

Automated Cost Estimating Integrated Rooks

Everything you wanted to know about Learning with Rate (but were afraid to ask)

Tecolote Research, Inc.

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Abstract

- Most cost analysts are familiar with learning curves and many use ACE's basic learning capabilities in their estimates. Many still have questions about ACE's advanced learning capabilities, such as Rate adjusted and broken learning, and when to use them.
- This presentation takes a practical look at learning curves. It discusses what learning curves mean, where they come from, and explains when and how to use adjusted or modified methods (e.g., broken learning, rate adjusted learning). When does using a rate term make sense based on what is going on in a manufacturing process and how do you calculate it? What scenarios exist where broken learning should be used? Come to this presentation to learn the answers to these questions and more.





What is Learning?

- What do learning curves mean?
- Where do they come from?

Learning with Rate

Other Rate Curve Considerations





Introduction

Production Start



Early Production



Peak Efficiency



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A learning curve is a mathematical model (equation) of productivity improvement in a manufacturing process.

1/27/2009





Introduced in 1936 by T.P. Wright

- Based on production of airplane assemblies
- Standard Model: The direct labor man-hours necessary to complete a unit of production will decrease by a constant percentage each time the production quantity is doubled





Unit vs. Cum Avg Theory

Two common theories of learning

- Unit As the total quantity of units doubles, the cost per **unit** goes down by a constant percentage
- Cum Average As the total quantity of units doubles, the average cost for x units goes down by a constant percentage
- Y = A * x ^b, where
 - Y = Unit or Cum Average Cost
 - A = First Unit Cost (T_1)
 - x = Unit Number
 - b = Learning Curve Exponent = In(Slope)/In(2)

Example: A 5% unit cost decrease corresponds to a 95% slope



Unit vs. Cum Avg Theory

Example 90% unit curve: doubling the unit number leads to a 10% decrease in the unit cost





Unit Curves & Lot Costs

- Unit Cost: C_i = T₁ * (i) ^ b
- Lot Cost of units 10 thru 20:
 - $C_{10} + C_{11} + \dots C_{20}$
 - Approximated by area under the curve for large lots





Where And Why?

Regression model from historical data

- Historical cost reporting (e.g., CSDR, CPR) for sequential production lots
 - Cost reporting by contract
 - CSDR Report Types
 - 1921: recurring, non-recurring, and total dollars
 - 1921-1: hours and \$ visibility by functional category (e.g., manufacturing)
 - 1921-2: Progress Curve; unit-by-unit or lot-by-lot detail
- Contractors may have more detailed or "unit" data

Typical Applications

- Use earlier lot data to project future lots for a system
- Use learning curve from analogous system to estimate new system
- More advanced: pooled learning regression



Cost Reports: 1921

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Cost Reports: 1921-2

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Data Sources: DACIMS (DCARC)

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⊕ AGM-114 (Interim Hellfire)	1) 🖻 🤴	(H) 1921 (6/30/1991), AGM-88 - N00019-88-C-0156 (Texas Instruments, Inc.)	Air Vehicle Lot 10
AGM-114 (Longbow Hellfire)	1) 🚔 🤑	(H) 1921 (6/30/1991), AGM-88 - N00019-88-C-0156 (Texas Instruments, Inc.)	Air Vehicle Lot 9
taria AGM-122 (Sidearm)	1) 🖻 🗒	(H) 1921 (9/30/1988) AGM-88 - N00019-86-C-0326 (Texas Instruments Inc.)	Air Vehicle Lot 8
GM-131 (Short Range Attack Missile (SF GM-136 (Tacit Rainbow)		(H) 1024 (Storig Depart (12/21/1020) A CM 92 N00010 96 C 0226 (Texas instruments, Inc.)	Air Vehicle Lot 7
⊕ AGM-154 (Joint Standoff Weapon (JSOW)		■ [H] 1921 Final Report (12/51/1969), AGW-66 - 1000019-66-C-0526 (Texas instruments, Inc.)	Air Vehicle Lot 8
GM-158 (Joint Air-To-Surface Standoff M GM-45 (Shrike)		(H) 1921 Final Report (12/31/1990), AGM-88 - N00019-86-C-0326 (Texas Instruments, Inc.)	Air Vehicle Lot 0
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Data Sources: ACDB (ODASA-CE)

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	R	T	N	A	System Type	System	^ Model	Contract Number	Task	Source
	R	T	N	А	AIR-TO-SURFACE	ALCM	AGM-86A	F33657-72-C-0923	ALCM, AGM-86A, AD/ALCM, AIR VEHICLE/CAE (BOEING	CDSR
	B	T	N	Α	AIR-TO-SURFACE	ALCM	AGM-86A	N00019-78-C-0195	ALCM, AGM-86A (MISSILE)	CDSR
	B	T	N	А	AIR-TO-SURFACE	ALCM	AGM-86A	N00019-78-C-0194	ALCM, AGM-86A, FSED, {GENERAL DYNAMICS} 78-0194	FCHR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-80-C-0558	HARM, AGM-88A, lot #-1 (MISSILE]	FCHR
	B		N		AIR-TO-SURFACE	HABM	AGM-88A	N00019-87-C-0088	HARM, AGM-88A, FY'87 ROCKET MOTOR PRODUCTION	FCHR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-85-C-0044	HARM, AGM-88A, lot #-5 (MISSILE]	FCHR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-85-C-0447	HARM, AGM-88A, lot #-6 (MISSILE]	FCHR
	B		N	Α	AIR-TO-SURFACE	HARM	AGM-88A	N00019-74-C-0410	HARM, SUBPHASE I, AGM-88A, WEAPON SYSTEM SUBF	CDSR
	B		N	А	AIR-TO-SURFACE	HARM	AGM-88A	N00019-74-C-0410	HARM, SUBPHASE II (TEXAS INSTRUMENTS) 74-0410	CPR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-84-C-0145	HARM, AGM-88A, lot #-4 (MISSILE]	FCHR
	B		N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-87-C-0088	HARM, AGM-88A, FY'87 ROCKET MOTOR PRODUCTION	CDSR
	B		N	Α	AIR-TO-SURFACE	HABM	AGM-88A	N00019-80-C-0542	HARM, SUBPHASE III, {TEXAS INSTRUMENTS} 80-0542	CPR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88A	N00019-82-C-0005	HARM, AGM-88A, lot #-2 (MISSILE]	FCHR
	B	T	N		AIR-TO-SURFACE	HABM	AGM-88A	N00019-83-C-0001	HARM, AGM-88A, lot #-3 (MISSILE]	FCHR
	B	T	N		AIR-TO-SURFACE	HARM	AGM-88B	N00019-88-C-0156	HARM, AGM-88B, lot #-9 (MISSILE)	CDSR
	B	T	N		AIR-TO-SURFACE	HABM	AGM-88B	N00019-86-C-0326	HARM, AGM-88B, lot #-8, ctr #-2 (MISSILE)	CDSR
	B	T	N		AIR-TO-AIR	SPARROW	AIM/BIM-7M	N00019-86-C-0147	SPARROW, AM/RM-7M, LOT #-7 (MISSILE) RAYTHEON	FCHR
	B	T	N		AIR-TO-AIR	SPARROW	AIM/BIM-7M	N00019-86-C-0147	SPARROW, AM/RM-7M, LOT #-7 (MISSILE) RAYTHEON	CDSR

Select WBS

Select Resources Filter Available Data Step 1: Select a standard WBS Select Resources Filter on - System Type MISSILES-EXPANDED 881B 15. QUALITY CONTROL, OVERHEAD 16. QUALITY CONTROL, OTHER DIRECT CHARGES 🔽 Template WBSs Only Find and Select 17. QUALITY CONTROL, TOTAL DOLLARS Step 2: Select standard WBS item 18. MANUFACTURING, DIRECT LABOR HOURS Exclude Selected Items 1.0 MISSILE SYSTEM 19. MANUFACTURING, DIRECT LABOR DOLLARS 🖮 🗹 1.1 AIR VEHICLE 20. MANUFACTURING, OVERHEAD SysType 1.1.1 PROPULSION 21. MANUFACTURING, MATERIAL 🗹 AIR-TO-AIR 1.1.1.1 STAGE I 22. MANUFACTURING, OTHER DIRECT CHARGES M AIR-TO-SURFACE 1.1.1.1.1 ROCKET MOTOR/BOOSTER 23. MANUFACTURING, TOTAL DOLLARS BATTLEFIELD SPRT/SPT ANTIARMOR 24. PURCHASED EQUIPMENT 1.1.1.1.2 ENGINE GUIDED BOMB UNIT 1.1.1.1.3 INTEGRATION AND ASSEMBLY 25. MATERIAL OVERHEAD PRECISION GUIDED MUNITIONS 1.1.1.1.4 OTHER 26. OTHER COSTS NOT SHOWN ELSEWHERE SURFACE-TO-AIR 🗹 🎫 27. TOTAL COST LESS G & A -____ 1.1.1.2 STAGE II SURFACE-TO-SURFACE 1.1.1.2.1 ROCKET MOTOR/BOOSTER 28 G % A 1.1.1.2.2 ENGINE 29. TOTAL COST PLUS G&A > < 1.1.1.2.3 INTEGRATION AND ASSEMBLY 30. FEE OR PROFIT 1.1.1.2.4 OTHER 31. TOTAL PRICE (SUM OF LINES 29 & 30) A A A A ATUER ATUA > >

1/27/2009

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Learning Curves in CO\$TAT

Variables	Variable ID	TASK1	TA SK2	TA SK3	TA SK4	TASK5	TA SK6	TASK7	TA	
		Johns Missilu	Johns Wissile	Johns Missile	Johns Miesile	Johns Missile	Johns Missile	Johns Miss	ile Johns	
Task		Lot 1	Lot 1	Lot 2	Lot 2	Lot 3	Lot 4	Lot	5	
\$ Unit, HR Unit (Infl Index: 09/10/2004)		ŞK, KHR	/ SK, KHR	\$K, KHR	SK KHR	\$K, KHR	SK, KHR	SK, KH	IR \$	
Base Year		2000	2000	2000	2000	2000	2000	20	00	
Total % Spent (ACWP/LRE)		95.15	94	53.65	99.32	55.03	93.64	82.	83	
System Buy Quantity	QTY	107	75	225	200	200	534	3	72	
System First Unit	FU	129	1	236	76	76	461	2	76	
System Last Unit	LU	235	75	460	275	275	194	6	47	
								0		
Unit Cost	UC	1202	822	644	613	504	101140	5	26	
							10190	1		
1.1 AIR VEHICLE						9 14				
R,27. TOTAL COST LESS G & A				DOM	h = (1) + (1)	5				
2.0 PRODUCTION	RecCst	128647	61685	5 214821	22563	100784	250504	1955	19	
TOT,27. TOTAL COST LESS G & A										
2.0 PRODUCTION		239795	72822	193834	145876	119741	314377	2494	15	
TECHNICAL DATA FOR 1.1 AIR VEHICL	E									
DIAMETER (in)										
LENGTH (in)										1
RANGE - EFFECTIVE RANGE (km)	<high></high>					<u>C</u> O\$TA	T <u>D</u> ata <u>W</u> in	dow <u>H</u> elp	Ado <u>b</u> e PE)F
RANGE - MSL FLYOUT (MAX) (mi)						🖉 N	ew Dataset	_	AZI	Alla 🚮 100%
SPAN - MAX (in)		/							Z* A*	
VELOCITY - MAX (ft/s)						D	ataset <u>P</u> roperties	S 0	.00	💷 🖂 - 🖄
WEIGHT (lb)						P	air <u>w</u> ise Analysis			
YEAR IN SERVICE									_	
_			-	1 Aug. 1		<u> </u>	ases		E	F
				1 N N.		A	nalyze	•	<u>L</u> inear.	
vvnat would	expl	ain th	IS?		10.00	c	riteria		Log Lin	ear
-	-	T			12	PI	rediction <u>I</u> nterval	s	Non Lin	ear
						R	eport <u>S</u> tyles		Le <u>a</u> rnin	g Curve
			1 - E			Н	elp		<u>U</u> nivari	ate
						A	utomated <u>T</u> utoria	al	<u>B</u> eta	
					-		bout		13	
							<u>b</u> out			1 2
						C	lose		7	5 4

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Learning Curves in CO\$TAT

II. Scatter Plot

UC Vs. QTY Correlation Coefficient = -0.7524 1400.0000 1200.0000 1000.0000 800.0000 3 600.0000 400.0000 200.0000 0.0000 0 100 200 300 400 500 600 700 800 300 QTY

Learning Analysis for Dataset Missile AV, UnitCurve Sunday, January 18, 10:12 pm

I. Model Form and Equation Table

Model Form.	Unweighted Learning Corve (Unit Theory)
Number of Observations Used:	16
Equation in Unit Space:	UNIT_COST = 3659 * UNIT_NUM ^ (-0.3345)
T1:	3659.4126
Quantity Slope:	79.31%
Dependent Variable:	ReoCst
Quantity Variable:	First Unit and Last Unit Variables

II. Fit Measures (in Fit Space)

Coefficient Statistics Summary

		Std Dev of		T-Statistic	Prob Not
Variable	Coefficient	Coef	Beta ¥alue	(Coef/SD)	Zero
Intercept	8.2051	0.3426		23.9470	1.0000
CUM_QTY	-0.3345	0.0509	-0.8692	-6.5775	1.0000

Dependent Variable VUC

Goodness-of-Fit Statistics

		R-Squared	Pearson's
Std Error (SE)	R-Squared	(Adj)	Corr Coef
0.2808	75.55%	73.81%	0.8692

Summary of Predictive Measures

Average Actual (Avg Act)	464.3039
Standard Error (SE)	202.5707
Root Mean Square (RMS) of % Errors	26.58%
Mean Absolute Deviation (Mad) of % Errors	22.21%
Coef of Variation based on Std Error (SE/Avg Act)	43.63%
Coef of Variation based on MAD Res (MAD Res/Avg Act)	25.50%
Pearson's Correlation Coefficient between Act & Pred	72.90%
Adjusted R-Squared in Unit Space	42.69%

100

 $Y = g_{1}$



Learning Curves in CO\$TAT

V. Learning Curve Data & Predicted LAC

			Lot Plot			Predicted
Lot #	First Unit #	Last Unit #	Point	LOT_QTY	Actual LAC	LAC
1	129.0000	235.0000	178.4265	107.0000	1202.3067	646,195
2	1.0000	75.0000	24.4845	75.0000	822.4667	1255.647:
3	236.0000	460.0000	339.6967	225.0000	643.6500	520.997
4	76.0000	275.0000	161.6399	200.0000	612.8170	667.907
5	76.0000	275.0000	161.6399	200.0000	503.9210	667.907
6	461.0000	994.0000	704.9480	534.0000	469.1093	408.118
7	276.0000	647.0000	444.1177	372.0000	525.5888	476.322
8	995.0000	1444.0000	1210.1901	450.0000	405.0014	340.633
9	648.0000	1097.0000	859.3814	450.0000	436.8199	381.955
10	1445.0000	1984.0000	1704.9859	540.0000	371.9586	303.735
11	1098.0000	1367.0000	1229.2017	270.0000	321.4575	338.862
12	1985.0000	2425.0000	2200.0840	441.0000	331.7447	278.909
13	2426.0000	3274.0000	2835.8613	849.0000	214.2241	
14	3275.0000	3787.0000	3526.8506	513.0000	217.4960	
15	2522.0000	3290.0000	2894.6369	769.0000	171.2030	
16	3788.0000	4201.0000	3992.1126	414.0000	179.0970	140





1/27/2009



Learning Curves in ACE

	WBS/CES Description	n	Approp	Unique ID	BASELIN E	Phasi Metho	od Ec	uation / Throughput				
	ARMY CES (MISSILE)				\$ 244.038 *							
	RDT&E FUNDED ELEMEN	NTS	RDTEA		\$ 107.067 *							
	DEVELOPMENT ENGIN	EERING	RDTEA	DE\$	\$ 41.941 *							
	AIR VEHICLE (Hardwa	re)	RDTEA		\$ 20.626 *		BE	HW_LRATE\$*H	W_SM			
	AIR VEHICLE (Software	e)	RDTEA		\$ 21.315 *		BE	SW_LRATE\$ * S	W_SM			
	PROTOTYPE MANUFACTURING		RDTEA	PROTO\$	\$ 25.515 *							
	AIR VEHICLE		RDTEA	AV\$	\$ 22.187*		%					
	Component 1		RDTEA		\$ 1.962 *			COMP1\$*F	ProtoQ			
	Component 2		RDTEA		\$ 17.675 *			COMP2\$ * P	rotoQ2			
	COTS Component		RDTEA		\$ 2.550 *			COMP3\$ * F	ProtoQ			
	INTEG/ASSY/TEST/CHKOUT		RDTEA		\$ 3.328 *		%	11	* AVR			
	SYSTEMS ENGINEERIN	IG/MGMT	RDTEA		\$ 25.499 *		Title:	AIR VEHICLE		Phasing M	1ethod: 🖪 🔜	
	OTHER RDT&E		RDTEA		\$ 14.112 *							
							Unique ID:			🛛 🛛 🔠 Pha	ising Wizard	
	PROCUREMENT FUNDED ELEME				\$ 94.234 *		Equation/Th	roughput:				
	RECURRING PRODUCT	ION	MIPA		\$ 90.911 *		[Similar Risł	Bounds] 3659				
	MANUFACTURING		MIPA		\$ 85.590 *							
	AIR VEHICLE		MIPA		\$ 85.590 *						CEB Lib	
	INTEG/ASSY/TEST	CHKOUT	MIPA		\$ 0.000 *							
	RECURRING ENGINE	ERING	MIPA		\$5.320*		·					
			Ъ., н		25	7	Summary	FY Inputs Leamin	9 Spread Total	RI\$K Defs		
		T ^ T			1.153	1 X	- Learnin					
_	CO\$	IAI					Theory					
Model F	orm:	Unveighted	l Learning O	urve (Unit Theor	y) //		Theory					
Number	of Observations Used:	16					D: 01	0				
Equation	n in Unit Space:	UNIT_COS	T = 3659 ° U	NIT_NUM^(-0.3	3345]		Phor Gt	/: U	Shra Ky	/wa:	Shrd	
TI: Ousetite	: 3659.4126				_							
Depende	nendent Variable: 73.31%						Buy Qty		Rate:			
Quantite	Variable:	First Unit a	nd Last Unit	Variables								
							Slope (3	J /9.3075	Rate Sl	ope (%):		
				-	1							
							Ref Cos	t: UC 🗸 Unit I	Number: 1	Last Unit:		





Rate-Adjusted Learning

Used to capture variations in production rate

- Unit costs may decrease more quickly than expected during build-up of production line
- Unit costs may slightly decrease during peak efficiency
- Unit costs may increase during ramp-down as number of units being built per year decreases

Commonly used for long production lines (many years, high total quantities)

- Typical for Aircraft and Missiles
- Rate may dominate learning with vehicles
- Others?



Rate-Adjusted Learning

- Typical Model: Y = A * x ^b * r ^c, where
 - Y = Unit or Cum Average Cost
 - A = First Unit Cost (assumed rate of 1)
 - x = Unit Number
 - b = Learning Curve Exponent = In(Slope)/In(2)
 - r = Annual Production Rate
 - c = Rate Learning Exponent = In(Rate Slope)/In(2)
- What does "assumed rate of 1" mean?
 - Set unit number (x) and rate (r) to 1.
 - Yields Y=A so the first unit cost A is based on r=1.
- What other options are there for the rate term (r)?
 - Why pick annual production rate?
 - Do we actually use "annual production rate"?



Rate-Adjusted Learning

- Difficult to fit a Rate Curve with just the early lots
 - Early in production cycle, learning term dominates
- What if you just have data on the first couple productions lots and you want to generate a learning curve to estimate the future lots?
 - Assume a fixed rate slope?
 - Fit a rate-adjusted curve to data for analogous system (adjust heuristically to the data for your system)
 - Pooled Regression

What if you just have data for 1 lot and want to assume learning or learning with rate (in ACE)?



Learning with Rate in CO\$TAT

Assu	Ime	а
Rate	Slo	pe

Searning Curve Model			
Specifications Results			
Case Name	Other Variables		Fitting a
UnitWRate	First Unit: FU	•	rate curve
	Last Unit: LU	•	Tale cuive
Dependent Variable	Bate:	_	
Name: RecCst			
Type: LTC 💌		<u> </u>	
Theory:	- Independent Variables -		
	Name No	ot Used Independ Dummy	
Hate Slope:			
Ridge Parameter:			
Error Term			
Multiplicative C Additive C MUPE MUPE M			
Maximum Iterations:			
Method:			
✓ ♠ // Pa ▼	<u>0</u> K	<u>C</u> ancel <u>H</u> elp	
		1.1	

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Learning with Rate in CO\$TAT

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I. Model Form and Equation Table

Model Form:	Unweighted Learning Curve (Unit Theory)				
Number of Observations Used.	10				
Equation in Unit Space:	UNIT_COST = 5964 _ UNIT_NUM ^ (-0.2713) * QTY ^ (-0.1555)				
11:	5964.3377				
Quantity Slope:	82.86%				
Bate Slope:	89.78%				
Dependent Variable:	RecCst				
Quantity Yariable:	Hirst Unit and Last Unit Variables				

II. Fit Measures (in Fit Space)

Coefficient Statistics Summary

		Std Dev of		T-Statistic	Prob Not
¥ariable	Coefficient	Coef	Beta ¥alue	(Coef/SD)	Zero
Intercept	8.6936	0.7995		10.8732	1.0000
CUM_QTY	-0.2713	0.1114	-0.7020	-2.4348	0.9700
QTY	-0.1555	0.2355	-0.1904	-0.6604	0.4795

Goodness-of-Fit Statistics

Std Error (SE)	R-Squared	R-Squared (Adj)	Pearson's Corr Coef
0.2853	76.55%	72.95%	0.8750

Multicollinearity Analysis

Indep Variables	Indiv R-Sqr (%)	F-Stats	Prob Related to Other Vars	Indiv R- Sqr/Model R-Sqr	Flags	
CUM_QTY	78.30%	50.5216	1.0000	1.0228	X /	¥
QTY	78.30%	50.5216	1.0000	1.0228	Х	

X = The indicated independent variable could be harmfully correlated to the other independent variables, i.e., it has a nearly better fit using the remaining independent variables than the dependent variable.

Multicollinearity is a common problem. Why?

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Learning with Rate in CO\$TAT

The Art of Ridge Regression





Learning with Rate in ACE

Without Ridge Parameter

Model Form:	Unweighted Learning Curve (Unit Theory)				
Number of Observations Used:	16				
Equation in Unit Space:	UNIT_COST = 5964 * UNIT_NUM ^ (-0.2713) * QTY ^ (-0.1555)				
T1:	5964.3377				
Quantity Slope:	82.86%				
Rate Slope:	89.78%				
Dependent Variable:	RecCst				
Quantity ¥ariable:	First Unit and Last Unit Variables				

With Ridge Parameter

I. Model Form and Equation Table

Model Form:	Unweighted Learning Curve (Unit Theory)
Number of Observations Used:	16
Equation in Unit Space:	UNIT_COST = 6579 * UNIT_NUM ^ (-0.2237) * QTY ^ (-0.2263)
T1:	6579.3258
Quantity Slope:	85.64%
Rate Slope:	85.48%
Ridge Parameter Specified:	0.0800
Dependent Variable:	RecOst
Quantity Variable:	First Unit and Last Unit Variables

II. Fit Measures (in Fit Space)

Coefficient Statistics Summary

Ridge Regression "Fixes" Significance of Rate Term

			Std Dev of		T-Statistic	Prob Not
	Variable	Coefficient	Coef	Beta Value	(Coef/SD)	Zero
	Intercept	8.7917	0.8060		10.9084	1.0000
	CUM_QTY	-0.2237	0.0688	-0.5789	-3.2532	0.9937
>	QTY	-0.2263	0.1453	-0.2771	-1.5572	0.8567

Summary of Predictive Measures

Average Actual (Avg Act)	464.3039
Standard Error (SE)	188.9897
Root Mean Square (RMS) of % Errors	26.80%
Mean Absolute Deviation (Mad) of % Errors	23.47%
Coef of Variation based on Std Error (SE/Avg Act)	40.70%
Coef of Variation based on MAD Res (MAD Res/Avg Act)	24.99%
Pearson's Correlation Coefficient between Act & Pred	77.33%
Adjusted R-Squared in Unit Space	50.11%





Pooled Regression

- Consider developing a composite learning curve across multiple systems.
 - Include one or more production lots from different systems.
 - Introduce one or more technical characteristics to stratify data.



Example: UC = (T1 * WGHT ^{b1}) * Unit# ^{b2} * Rate ^{b3}

Pooled Regression In CO\$TAT

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600

QTY

800

400

Variables	Variable ID	TASK1	TA SK2	TA SK3	TASK4	TASK5	TASK6	TASK7	TASK8	TASK9	TASK10
		MsI A	MsI A	MsI A	MsI A	MsI A	Msl B	MsI C	MsI C	MsI C	MsI D
Task		Lot 1	Lot 2	Lot 3	Lot 4	Lot 5	Lot 3	Lot 2	Lot 3	Lot 4	Lot 3
\$ Unit, HR Unit (Infl Index: 09/10/2004)		\$K, KHR	\$K, KHR	\$K, KHR	\$K, KHR	\$K, KHR	SK, KHR	SK, KHR	\$K, KHR	\$K, KHR	\$K, KHR
Base Year		2000	2000	2000	2000	2000	2000	2000	2000	2000	2000
Total % Spent (ACWP/LRE)		95.15	94	53.65	99.32	55.03	93.64	82.83	69.7	95.61	77.65
Custom Due Overtitu			50	100	100	100	1000	200	250	500	500
System Buy Quantity		20	50	100	100	100	1000	200	250	1200	500
System First Unit	FU		26	/6	1/6	276	15524	850	1050	1300	650
System Last Unit	LU	25	/5	1/5	2/5	3/5	16523	1049	1299	1799	1149
Unit Cost	UC	4087	2962	2324	2109	2014	701	862	852	734	2101
1.1 AIR VEHICLE	RecCst	102174	148120	232442	210949	201421	701417	172478	213107	367128	1050686
TECHNICAL DATA FOR 1.1 AIR VEHICI	LE										
DIAMETER (in)											
LENGTH (in)								UC Vs. Q7	TY 		
RANGE - EFFECTIVE RANGE (km)	<high></high>						Correlat	ion Coeffici	ent = -0.597	/2	
RANGE - MSL FLYOUT (MAX) (mi)						_					
SPAN - MAX (in)					4500.0	2000					
VELOCITY - MAX (ft/s)					4000.	.0000					
WEIGHT (lb)	WGHT	250	250	250	1						1
YEAR IN SERVICE					3500./	0000					
			1.		3000.	.0000					
				SR.	2500						
				1. 20	9 <u> </u>	*					
			1.1	1.1	. 2000 /	.0000	<u>* </u>	<u> </u>			
				1.1	1500.	.0000		· · ·			
					1000.7	2000	* *				

0.0000

Dependent Variable

Independent Variable

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Pooled Regression In CO\$TAT

🌭 Learning Curve Model			
Specifications Results			
Case Name	Other Variables		
Case 1	First Unit:	FU	.
	Last Unit:	LU	_
Dependent Variable	Rate:	QTY	-
Type: LTC	Weighting:		•
Theory: Unit	-Independent Vari	ables	
Rate Slope:	Name UC WGHT	Not Indepen	Dummy C C
Error Term Multiplicative C Additive C MUPE Maximum Iterations:			
✓ ♠ <u>∦</u> ≞ ▼	<u></u> K	<u>C</u> ancel	Help

I. Model Form and Equation Table

Model Form:	Unweighted Learning Curve (Unit Theory)
Number of Observations Used:	16
Equation in Unit Space:	UNIT_COST = 167.3 * UNIT_NUM ^ (-0.167) * QTY ^ (-0.1689) * WGHT ^ 0.7641
T1:	167.3170
Quantity Slope:	89.07%
Rate Slope:	88.95%
Dependent Variable:	RecCst
Quantity Yariable:	First Unit and Last Unit Variables

II. Fit Measures (in Fit Space)

Coefficient Statistics Summary

		Std Dev of		T-Statistic	Prob Not
Variable	Coefficient	Coef	Beta Value	(Coef/SD)	Zero
Intercept	5.1199	0.3417		14.9853	1.0000
CUM_QTY	-0.1670	0.0238	-0.5962	-7.0078	1.0000
QTY	-0.1689	0.0400	-0.3455	-4.2263	0.9988
VGHT	0.7641	0.0587	0.7341	13.0072	1.0000

Goodness-of-Fit Statistics

		R-Squared	Pearson's
Std Error (SE)	R-Squared	(Adj)	Corr Coef
0.1056	96.62%	95.77%	0.9829

Summary of Predictive Measures

Average Actual (Avg Act)	1933.1814
Standard Error (SE)	168.4335
Root Mean Square (RMS) of % Errors	10.32%
Mean Absolute Deviation (Mad) of % Errors	6.20%
Coef of Variation based on Std Error (SE/Avg Act)	8.71%
Coef of Variation based on MAD Res (MAD Res/Avg Act)	5.24%
Pearson's Correlation Coefficient between Act & Pred	98.93%
Adjusted R-Squared in Unit Space	96.31%

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Real-World What-If

Consider: What if you have actual cost reporting for a single (early) production lot.

- Lot Total Cost of Units 5 through 10 is \$1000 (say LRIP 1).
- You need to use this information to estimate future LRIP and productions.
- You want to assume (for lack of better information) a 90% unit theory learning curve with 95% rate.

WBS/CES Description	Unique ID	Point Estimate	Phasing Method	Equation / Throughput	Start Date	Finish Date	Theory:
Calculated LTC Units 5 - 10		875.823 *	R	LTCi			Prior Qty: PQ Shrd Kywd: Shrd
Prior QTY	PQ	4.000 *	С	4			Buy Qty: QTY 🔐 Rate: QTY
Buy QTY	QTY	6.000 *	F	6	2009	2009	Slope (%): L_SLP
Input LTC (Units 5-10)	LTCi	1,000.000 *	С	1000			
							Ref Cost: LTC 🗸 First Unit: 5 🌇 Last Unit: 10 🛅
Learning Slope	L_SLP	90.000 *	С	90			
Rate Slope	R_SLP	95.000 *	С	95			

What is wrong with this picture?



Real-World What-If

- A reference cost on a rate adjusted learning curve has an assumed rate of 1.
 - The given LTC = \$1000 is for units 5 10; annual rate is 6 units
 - Need to manually adjust reference cost to rate of 1.
 - Key fact: The rate exponent = In(Rate Slope)/In(2)

WBS/CES Description	Unique ID	Point Estimate	Phasing Method	Equation / Throughput	Start Date	Finish Date
Calculated LTC Units 5 - 10	(1,000.000 *	R	LTCi / (6 ^ (In(R_SLP/100) / In(2)))		
Calculated LTC Units 5 - 10 Wrong		875.823 *	R	LTCi		
Prior QTY	PQ	4.000 *	С	4		
Buy QTY	QTY	6.000 *	F	6	2009	2009
Input LTC (Units 5-10)	LTCi	1,000.000 *	С	1000		
Learning Slope	L_SLP	90.000 *	С	90		
Rate Slope	R_SLP	95.000 *	С	95		
·						





- Learning curves are commonly used in many cost modeling activities
 - Rate adjusted learning is frequently needed to model long production runs and the later production lots.
 - To correctly understand and apply learning, you need to consider the source... historical data.
- ACEIT makes using learning easy
 - ACDB & CO\$TAT: access historical data and developing curves
 - ACE: Easy implementation of learning and learning with rate