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NASA Cost and Schedule Symposium

Math is Hard

2021 NASA Cost & Schedule Symposium

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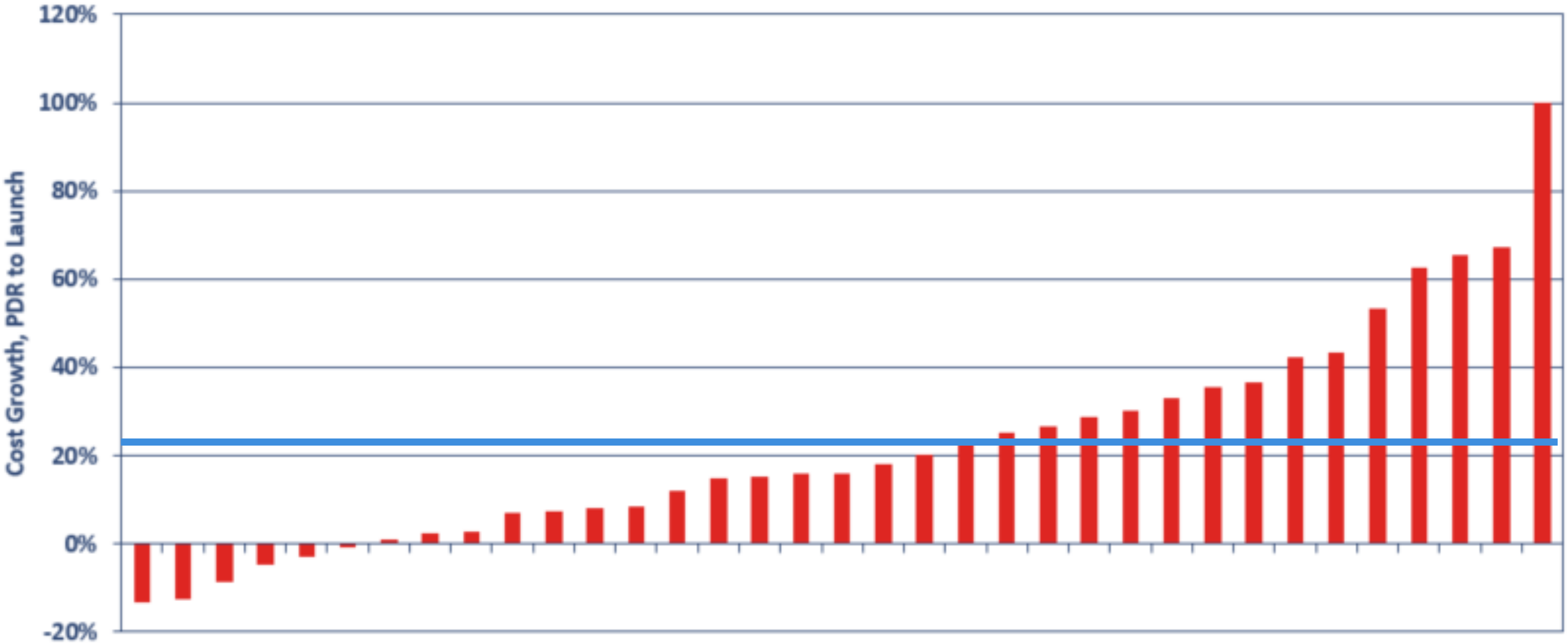
Background

- The NASA cost community relies on risk analyses to estimate confidence in a project's budget. At PDR, convention requires that baseline cost/schedule confidence should be around the 50^{th} percentile and cost plus reserves should be around the 70^{th} percentile of the joint distribution of total cost and schedule. But how can we test whether our approach to determining 50^{th} and 70^{th} percentiles for missions going into PDR is reliable?
- Our research will examine the NASA cost community's approach to reserve postures. Using the empirical dataset as our guide, how can projects approaching PDR provide cost and schedule analysis that supports the goal of achieving 70% confidence in the budget at the portfolio level?

Methodology: Data Collection & Normalization

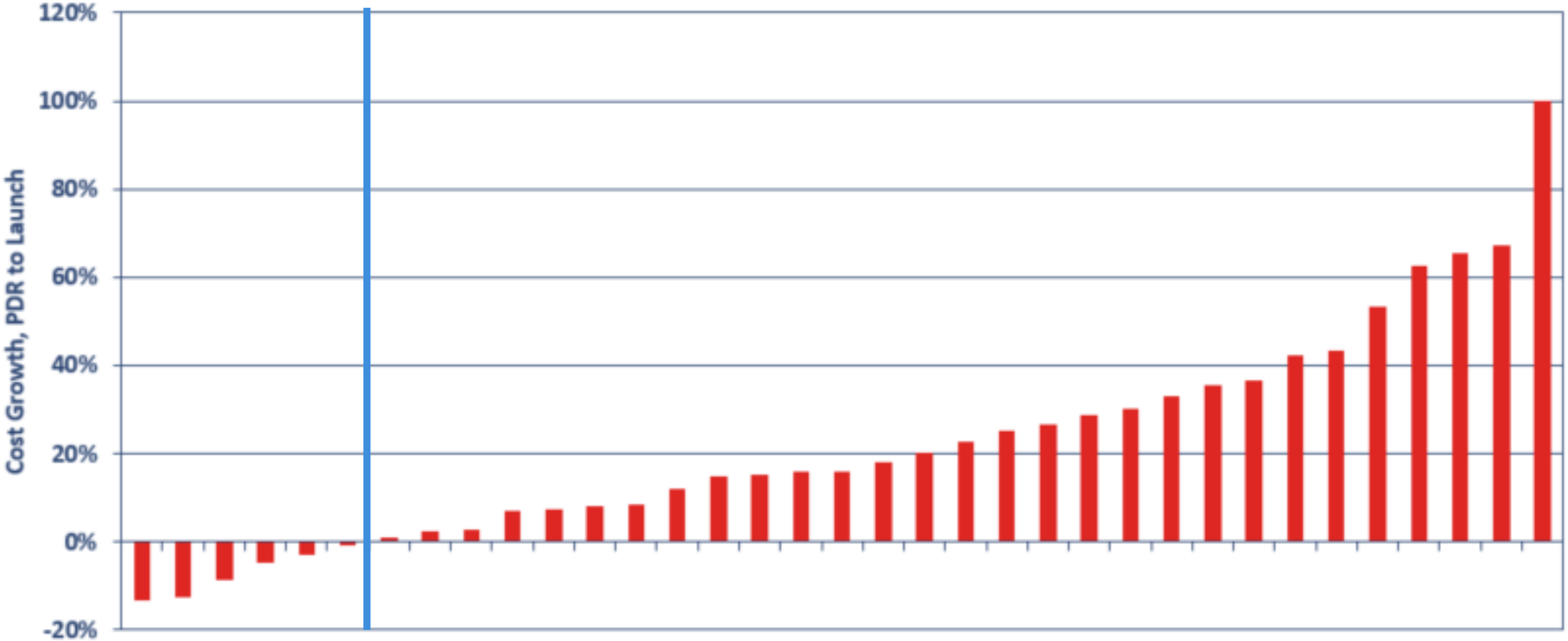
- Cost data collected via PDR and Launch CADRes (Part C)
- Programmatic data collected via CADRes (Part B)
- Looking at a total of 35 robotic missions:
  - Launch dates from 2002 to 2021
  - Costs up to $1B RY
- Costs were normalized:
  - Exclude launch vehicle costs
  - Include reserves

NASA Mission Cost Growth



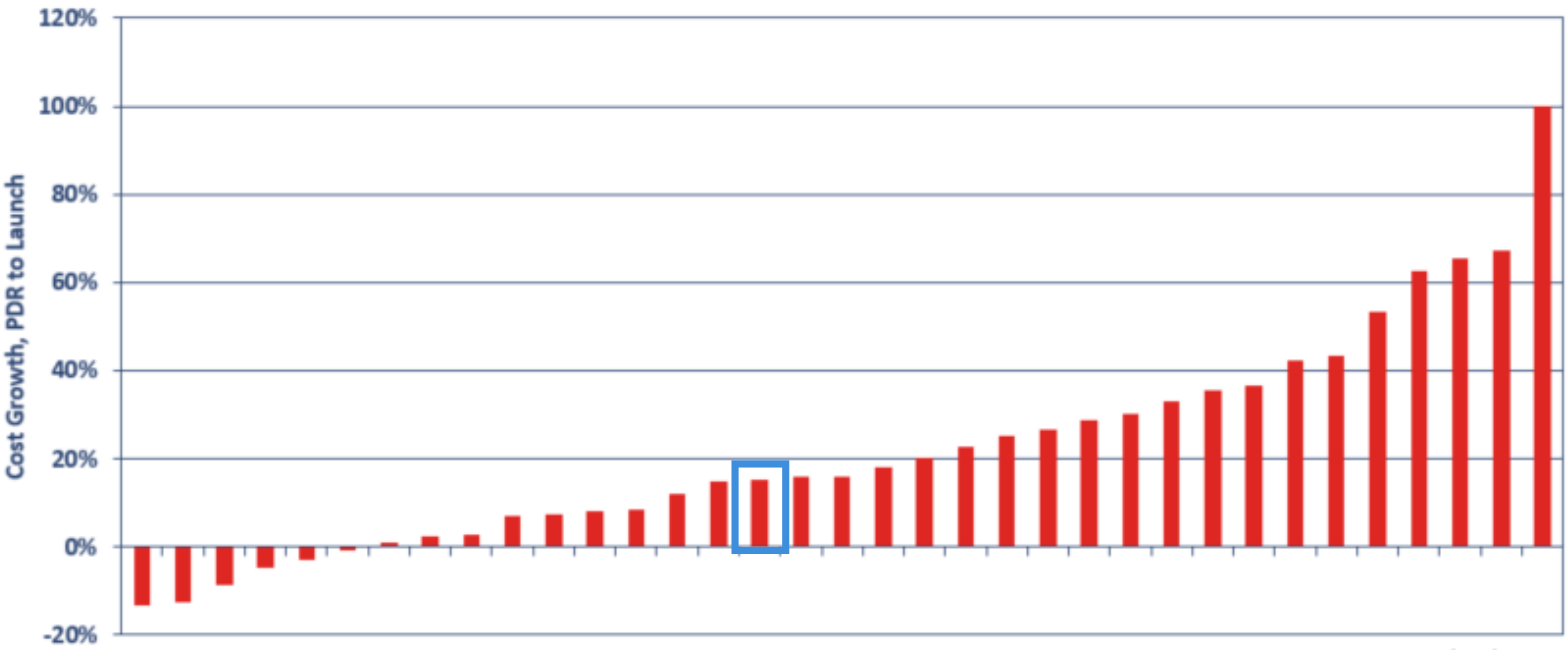
Summary Statistics	
Average Cost Growth	22%
Standard Deviation of Cost Growth	0.27

NASA Mission Cost Growth



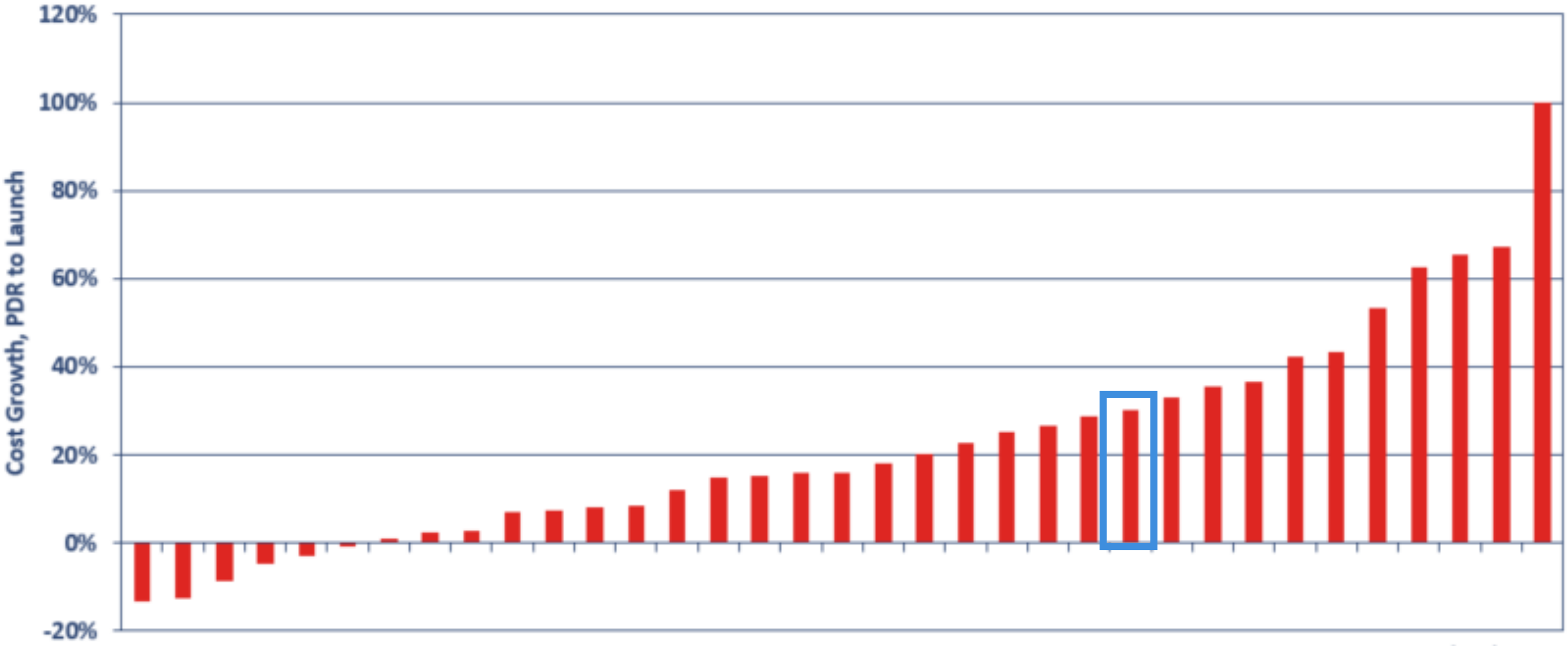
- 17% probability (6/35 chance) that a mission does not experience cost growth after PDR
- 83% probability (29/35 chance) that a mission experiences cost growth after PDR

NASA Mission Cost Growth



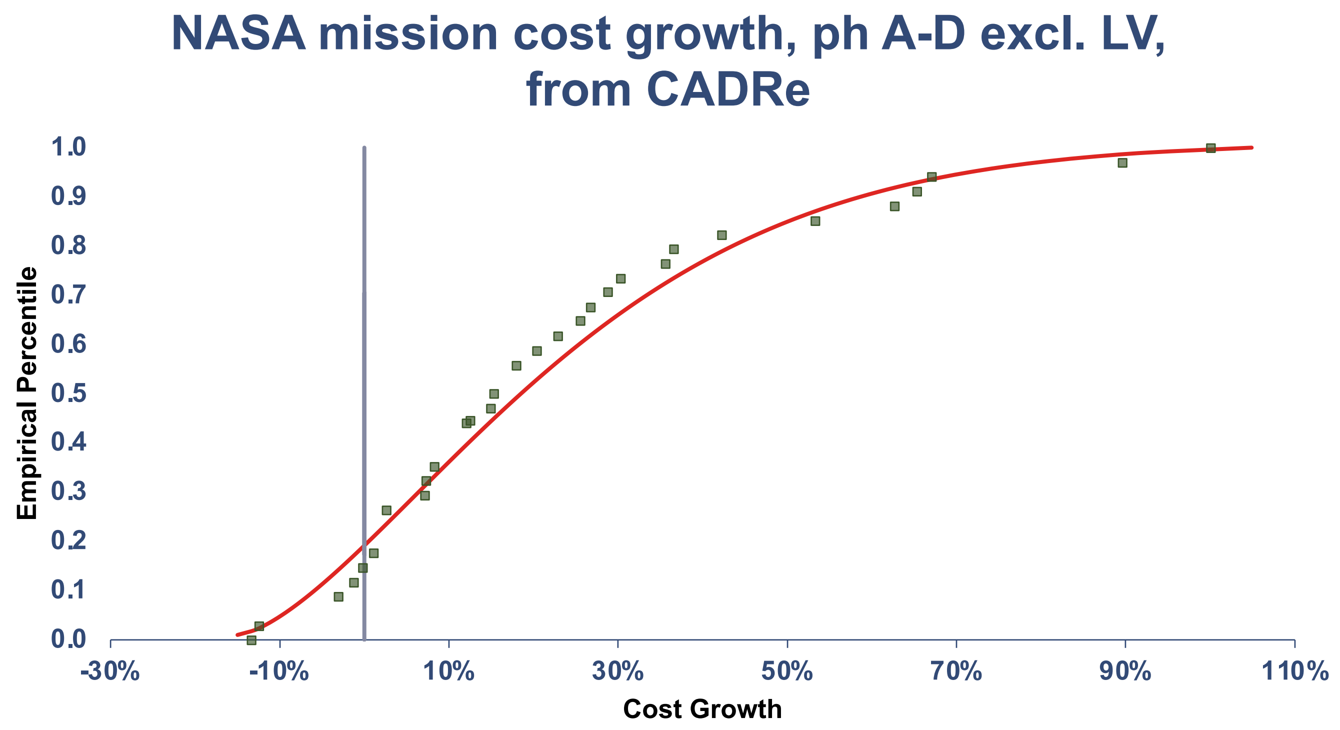
- At the empirical 50th percentile (18/35), cost growth is 16% in addition to reserves

NASA Mission Cost Growth



- At the empirical 70th percentile (25/35), cost growth is 30% in addition to reserves

NASA Mission Cost Growth



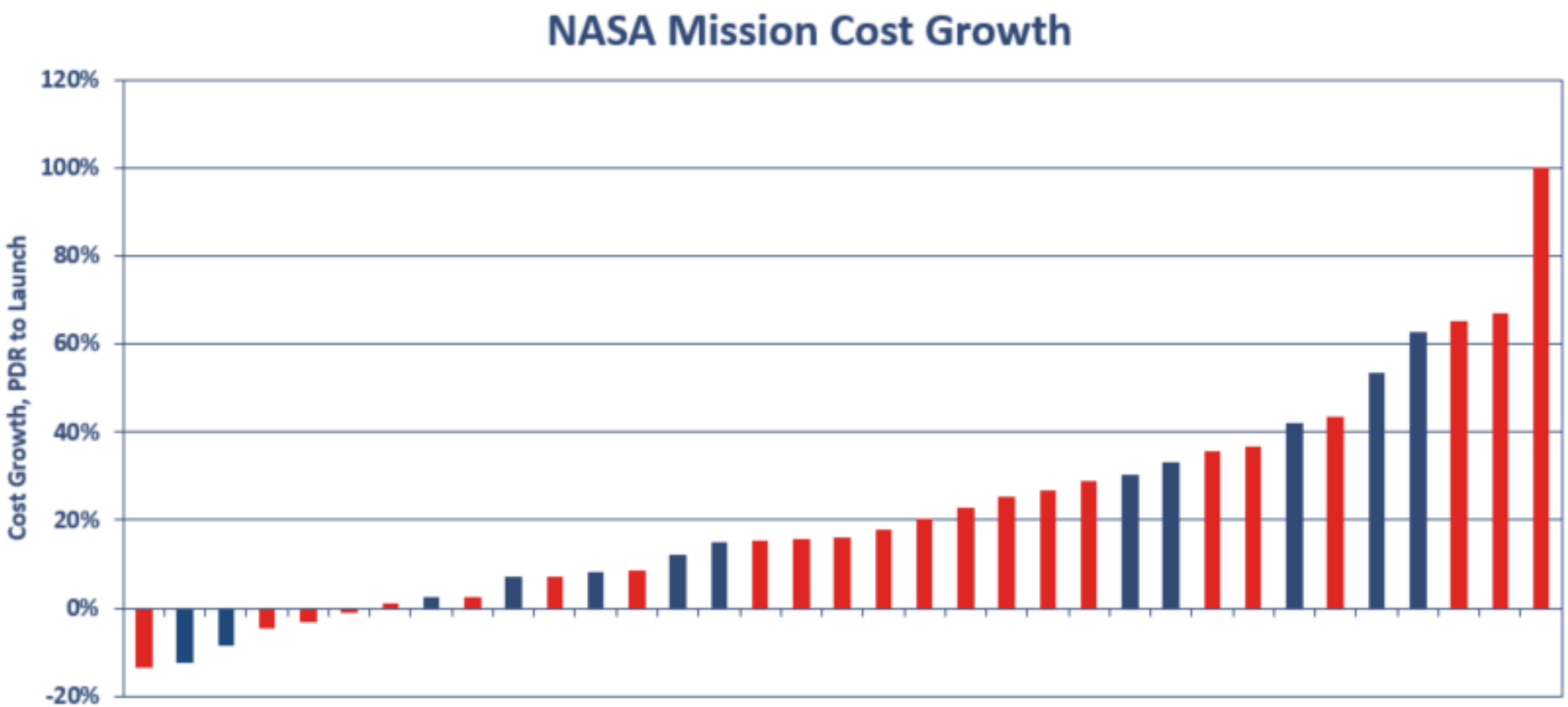
- At the empirical 50th and 70th percentiles, NASA missions are spending their full budgets plus 16% and 30%, respectively

Slice & Dice the Data

Categories	Group 1	Group 2
Destination	*Earth Orbiting*	*Planetary*
Requirements	*Pre-Version E*	*Version E*
Acquisiton Strategy	*Competed*	*Directed*

- We looked at a few different ways to “slice & dice” the data
- Does cost growth look different when the data is split up into groups?

Does Destination Matter?



= Planetary

= Earth Orbiting

Does Destination Matter?

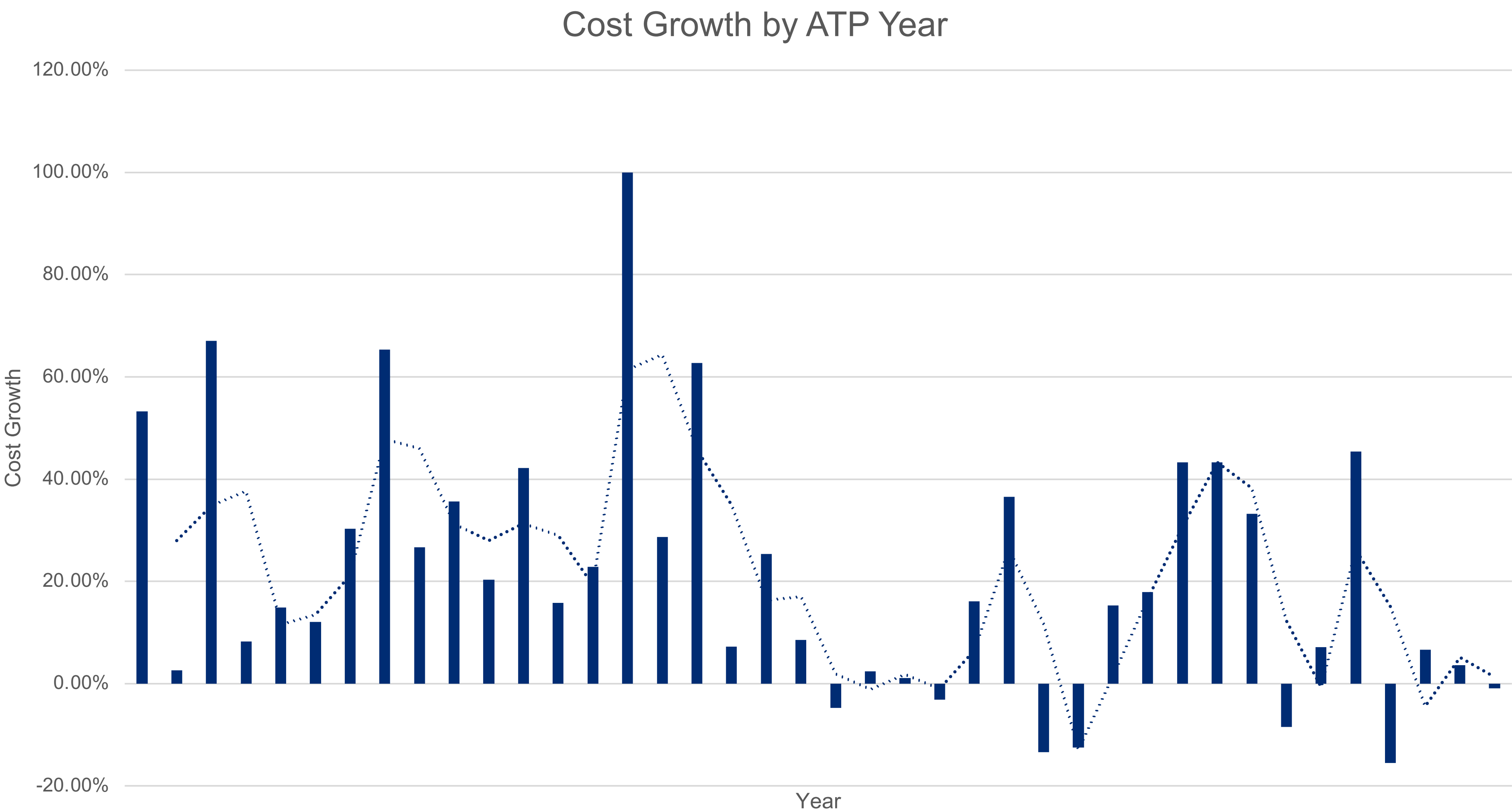
Destination	Average Cost Growth
Earth Orbiting	24%
Planetary	20%

- We looked at earth-orbiting missions compared to planetary missions
  - We hypothesized that planetary missions would have less cost growth since they are less likely to have schedule growth due to fixed launch windows
- H_0: $\mu_{earth\ orbiting} \neq \mu_{planetary}$
- H_1: $\mu_{earth\ orbiting} > \mu_{planetary}$

T Test Summary	
T statistic	0.44
P value	0.33

- However, the difference is not significant

Does Changing Requirements for Programmatic Controls Matter?



Do 7120.5E Requirements Matter?

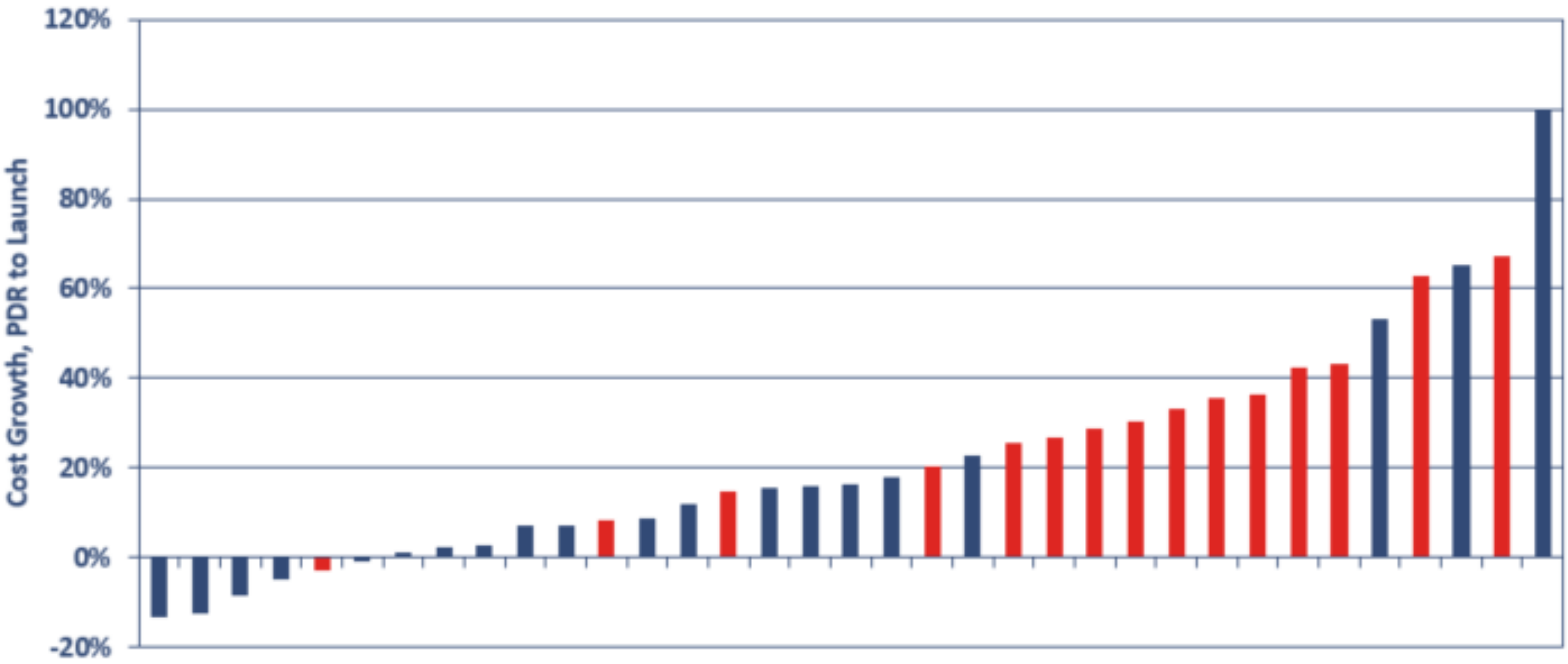
NASA Requirements	Average Cost Growth
Pre-Version E	24%
Version E	15%

- We looked at missions prior to 7120.5E requirements compared to missions with 7120.5E requirements
- H_0: $\mu_{pre\ 7120.5E} \neq \mu_{version\ 5E}$
- H_1: $\mu_{pre\ 7120.5E} > \mu_{version\ 5E}$

T Test Summary	
T statistic	0.78
P value	0.23

- However, the difference is not statistically significant. As newer data points become available, we should continue to monitor whether new programmatic requirements help NASA control costs

Does Acquisition Strategy Matter?



= Directed
= Competed

Does Acquisition Strategy Matter?

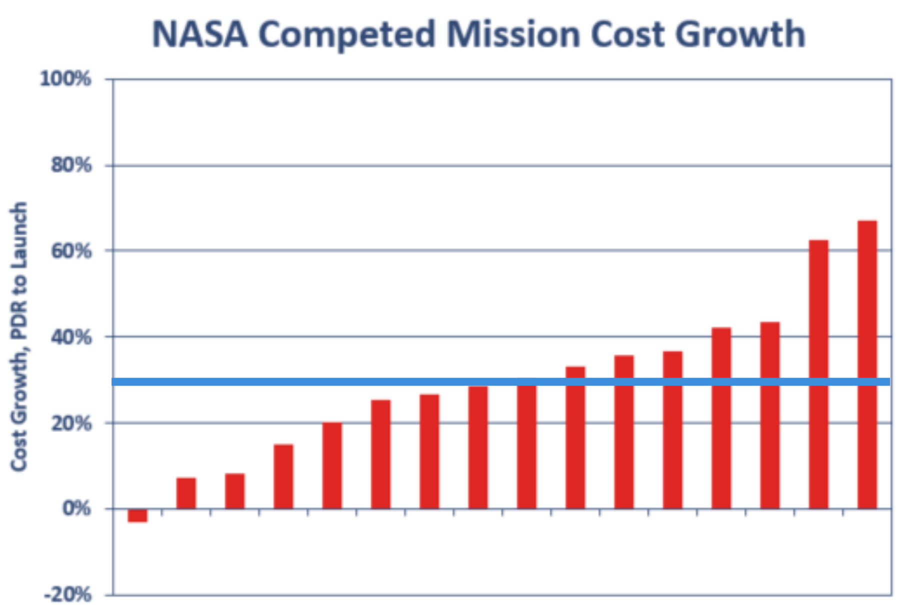
Acquisition Strategy	Average Cost Growth
Competed	30%
Directed	17%

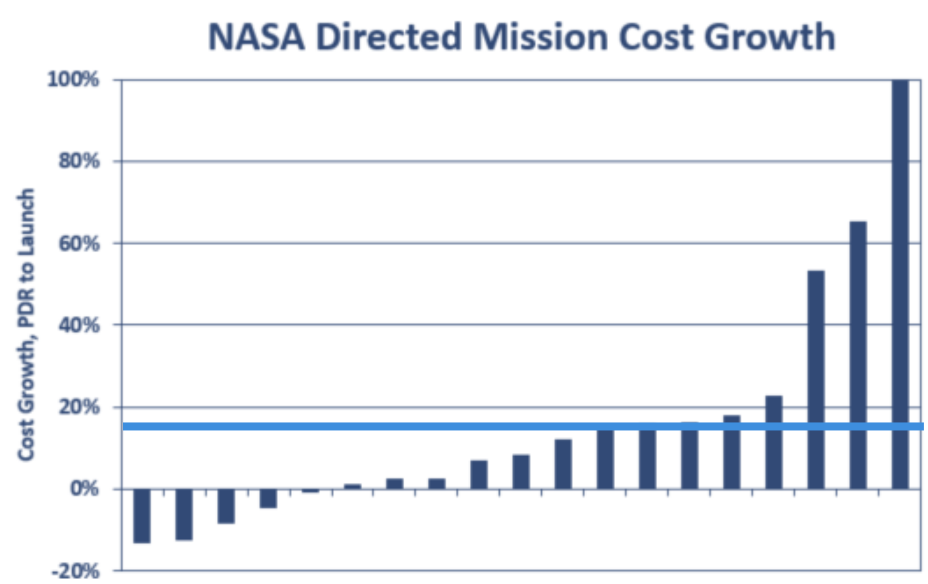
- We looked at competed missions compared to directed missions
  - We hypothesized that directed missions would have less cost growth
- H_0: $\mu_{competed} \neq \mu_{directed}$
- H_1: $\mu_{competed} > \mu_{directed}$

T Test Summary	
T statistic	1.76
P value	0.04

- The difference is significant so we accept the alternate hypothesis
  - Let's explore this significant difference more…

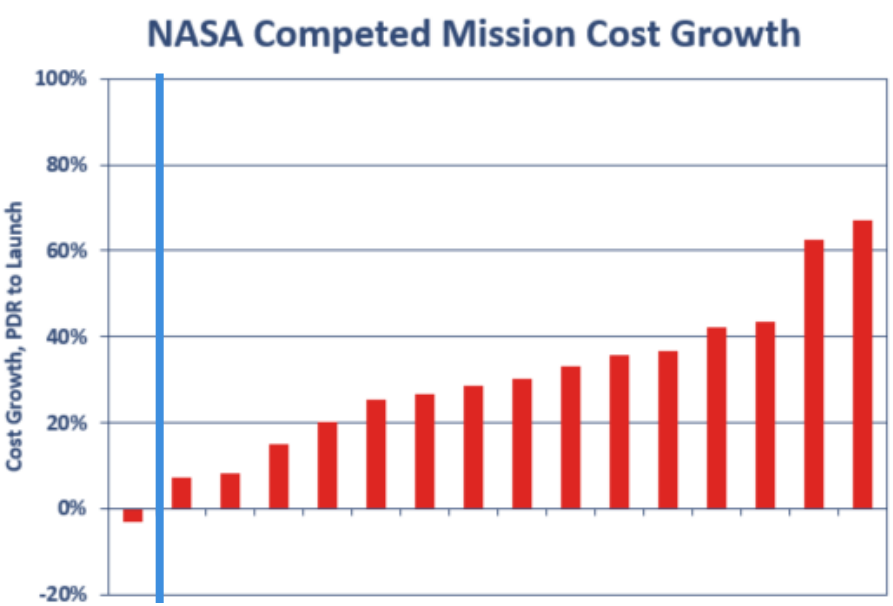
Competed vs Directed Cost Growth

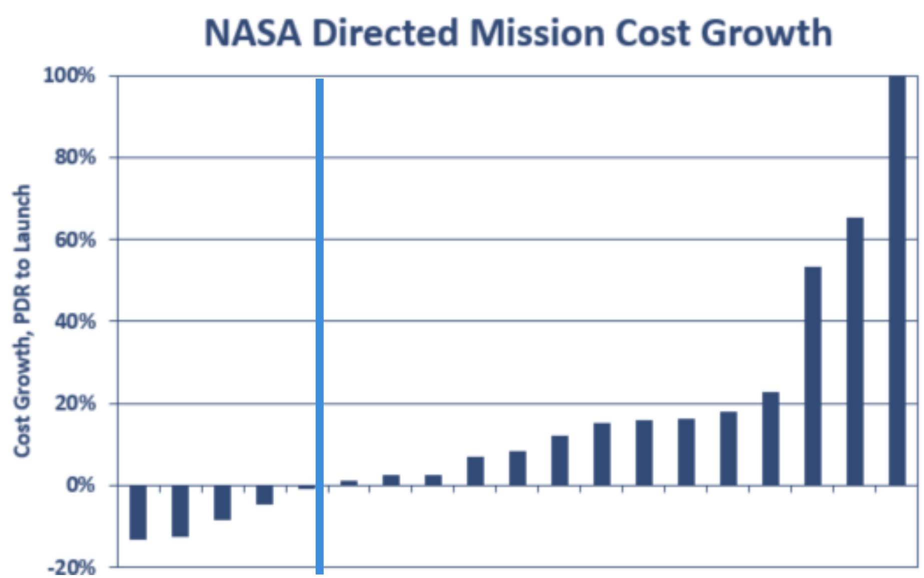




- 30% average cost growth for competed missions
- 17% average cost growth for directed missions

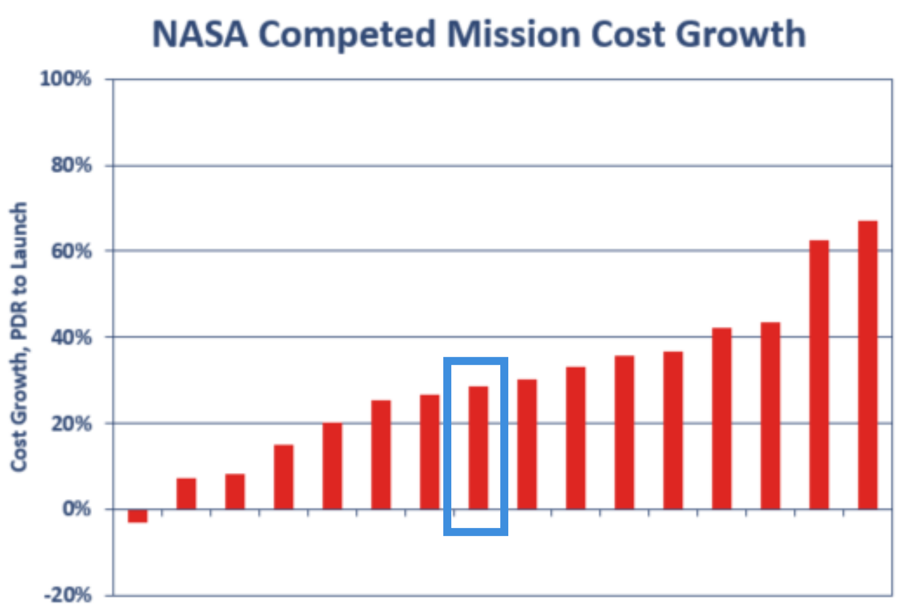
Competed vs Directed Cost Growth

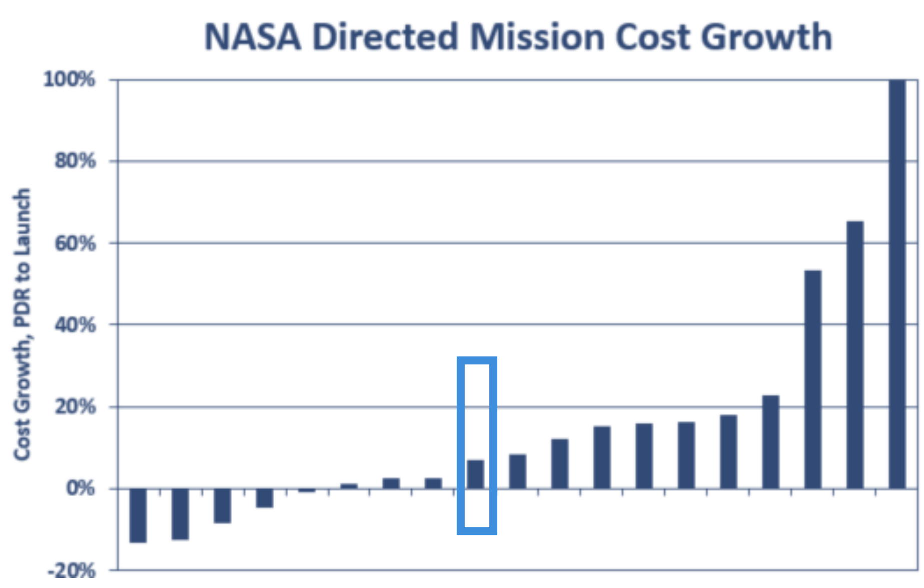




- 94% chance that competed mission experiences cost growth after PDR
- 74% chance that directed mission experiences cost growth after PDR

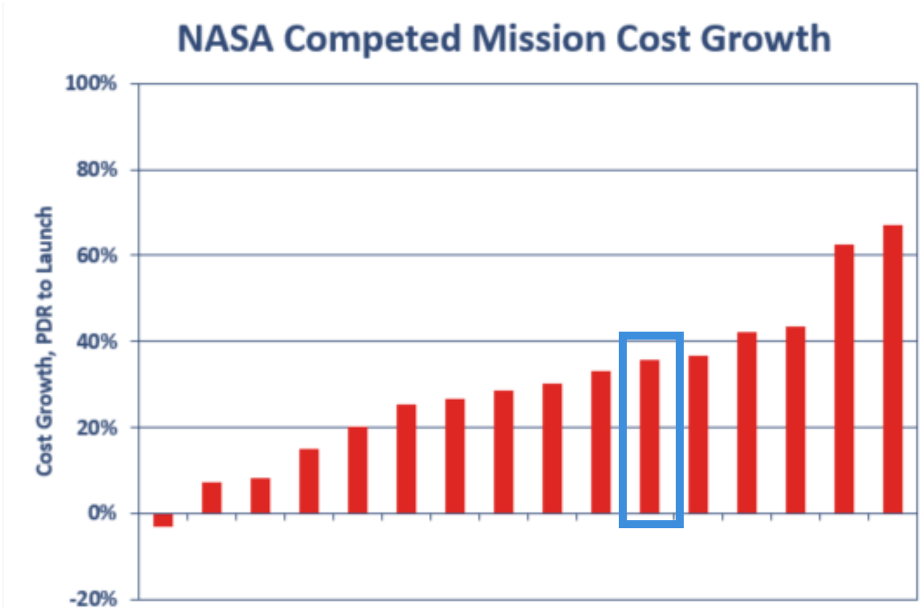
Competed vs Directed Cost Growth

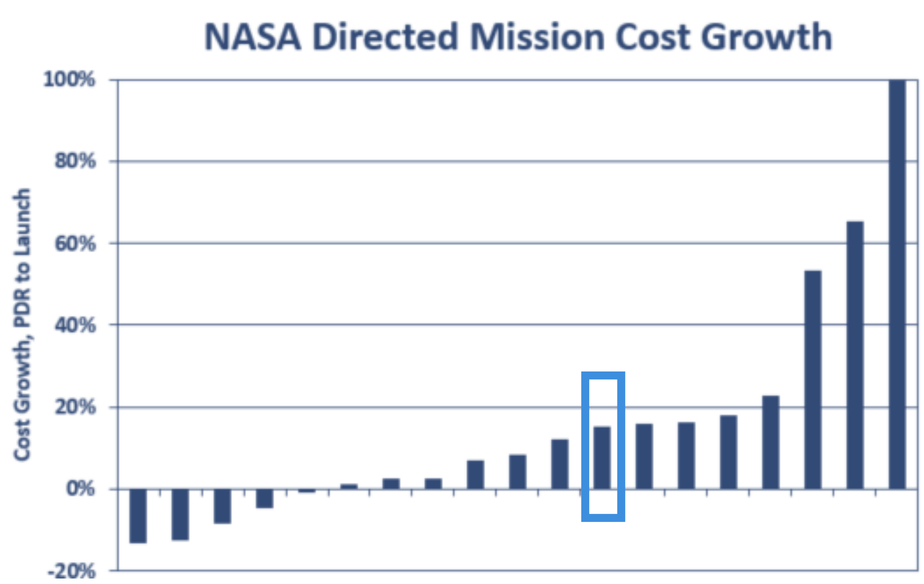




- At the empirical 50th percentile of competed missions, cost growth is 30%
- At the empirical 50th percentile of directed missions, cost growth is 7%

Competed vs Directed Cost Growth





- At the empirical 70th percentile of competed missions, cost growth is 36%
- At the empirical 70th percentile of directed missions, cost growth is 16%

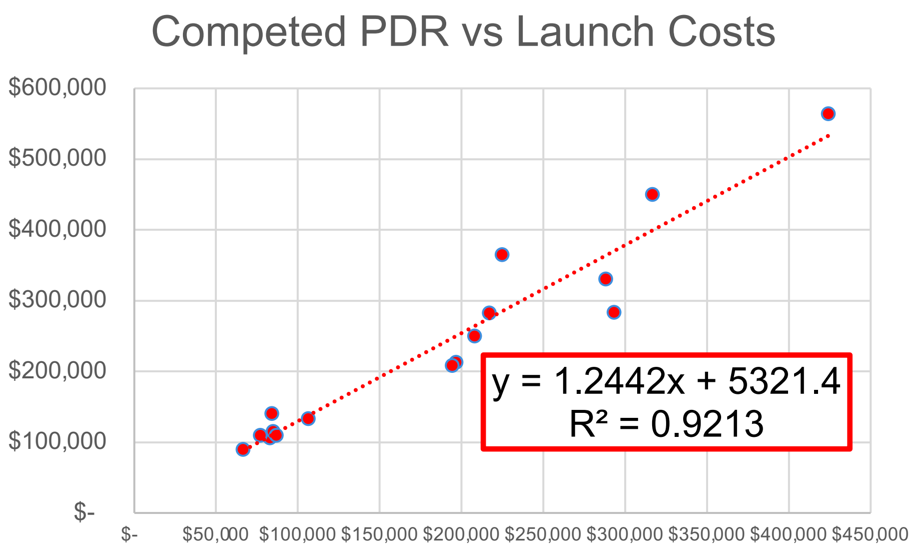
What This Really Means…

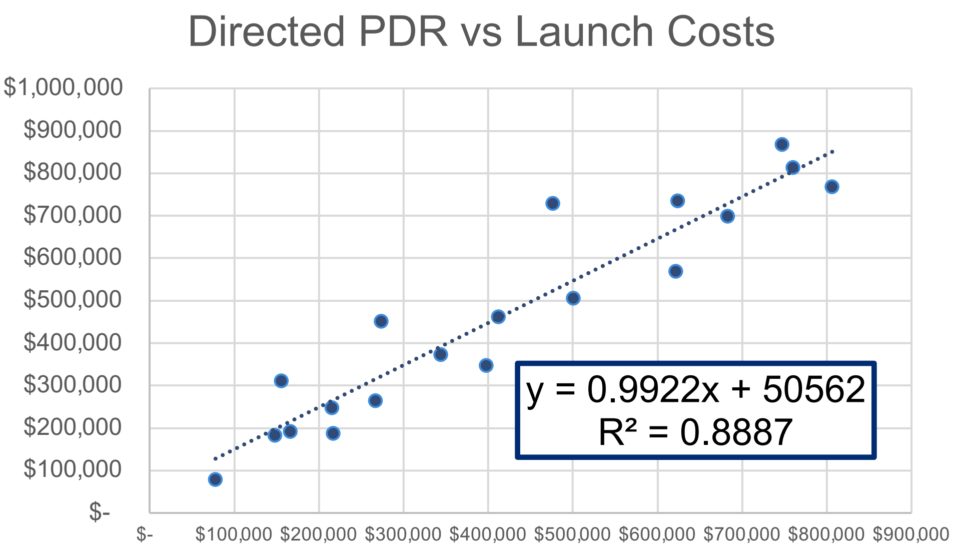
- Given the available data set, the difference between the average cost growth of competed versus directed missions is significant
- We also know there are large differences in the probability that a competed mission experiences cost growth compared to a directed mission

WHY?

- Are more resources available early in the formulation process for directed missions to generate robust cost estimates than for proposals/competed missions?
- Are we overly optimistic when we generate cost estimates and risk analyses?
- Are we setting overly ambitious science goals for competed missions in each of the mission classes?

Predicted Launch Costs of Competed vs Directed Missions

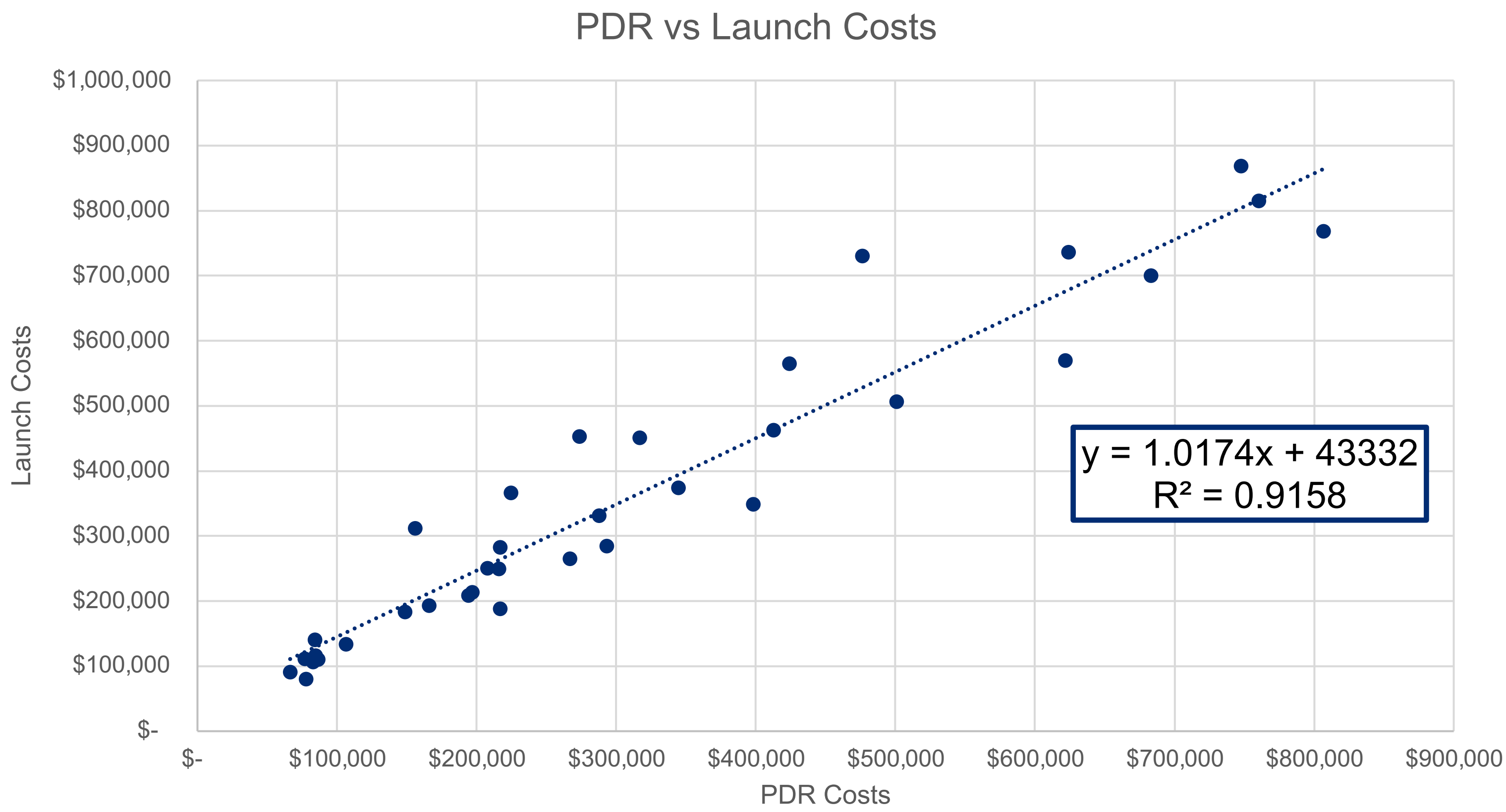




- Average prediction error 1%
- Predictor error standard deviation of 0.14

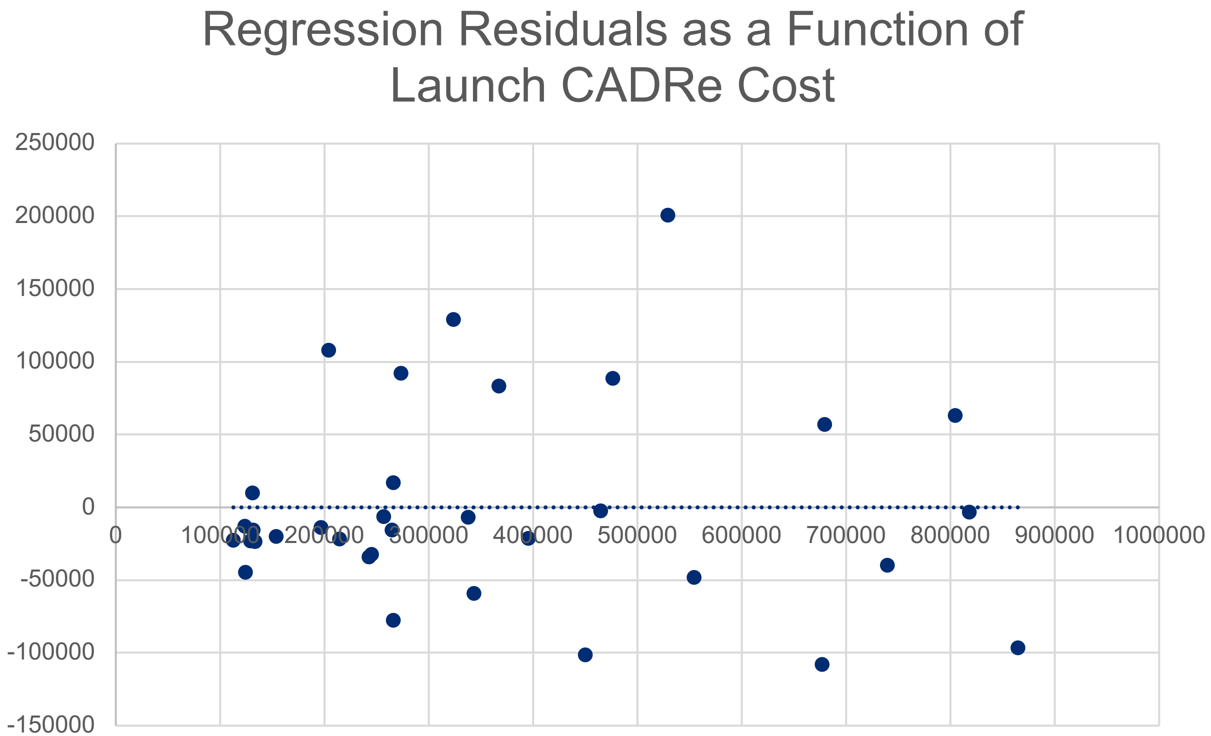
- Average prediction error 6%
- Predictor error standard deviation of 0.23

Predicted Launch Costs of All Missions



- Average prediction error 5%
- Predictor error standard deviation of 0.19

Test for Heteroscedasticity



- No quantitative pattern to regression residuals (trendline on the x-axis)
- Errors are uncorrelated and distributed normally (constant variance)
- → Thus, the model is homoscedastic

Conclusions

- MATH IS HARD
- 83% of NASA missions experienced cost growth post-PDR
  - Given the available dataset, 94% of competed missions experienced post-PDR cost growth
  - 74% of directed missions in our dataset experienced post-PDR cost growth
- The average NASA mission cost grew 22% from PDR to Launch
  - Competed missions in the dataset experienced 30% post-PDR cost growth on average
  - Directed missions in the dataset experienced 17% post-PDR cost growth on average
- Directed missions in the dataset were doing something right. More recent experience with cost growth in directed missions might change the result, but the data we have shows a clear difference between cost growth in competed versus cost growth in directed missions
- One of the ways the community can help is to treat every cost estimate with a high level of rigor and skepticism, devote the right resources to get the details worked out, and approach risk and uncertainty with candor

Conclusions

- At the empirical 50th and 70th percentiles, NASA missions were spending their full budgets plus 16% and 30%, respectively
- Historically, in order to achieve a 50% chance of coming in on budget, missions would have had to hold 46% reserves in order to be 50% confident
- If missions had held 46% reserves, then 50% of missions would come in on budget compared to 17%
- Given that missions continue to hold 30% reserves against their baseline cost estimates, NASA needs to be holding an additional 30% against its mission portfolio in order to be at the empirical 70th percentile
- If missions had held 46% reserves and NASA had held 14% UFE, then NASA would have been 70% certain
- Math is hard, and sometimes it gives us answers we either don't like, or that surprise us. But it's worthwhile to do this work!

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