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Complexity the Right Way

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May 2, 2023

The Setup

- **About 10 – 12 years ago I started reading books:**
  - Dan Ariely: Predictably Irrational
  - Douglas Hubbard: How to Measure Anything
  - Daniel Kahneman: Thinking, Fast and Slow
  - Leonard Mlodinow: The Drunkard’s Walk, How Randomness Rules our Lives
  - Nate Silver: The Signal and the Noise: Why most Predictions Fail but some Don’t
  - And many other book and articles
- **These readings gave me insights into how human judgment works, and how that judgment affects our cost estimates**
- **Outcome: The Psychology of Cost Estimating**

The Psychology of Cost Modeling

- **A further result of my readings was an assessment of how we develop cost models**
- **In the paper "The Dangers of Parametrics," I addressed many of the sins of parametric model development, most prominently the use of complexity factors**

We misuse subjective parameters when we put them into our regression analyses and treat them the same as more objective system parameters. This creates the illusion that a judgment-based parameter is equal in value to an objective parameter. This illusion is further reinforced when these parameters turn out to have a predictive value, as measured by the statistics, which is at least as good as the objective parameters. **However, what we are really doing is cleverly modeling the noise.**

The Dangers of Parametrics – 2016, emphasis added

A Furor Erupts!

- The use of complexity factors has a long history in the field of parametric cost estimating
- Many distinguished cost analysts (Hamaker, Smart, etc.) disagreed, citing the value of judgment and experience
- Since I had the academics and a Nobel Laureate on my side, I figured I had to be right
- Still, the argument remained unresolved…

Rethinking

- In developing new CERs for PCEC, we were hitting a ceiling on predictive power despite having a large and rather homogenous data set
- Read a new book: “Noise, A Flaw in Human Judgment” (Kahneman, Sibony, Sunstein)
- Recalled a story of Kahneman as a young psychologist in Israel
- Remembered an instrument cost model I developed early in my NASA career that relied heavily on multiplicative factors

Marshall Instrument Cost Model

$$Cost = f(\alpha, \beta, \gamma) \cdot \prod_{i=1}^{n} \tau_i$$

Three Objective Parameters
$Y = ax^b y^c z^d$

n multiplicative factors, including a complexity factor based on the unexplained variation in the data after accounting for all other parameters

What is a Complexity Factor?

A Financial Definition: Number that denotes the level of complexity of a condition or situation. Complexity factor is arrived at usually through estimation or judgment of the (1) number of parts or factors, (2) type and number of their interrelationships and interconnections, (3) number of unknowns, and (4) degree of uncertainty. (https://indianmoney.com/financial-dictionary/c/complexity-factor)

In our world, a complexity factor is often officially used to denote a degree of difficulty, *but in reality, it is also used to explain variations in the data for which we have no other explanation*

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Are Complexity Factors Necessarily Evil?

- **I used to think so (NAFCOM experience)**
- **But I have come to realize that judgment (i.e., a complexity factor) is an important part of cost estimation and analysis, *but it must be done correctly!***

> Algorithmic evaluation is guaranteed to eliminate noise – indeed, it is the only approach that can eliminate noise completely. … <u>But it is unlikely that algorithms will replace human judgment in the final stage of important decisions – and we consider this good news</u>. However, judgment can be improved, by both the appropriate use of algorithms and the adoption of approaches that make decisions less dependent on the idiosyncrasies of one professional.

Noise, a Flaw in Human Judgment; page 371; emphasis added

Back to the Future

- Approach: calculate complexity factors to account for the unexplained variation after development of the CER using objective parameters
- Base the factors on the relationship between the actual and estimated cost
- Don’t try to explain why the variation is the variation
- Do not include the complexity factors in the CER! Use the MICM approach and have them applied as a multiplier to the CER results

Test the Approach

- Develop a simple CER
- Calculate complexity factors to explain the remaining noise (error)
- Compare the residual error of the simple CER to the residual error after application of the complexity factors
- Perform some validation of the results

Calculating Error

The Test Statistic

- For the Power Equation with Multiplicative Residuals, i.e.,

$$Y = aX^b \varepsilon$$

CER Equation Form, Derived thru LTOLS

- The Regression Estimates Vary Based on the Variation of the Residual

$$\varepsilon = \frac{Y}{aX^b}$$

Use the Ratio of Actual to Estimated Cost to Develop Complexity Factors

- Also Common to Adjust This to Treat ε as a Percentage, i.e., Set

$$Y = aX^b(1+\varepsilon)$$

$$\varepsilon = \frac{aX^b - Y}{aX^b} = \left(\frac{Estimate - Actual}{Estimate}\right)^2$$

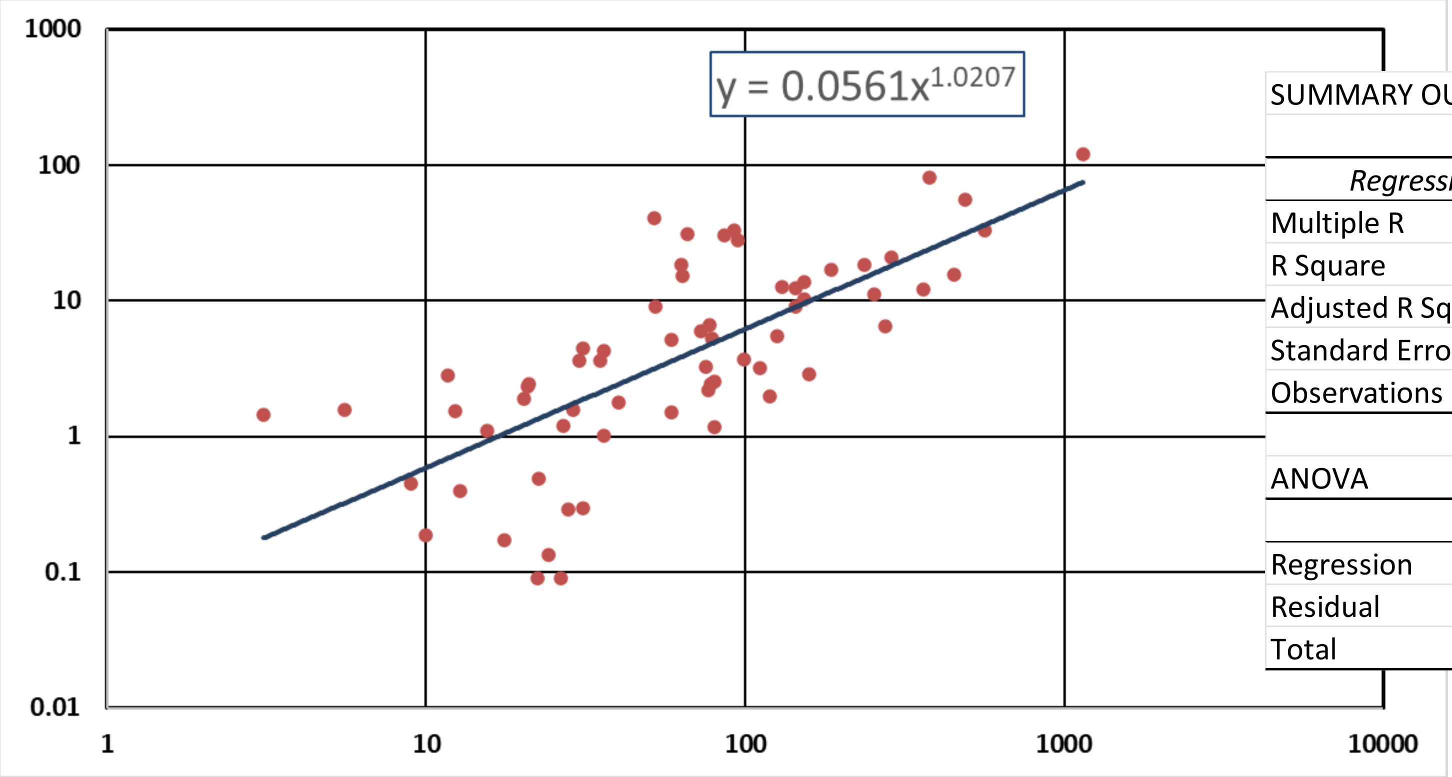
Goodness of Fit Calculated using the Minimum Unbiased Percentage Error (MUPE) Ratio, Squared for Each Data Point

- Actual Cost = Estimate +/- Percentage of Estimate

Stolen from Christian Smart's paper "Cutting the Gordian Knot: Maximum Likelihood Estimation for Untransformed Lognormal Error

The Simple CER

- Escaped from NASA with a dataset of NAFCOM cost and weight for a spacecraft subsystem (to remain nameless)
- Used the dataset to develop a weight-based CER



SUMMARY OUTPUT					
Regression Statistics					
Multiple R	0.723				
R Square	0.523				
Adjusted R Square	0.515				
Standard Error	1.162				
Observations	65				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	93.149	93.149	69.037	1.02981E-11
Residual	63	85.004	1.349		
Total	64	178.153			

Mean MUPE (MMUPE) = 5.720
Average Act/Est Ratio = 1.820

Develop the Complexity Factors

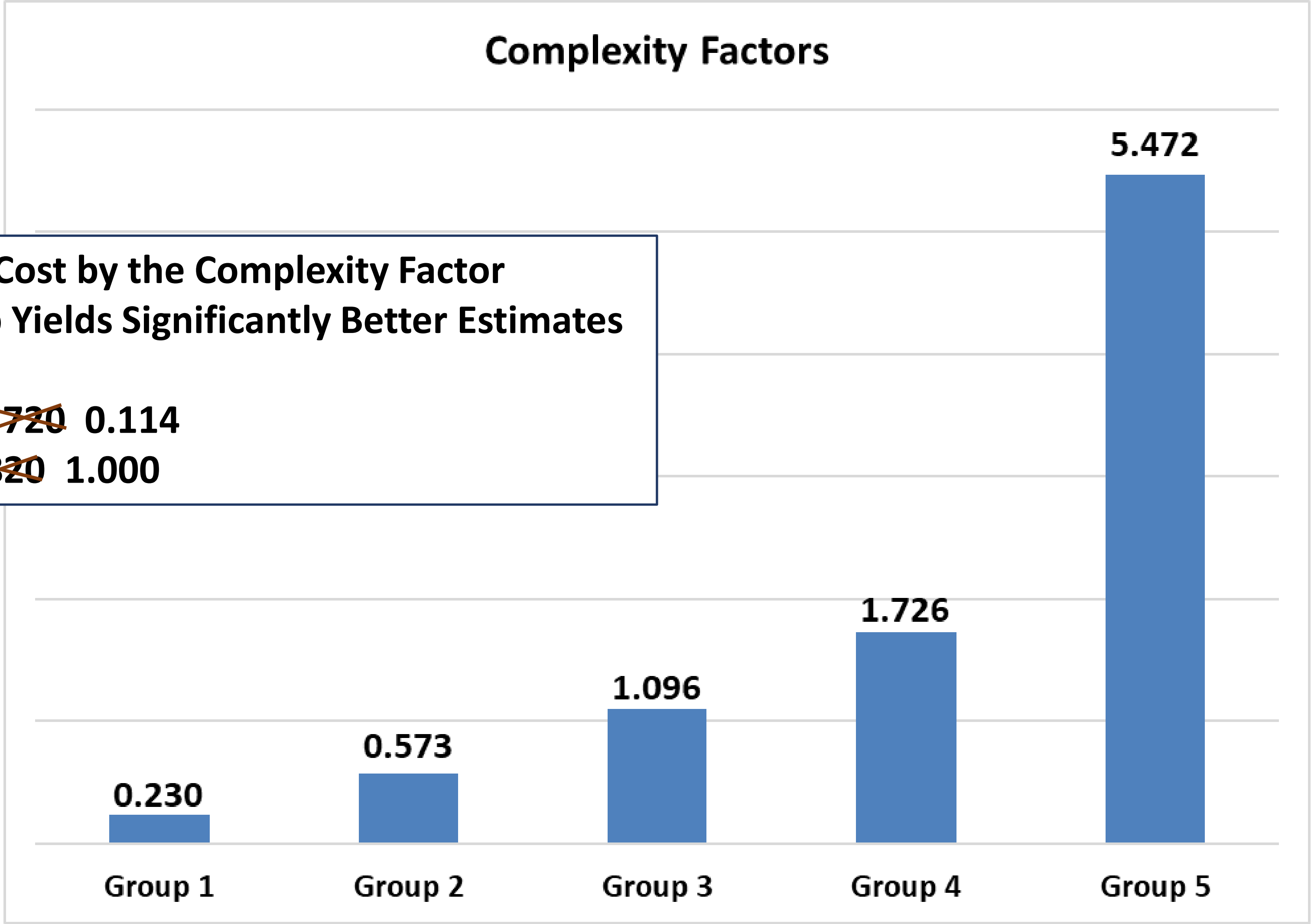
Actual/Estimated Cost Ratios	
0.057	
0.068	
0.092	
0.160	
0.166	
0.171	
0.239	Average = 0.230
0.268	
0.295	
0.319	
0.358	
0.373	
0.421	
0.462	
0.464	
0.467	
0.513	
0.515	
0.523	
0.526	Average = 0.573
0.544	
0.609	
0.695	
0.697	
0.700	
0.735	

1. **Calculate the Actual/Estimated cost ratios**
2. **Sort the data set from smallest to largest ratio**
3. **Segregate into 5 equal groups of 13 each (65/5=13), starting with the smallest ratio**
4. **Take the average of the cost ratios for each of the 5 groups**
5. **Result is 5 complexity factors**

Complexity Factors for Spacecraft Subsystem X

Multiplying the Estimated Cost by the Complexity Factor Appropriate for that Group Yields Significantly Better Estimates

Mean MUPE (MMUPE) = ~~5.720~~ 0.114
Average Act/Est Ratio = ~~1.820~~ 1.000



Interpretation

- **What this method is not:**
  - Not a way to model the regression error (noise)
  - Not an assessment of the complexity of the underlying data points nor does this method tell you how to assess the complexity of a new system
- **What this method is:**
  - A way to translate the regression error (noise) into adjustment factors
  - A way to provide guardrails (or boundaries) for adjusting an estimate
  - An alternative way to account for estimating error in a risk analysis
  - Enables a serial approach to estimating (objective approach first, judgment second) that when applied correctly will result in more consistent estimates

Testing

- **Evaluate the methodology for stability and usefulness**
- **Approach: use a type of cross-validation**
  1. Use the RAND() function in Excel to assign a random number to each data point and Copy-Paste-Values to freeze the assignment
  2. Sort the data point by the random numbers from smallest to largest
  3. Starting at the top, take the first 13 data points and assign to Test Set #1, the second 13 and assign to Test Set #2, and so on, until all 65 data points are assigned to a Test Set
  4. Remove Test Set #1 from the data set, use the remain 52 data points as the training set
  5. Us the training set to develop a simple weight-based CER, develop new complexity factors using the approach on slide 13
  6. Use the simple CER to estimate the cost of the test set data
  7. Determine the effectiveness of the new complexity factors on the test set data using three different assumptions (see next chart)
  8. Repeat steps 4 through 7 for the other 4 groups

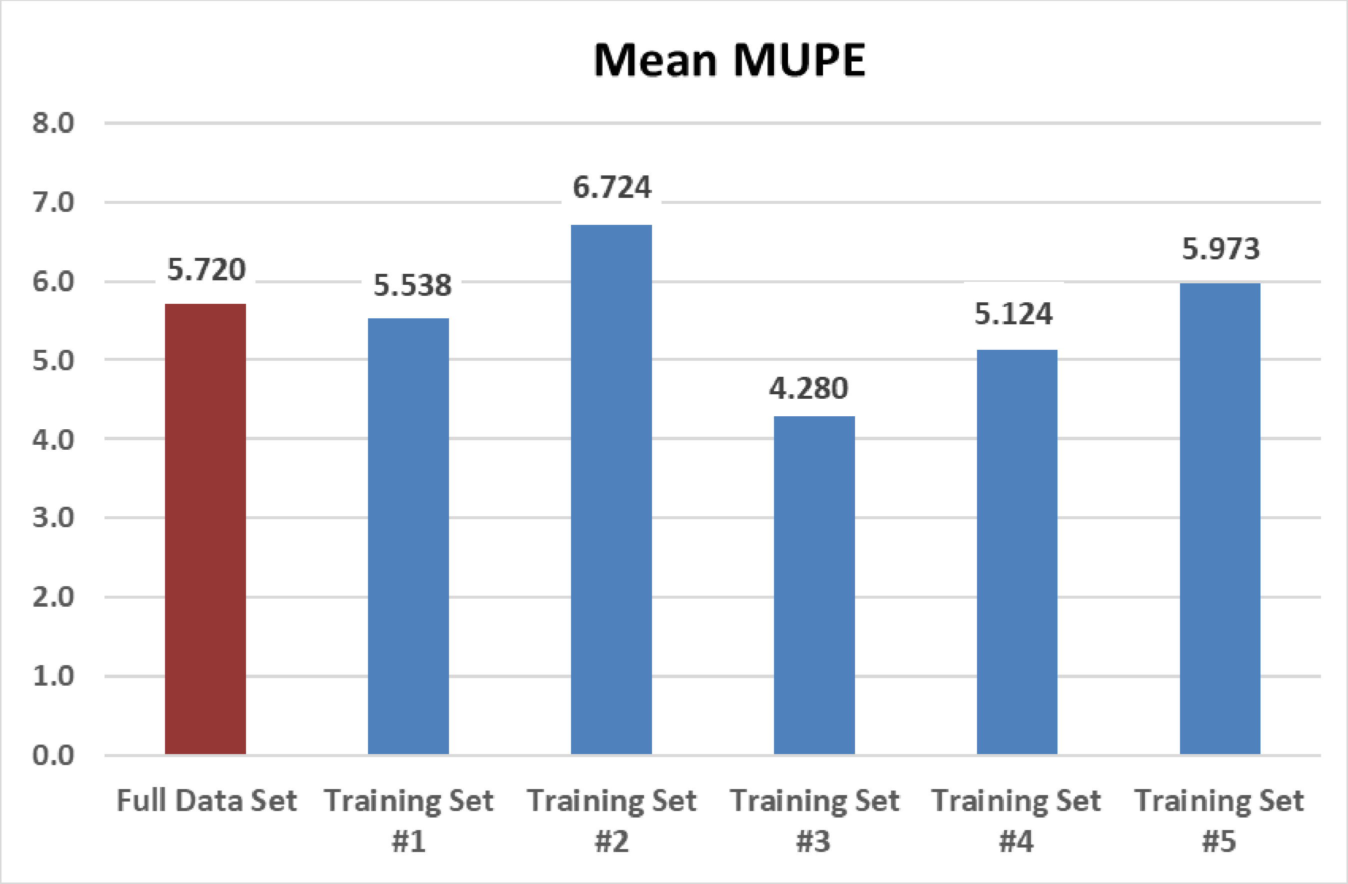
Tests for Stability & Usefulness

- **Applied the new complexity factors derived from the training data set using three different assumptions**
  - Hit the Nail on the Head
  - Random Guess
  - In the Ball-Park
- **Nail on the Head – picks the complexity factor based on the actual/estimated cost ratio for that data point – assumes you pick the right complexity adjustment**
- **Random Guess – assumes your complexity factor choice is completely random – uses the average of all 5 complexity factors**
- **In the Ball-Park – assumes that your choice is close (intelligent guess), that you will get it right or almost right – uses composite complexity factors (calculation on next chart)**

In the Ball-Park

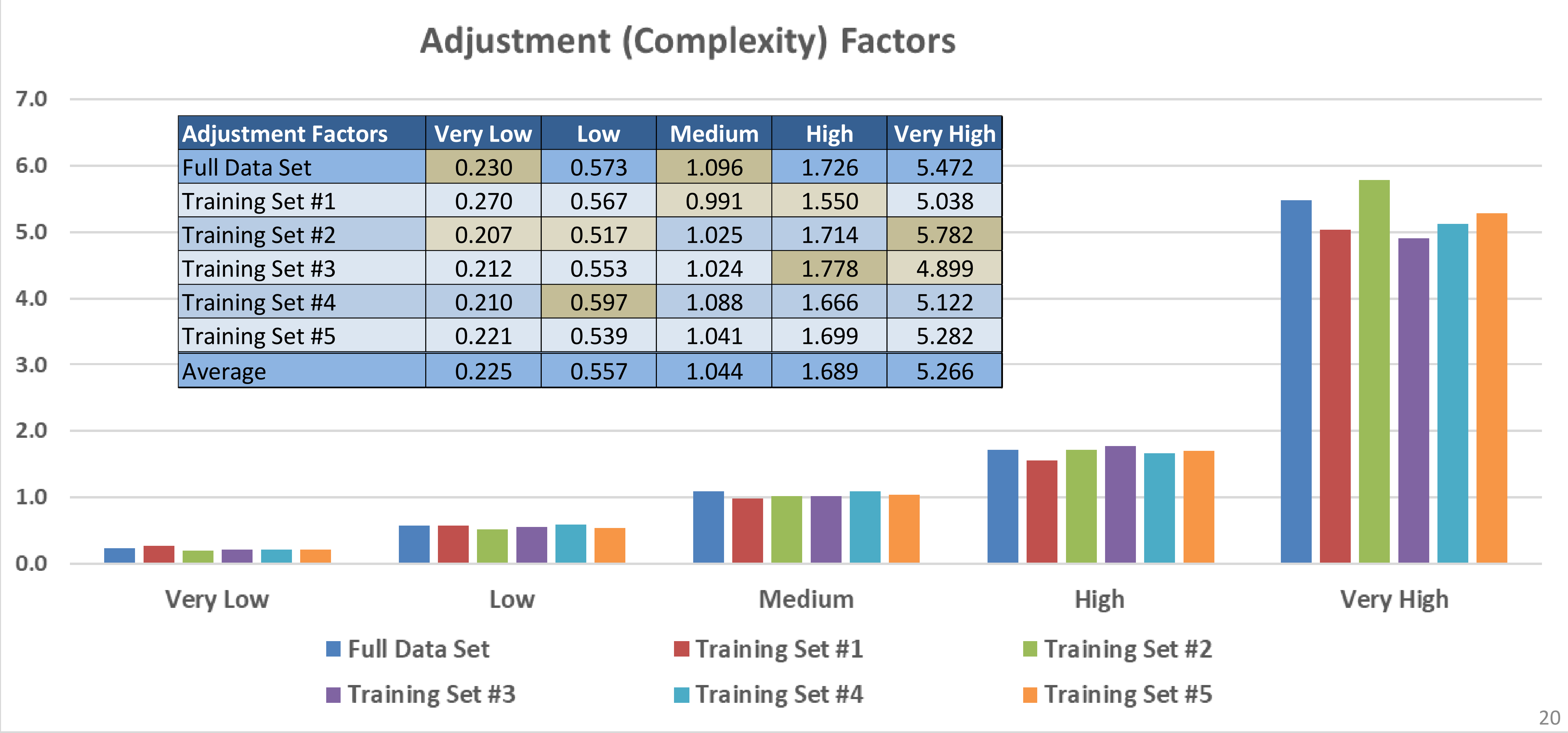
If the Real Adjustment Factor is:	The Applied Adjustment Factor is:
Factor #1	50% Factor #1 + 50% Factor #2
Factor #2	33.3% Factor #1 + 33.3% Factor #2 + 33.3% Factor #3
Factor #3	33.3% Factor #2 + 33.3% Factor #3 + 33.3% Factor #4
Factor #4	33.3% Factor #3 + 33.3% Factor #4 + 33.3% Factor #5
Factor #5	50% Factor #4 + 50% Factor #5

Results – Simple CER



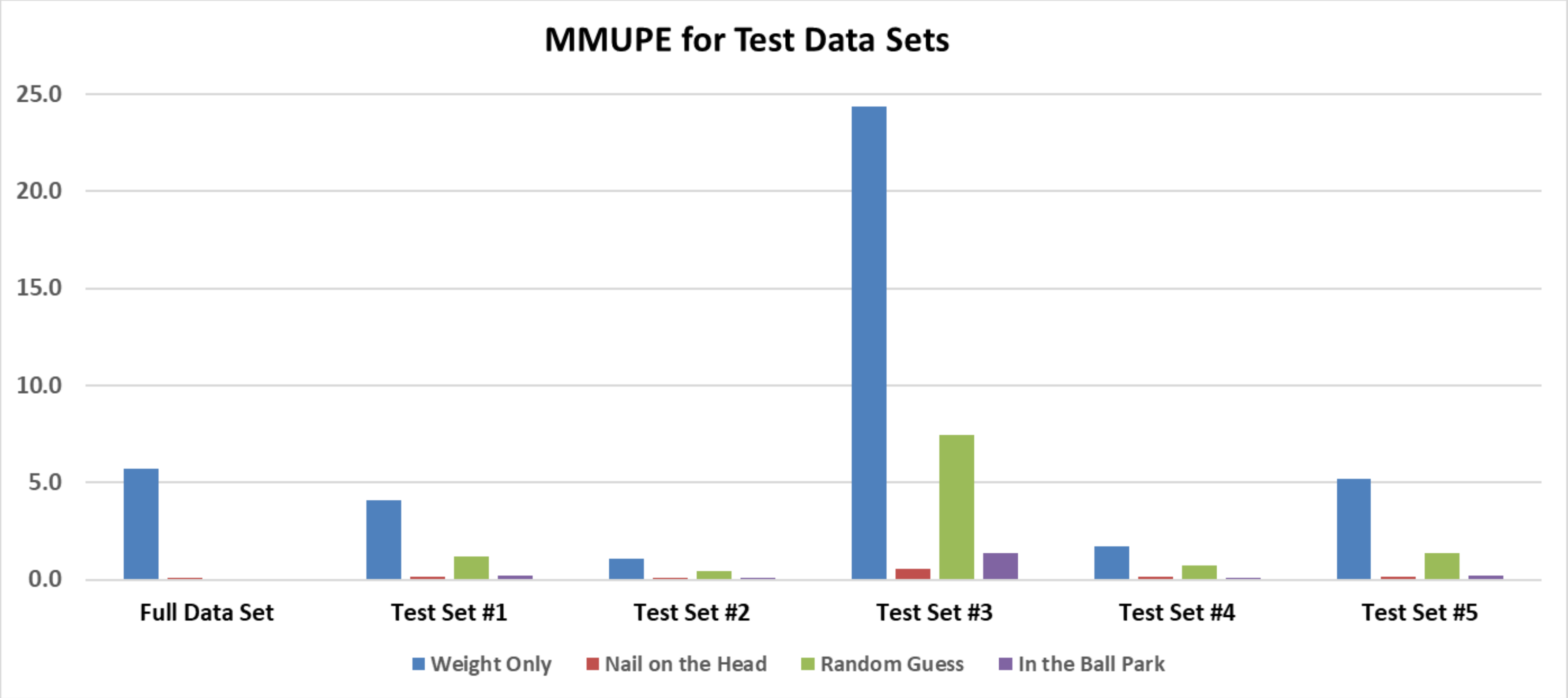
Weight-Based CERs	a-value	b-value	r^2
Full Data Set	0.056	1.021	0.523
Training Set #1	0.062	1.006	0.567
Training Set #2	0.049	1.063	0.492
Training Set #3	0.039	1.078	0.528
Training Set #4	0.069	0.995	0.530
Training Set #5	0.065	0.977	0.502

Results – Adjustment Factors



Adjustment Factors	Very Low	Low	Medium	High	Very High
Full Data Set	0.230	0.573	1.096	1.726	5.472
Training Set #1	0.270	0.567	0.991	1.550	5.038
Training Set #2	0.207	0.517	1.025	1.714	5.782
Training Set #3	0.212	0.553	1.024	1.778	4.899
Training Set #4	0.210	0.597	1.088	1.666	5.122
Training Set #5	0.221	0.539	1.041	1.699	5.282
Average	0.225	0.557	1.044	1.689	5.266

Results – Test Data MMUPE



MMUPE	Weight Only	Nail on the Head	Random Guess	In the Ball Park
Full Data Set	5.720	0.114		
Test Set #1	4.075	0.143	1.208	0.236
Test Set #2	1.100	0.075	0.436	0.097
Test Set #3	24.379	0.540	7.476	1.386
Test Set #4	1.720	0.154	0.747	0.107
Test Set #5	5.195	0.130	1.388	0.209

Observations

- Data driven approach to developing complexity factors
- Requires no judgment on the part of the analyst to pre-judge complexity of the model data (eliminates confirmation bias!)
- Stability is a concern – perhaps could be addressed using a re-sampling technique and taking the average values
- Technique will not work for small data sets

A Final Thought*

True knowledge is to be aware of one's ignorance.
Rudolf Virchow, letter to his father, ca. 1830s

* Quote taken from "Song of the Cell" by Siddhartha Mukherjee