 1.1 IR Sensor | aperture dia. (m) | 0.2–1.2 | $356{,}851\ X^{0.562}$ | 53,559† |
| 1.2 Visible Light Sensor | aperture dia. (m) | 0.2–1.2 | $128{,}827\ X^{0.562}$ | 19,336† |
| 1.3 Communications | comm. subsystem wt. (kg) | 65–395 | 353.3 X | 51 |
| 2. Spacecraft | spacecraft dry wt. (kg) | 235-1,153 | 101 X | 33 |
| 2.1 Structure | structure wt. (kg) | 54–392 | $157\ X^{0.83}$ | 38 |
| 2.2 Thermal | $X_1$ = thermal wt. (kg)<br>$X_2$ = spacecraft wt. + payload wt. (kg) | 3–48<br>210–404 | $394\ X_1^{0.635}$<br>$1.1\ X_1^{0.610}\ X_2^{0.943}$ | 45<br>32 |
| 2.3 Electrical Power System (EPS) | $X_1$ = EPS wt. (kg)<br>$X_2$ = BOL power (W) | 31–491<br>100–2,400 | $62.7\ X_1$<br>$2.63\ (X_1\ X_2)^{0.712}$ | 57<br>36 |
| 2.4 Telemetry, Tracking & Command (TT&C)/DH‡ | TT&C/DH wt. (kg) | 12–65 | $545\ X^{0.761}$ | 57 |
| 2.5 Attitude Determination & Control Sys. (ADCS) | ADCS wt. (kg) | 20–160 | $464\ X^{0.867}$ | 48 |
| 2.6 Apogee Kick Motor (AKM) | AKM wt. (kg) | 81–966 | $17.8\ X^{0.75}$ | — |
| 3. Integration, Assembly & Test (IA&T) | spacecraft bus + payload total RDT&E cost (FY00$K) | 2,703 – 395,529 | 989 + 0.215 X | 46 |
| 4. Program Level | spacecraft bus + payload total RDT&E cost (FY00$K) | 4,607 – 523,757 | $1.963\ X^{0.841}$ | 36 |
| 5. Ground Support Equipment (GSE) | spacecraft bus + payload total RDT&E cost (FY00$K) | 24,465 – 581,637 | $9.262\ X^{0.642}$ | 34 |
| 6. Launch & Orbital Operations Support (LOOS) | N/A | | | |

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# CER for software

The relevant parameters is **Kilolines of code (KLOC)**

- Traditional software cost estimation is done on the basis of lines of code (1 KLOC = 1000 lines of code)
- In simple models, cost or effort (person-months) is assumed to be <u>directly proportional to KLOC</u>
- Factor of proportionality changes based on . . .
    - Programming language
    - Platform (Unix, PC)
    - Degree of autonomy (autonomous, human-operated)
- For example, in aerospace

$C = 718 \cdot KLOC$ for <u>flight software</u> in C

$C = 200 \cdot KLOC$ for <u>ground software</u> in Unix

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Now let's look at how we estimate this

$$C = 718 \cdot KLOC$$ for <u>flight software</u> in C

$$C = 200 \cdot KLOC$$ for <u>ground software</u> in Unix

# Constructive Cost Model (COCOMO)

- **COCOMO** is a cost-estimating methodology for software
- Its **basic** version used a CER that estimates **effort** in person-months based on KLOC, with different parameters for small and simple (organic), medium (semi-detached), and large/complex (embedded) projects

$$E = a_b \cdot KLOC^{b_b} \text{ person-months}$$

| Software project | $a_b$ | $b_b$ |
|---|---|---|
| Organic | 2.4 | 1.05 |
| Semi-detached | 3.0 | 1.12 |
| Embedded | 3.6 | 1.20 |

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**How can we incorporate subjective things (like complexity) in our cost models?**

| Software project | $a_b$ | $b_b$ |
|---|---|---|
| Organic | 2.4 | 1.05 |
| Semi-detached | 3.0 | 1.12 |
| Embedded | 3.6 | 1.20 |

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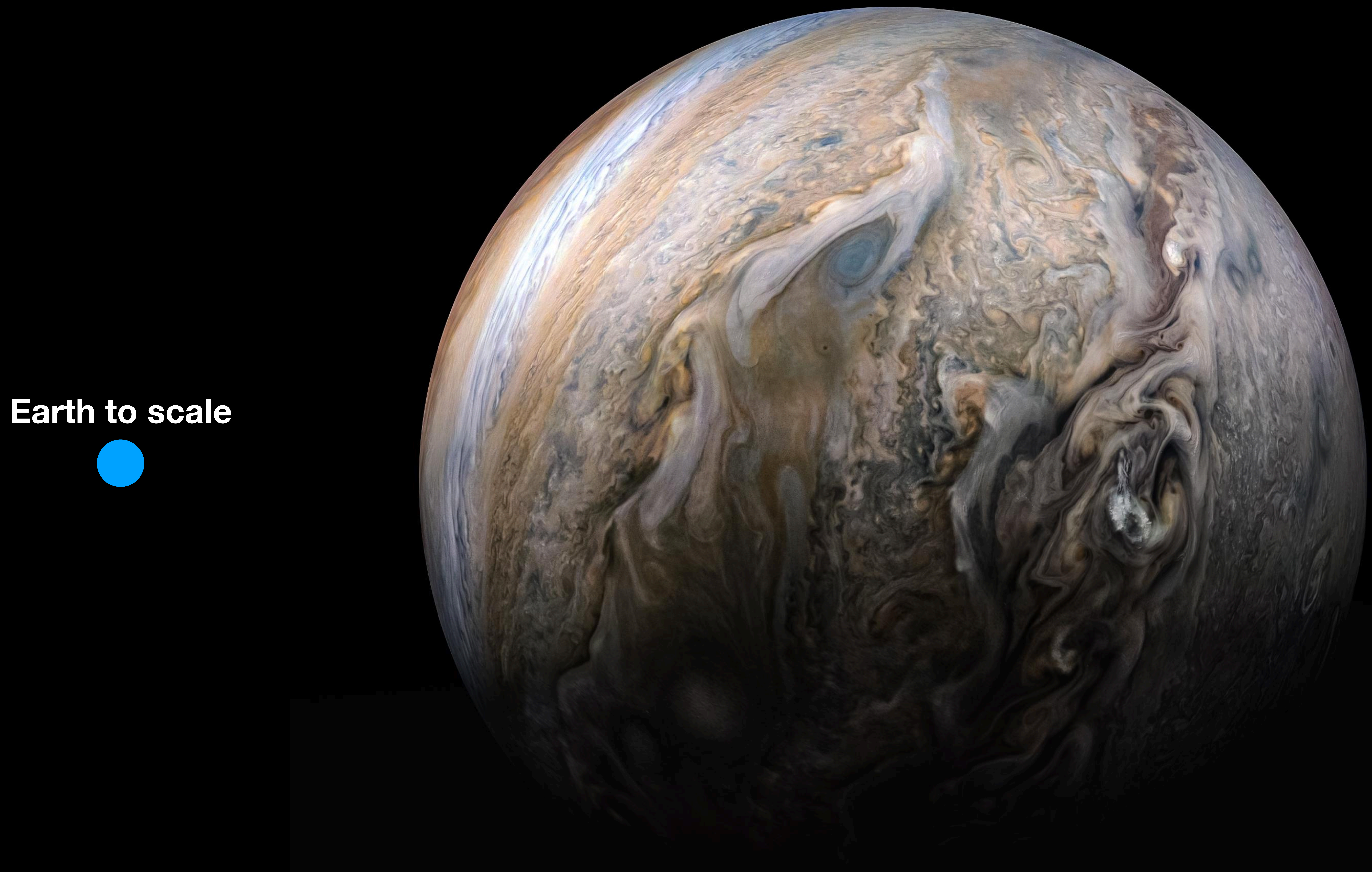



Don’t forget the point of all of this.

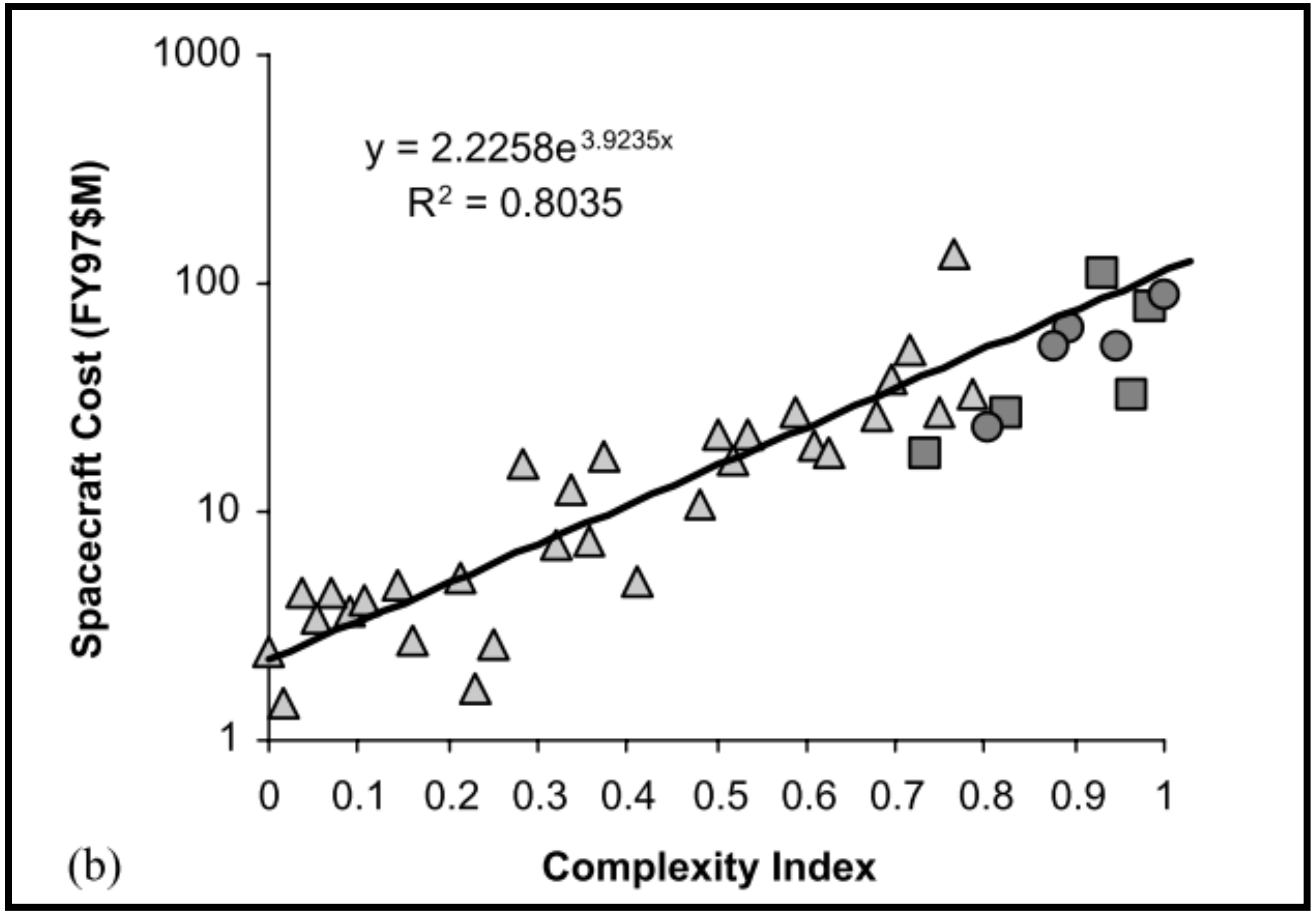
# Accounting for complexity and other subjective cost drivers

- Typical to incorporate complexity and other subjective cost drivers into cost estimates by means of categorical (binary) variables
- Examples of correction factors
  - If a system is “complex” ($x_{complex} = 1$), +50% ($k_{complex} = 1.5$)
  - If a system is unprecedented, +10%
  - If the organization has “limited experience” with this kind of technology . . .
  - If there are “immature” technologies . . .
  - If there are “mechanical issues” . . .
  - If there are “electromagnetic compatibility issues” . . .
- Of course, this assumes that there are no interactions between these factors

$$C(x_1, x_2, x_{complex}, x_{maturity}) = C_0 \cdot \left(\frac{x_1}{x_{ref}}\right)^{\beta_1} \cdot \left(\frac{x_2}{x_{2ref}}\right)^{\beta_2} \cdot \left(k_{complex}^{x_{complex}}\right) \cdot \left(k_{maturity}^{x_{maturity}}\right) \ldots$$

# Accounting for complexity and other subjective cost drivers

- Alternatively, you may combine multiple factors into a single one
- A **complexity index** can be constructed which is the average of several complexity factors




$$CI = \frac{1}{N}\sum_{i=1}^{N} F_i$$

$$F_i(x \in X) = percentrank(x, X)$$

- Then, the CI can be used as a single, independent variable for estimating cost

- Intermediate and advanced COCOMO use **Effort Adjustment Factor (EAF)** accounting for many more cost drivers including:
    - product attributes (complexity, reliability)
    - hardware attributes (runtime constraints, memory constraints)
    - personnel attributes (software engineering experience, programming language experience)
    - project attributes (use of software engineering tools and methods, schedule)
- EAF is the product of all 15 factors

$$E = a_b \cdot KLOC^{b_b} \cdot EAF \text{ person-months}$$

| | Ratings | | | | | |
|---|---|---|---|---|---|---|
| **Cost Drivers** | Very Low | Low | Nominal | High | Very High | Extra High |
| **Product attributes** | | | | | | |
| Required software reliability | 0.75 | 0.88 | 1.00 | 1.15 | 1.40 | |
| Size of application database | | 0.94 | 1.00 | 1.08 | 1.16 | |
| Complexity of the product | 0.70 | 0.85 | 1.00 | 1.15 | 1.30 | 1.65 |
| **Hardware attributes** | | | | | | |
| Runtime performance constraints | | | 1.00 | 1.11 | 1.30 | 1.66 |
| Memory constraints | | | 1.00 | 1.06 | 1.21 | 1.56 |
| Volatility of the virtual machine environment | | 0.87 | 1.00 | 1.15 | 1.30 | |
| Required turnabout time | | 0.87 | 1.00 | 1.07 | 1.15 | |
| **Personnel attributes** | | | | | | |
| Analyst capability | 1.46 | 1.19 | 1.00 | 0.86 | 0.71 | |
| Applications experience | 1.29 | 1.13 | 1.00 | 0.91 | 0.82 | |
| Software engineer capability | 1.42 | 1.17 | 1.00 | 0.86 | 0.70 | |
| Virtual machine experience | 1.21 | 1.10 | 1.00 | 0.90 | | |
| Programming language experience | 1.14 | 1.07 | 1.00 | 0.95 | | |
| **Project attributes** | | | | | | |
| Application of software engineering methods | 1.24 | 1.10 | 1.00 | 0.91 | 0.82 | |
| Use of software tools | 1.24 | 1.10 | 1.00 | 0.91 | 0.83 | |
| Required development schedule | 1.23 | 1.08 | 1.00 | 1.04 | 1.10 | |

# Approaches to cost estimation

## Bottom-up

- Uses Work Breakdown Structure (WBS)

## Top-down

- Uses parametric Cost Estimation Relationships (CER)

## Analogy

- Uses nearest-neighbor estimation + correction factors

**Now this**

# Cost estimation by analogy

- Basic idea: estimate the cost of a new product based on the cost of the **most similar past project** from a data base (called the *nearest neighbor*)
- Then, subjective adjustments (e.g. based on complexity or others) are made by experts
- Problems
  - There may not be a good analog!
  - Subjective

# More concepts in cost estimation

- Learning curve
- Cash flows
- Net present value
- Choosing discount rates

- **CER do not take production lines into account**
  - Economies of scale
  - First unit of anything is hard. Second and subsequent units are easier due to learning effects in employees

- Cumulative cost of building $N$ units

$$C(N) = C(1) \cdot N^B$$

- Average cost of each unit

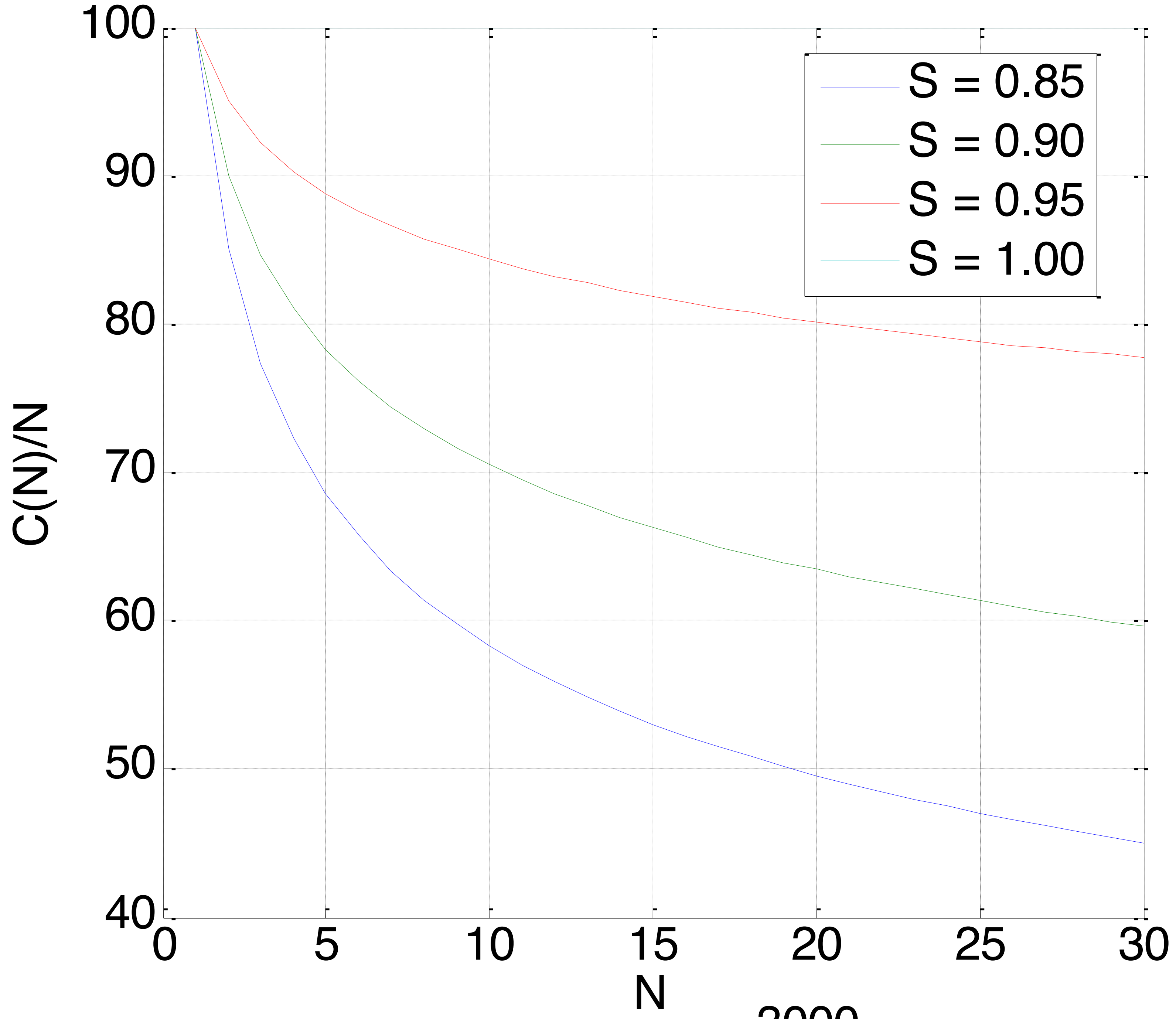
$$\frac{C(N)}{N} = C(1) \cdot N^{B-1}$$

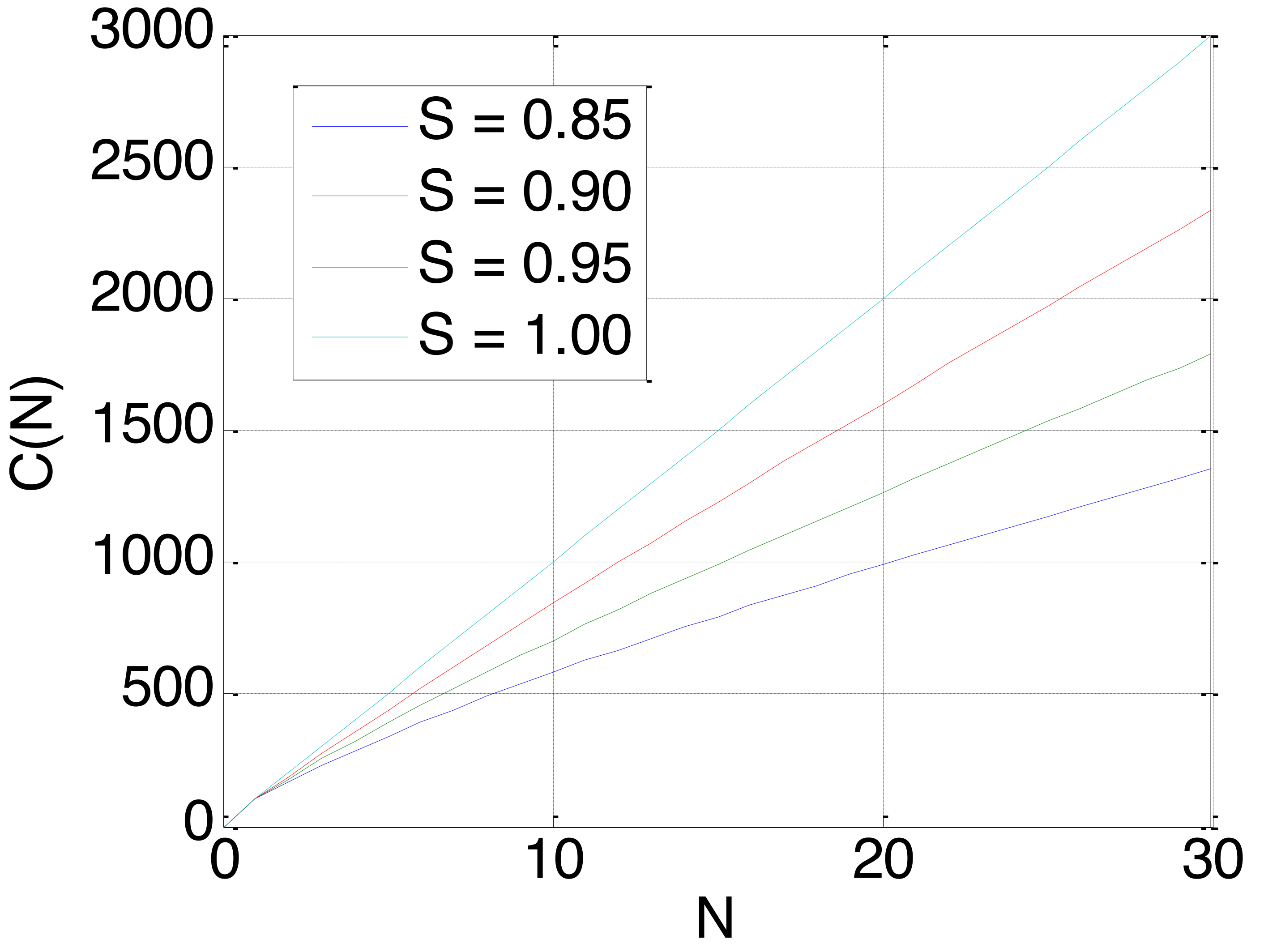
- Note that

$$\frac{C(2N)}{C(N)} = 2^B \longrightarrow \frac{C(2N)/2N}{C(N)/N} = 2^{B-1} = S$$

**$S$ represents (one minus) the percent reduction in average cost per unit when production is doubled**

# Learning curve



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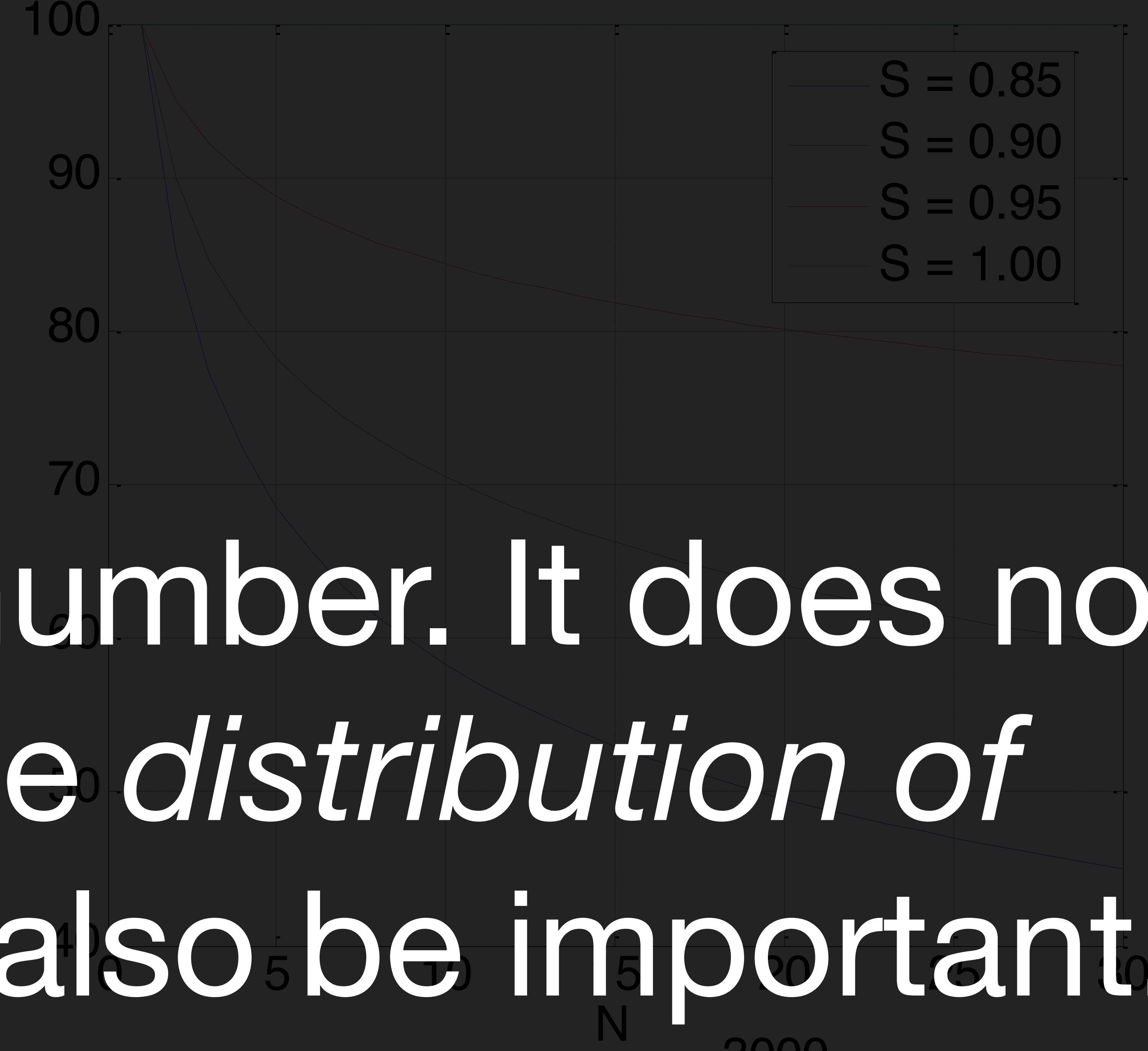
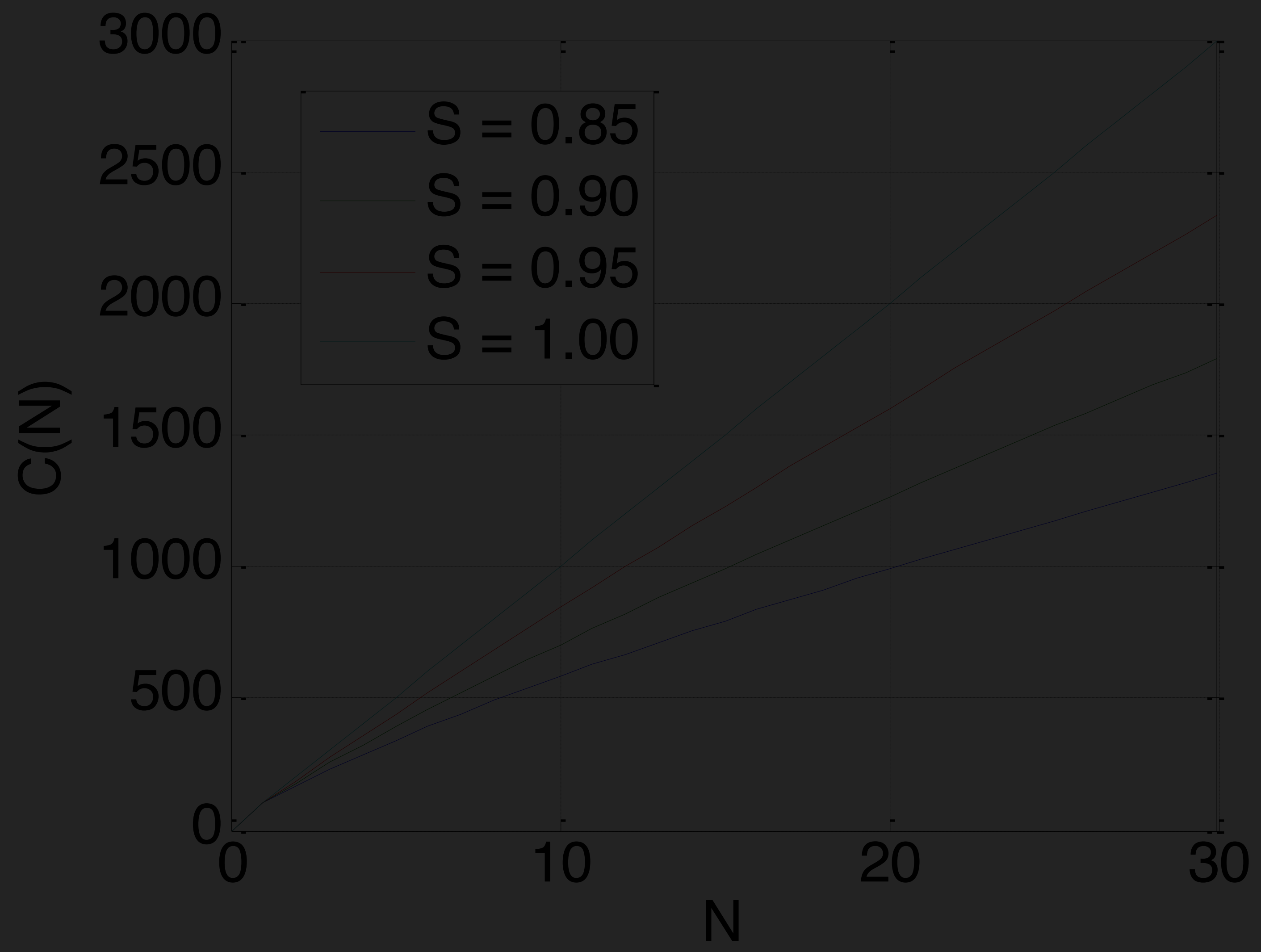


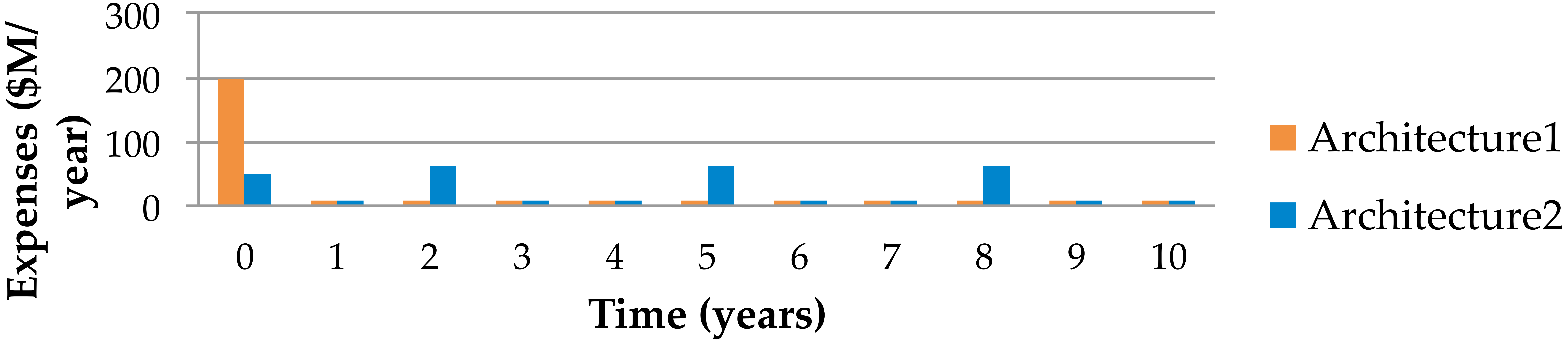




Lifetime cost is a single number. It does not tell the whole story. The *distribution of spending over time* may also be important.

# Cash flows

The **total expenses in a time period** (e.g. year), including revenues if there are any

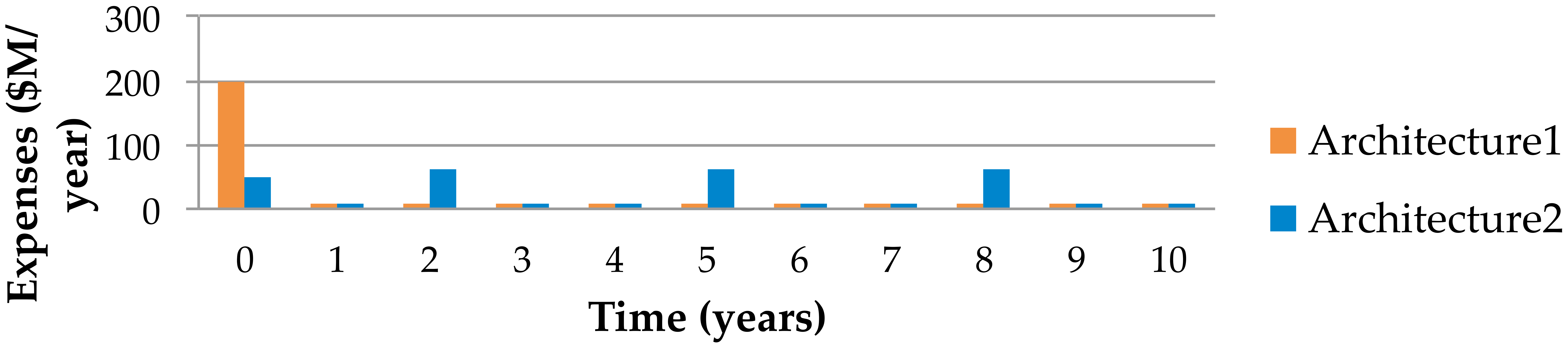
Two architectures with the same lifetime cost and different cashflows. Architecture 1 requires more spending on year 1. Which one do you prefer?



# Cash flows

The **total expenses in a time period** (e.g. year), including revenues if there are any

**The claim:** A dollar today is not the same as a dollar tomorrow. We need a way to compare apples to apples.



# Net present value

How we compare dollars today to dollars tomorrow.

Net present value **discounts future cash flows** (revenues $B_t$ and costs $C_t$) by a certain *discount rate* $r > 0$

$$NPV = \sum_{t=0}^{T} \frac{B_t - C_t}{(1+r)^t} = \frac{B_0 - C_0}{(1+r)^0} + \frac{B_1 - C_1}{(1+r)^1} + \cdots + \frac{B_T - C_T}{(1+r)^T}$$

| **Today** | | **In 1 year** |
|---|---|---|
| $\frac{1}{1+0.05} = \$0.9524$ | $\xleftarrow{r=5\%}$ | $\$1$ |

**For $r = 0.05$, a dollar in one year costs only 95 cents today.**

| | | C_(t,2) | C_(t,1)/(1+r)^t | | | C_(t,2)/(1+r)^t | | |
|---|---|---|---|---|---|---|---|---|
| t | Arch1 | Arch2 | 0% | 5% | 10% | 0% | 5% | 10% |
| 0 | 200 | 50 | 200.00 | 200.00 | 200.00 | 50.00 | 50.00 | 50.00 |
| 1 | 10 | 10 | 10.00 | 9.52 | 9.09 | 10.00 | 9.52 | 9.09 |
| 2 | 10 | 60 | 10.00 | 9.07 | 8.26 | 60.00 | 54.42 | 49.59 |
| 3 | 10 | 10 | 10.00 | 8.64 | 7.51 | 10.00 | 8.64 | 7.51 |
| 4 | 10 | 10 | 10.00 | 8.23 | 6.83 | 10.00 | 8.23 | 6.83 |
| 5 | 10 | 60 | 10.00 | 7.84 | 6.21 | 60.00 | 47.01 | 37.26 |
| 6 | 10 | 10 | 10.00 | 7.46 | 5.64 | 10.00 | 7.46 | 5.64 |
| 7 | 10 | 10 | 10.00 | 7.11 | 5.13 | 10.00 | 7.11 | 5.13 |
| 8 | 10 | 60 | 10.00 | 6.77 | 4.67 | 60.00 | 40.61 | 27.99 |
| 9 | 10 | 10 | 10.00 | 6.45 | 4.24 | 10.00 | 6.45 | 4.24 |
| 10 | 10 | 10 | 10.00 | 6.14 | 3.86 | 10.00 | 6.14 | 3.86 |
| | | | **300.00** | **277.22** | **261.45** | **300.00** | **245.59** | **207.14** |

- If we compare the two architectures in NPV with $r > 0$ it is clear that Architecture 2 is better
- Note that NPV($r = 0$) = LCC
- The higher the discount rate, the better Arch 2 is with respect to Arch 1

# Net present value

## How do we choose the discount rate, $r$?

- NPV depends strongly on your choice of discount rate
- How do we choose the discount rate?
  - Central idea is that it needs to be **comparable to the best investment opportunities to which you have access**
- Typically . . .
  - 10-15% for private companies
  - 0-5% for government
- Two main methods for choosing discount rate . . .
  - Weighted Average Cost of Capital (WACC)
  - Capital Asset Pricing Model