

Calibrating the COCOMO II Post Architecture Model

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ICSE 98

Outline

- ➔ **Brief History of COCOMO**
- ◆ **Modeling Methodology**
- ◆ **COCOMO II Calibration Approaches**
 - **COCOMO II.1997 Calibration**
 - ❖ **Process**
 - ❖ **Prediction Accuracies**
 - **COCOMO II.1998 Calibration**
 - ❖ **Simple Cost Model Bayesian Prototype**
 - ❖ **Status**
- ◆ **Updates and Plans**
 - **Plans for Improving Prediction Accuracies**

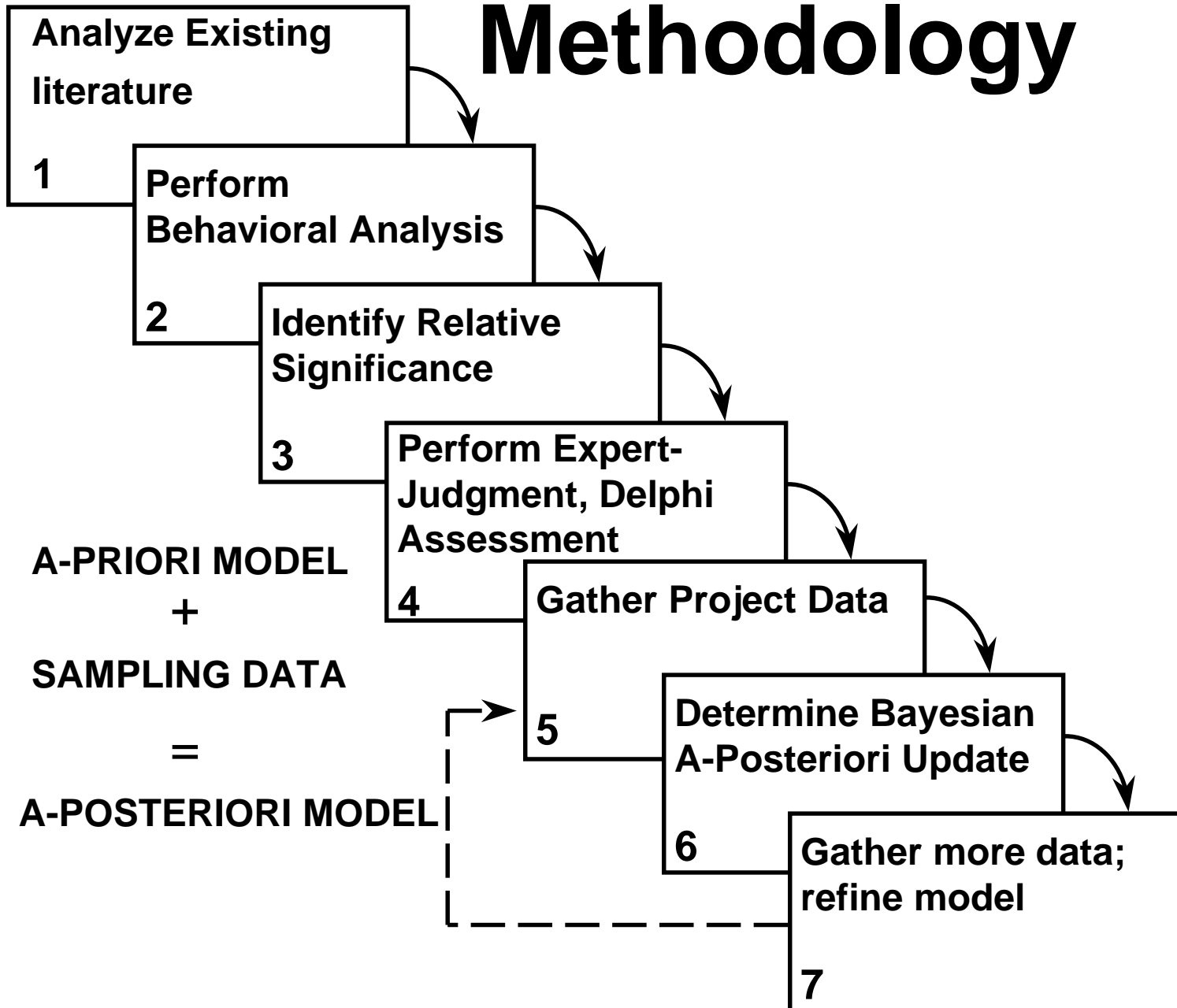
COntstructive COst MOdel (COCOMO)

- ◆ **COCOMO published since 1981**
- ◆ **Commercial implementations of COCOMO**
 - ❖ **CoCoPro, CB COCOMO, COCOMOID, COSTMODL, GECOMO Plus, SECOMO, etc.**
- ◆ **Other models based on COCOMO**
 - ❖ **REVIC, Gulezian**
- ◆ **COCOMO II**
 - ❖ **Research effort started in 1994 to develop a 1990's-2000's software cost model**
 - ❖ **Address new processes and practices**
 - ❖ **COCOMO II.199Y/200Y**

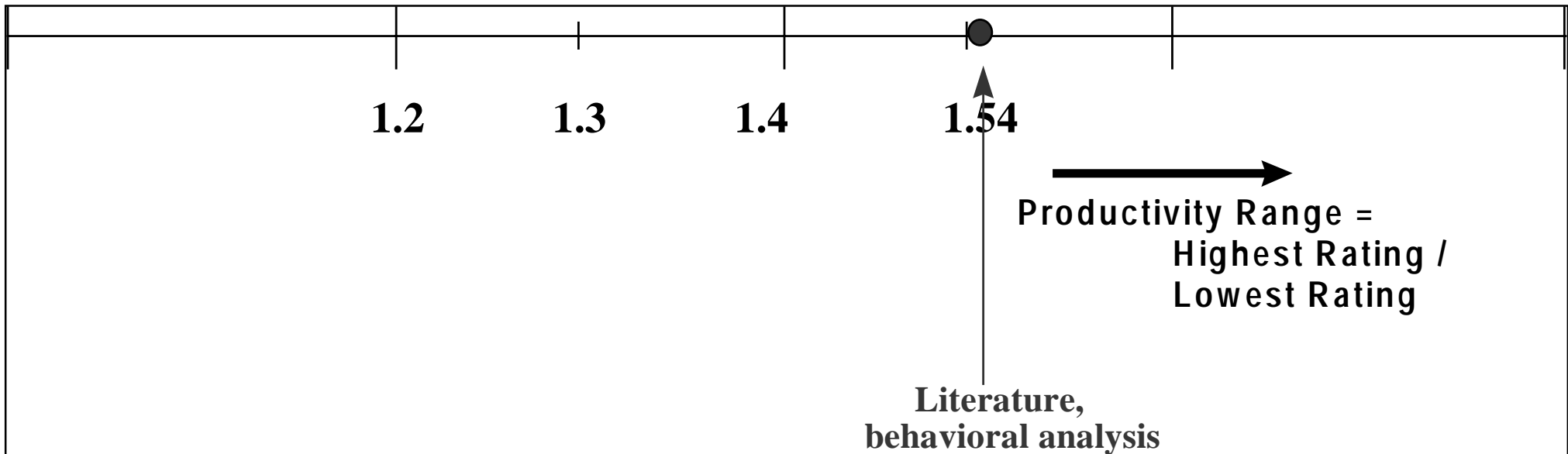
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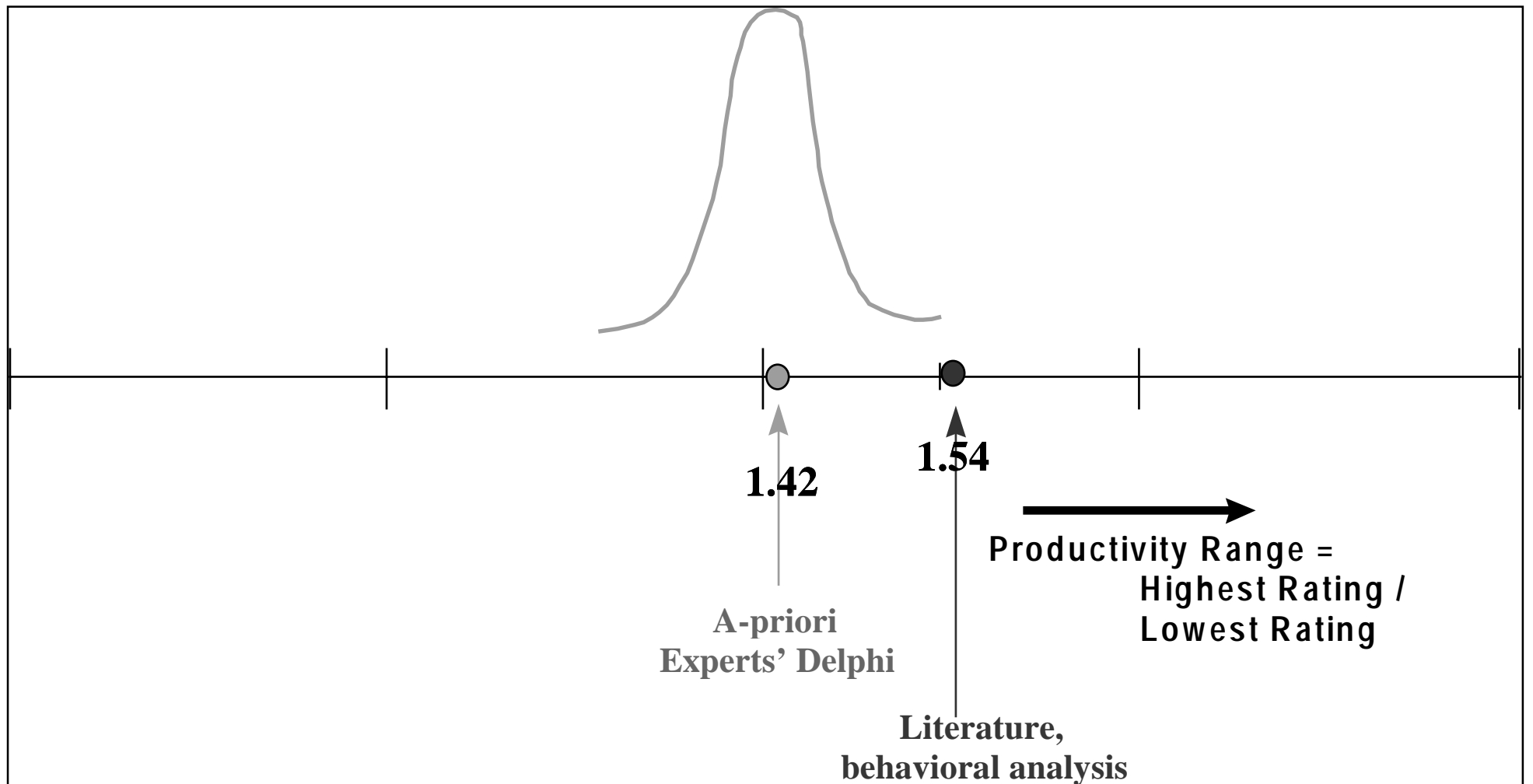
The Seven-Step Modeling Methodology



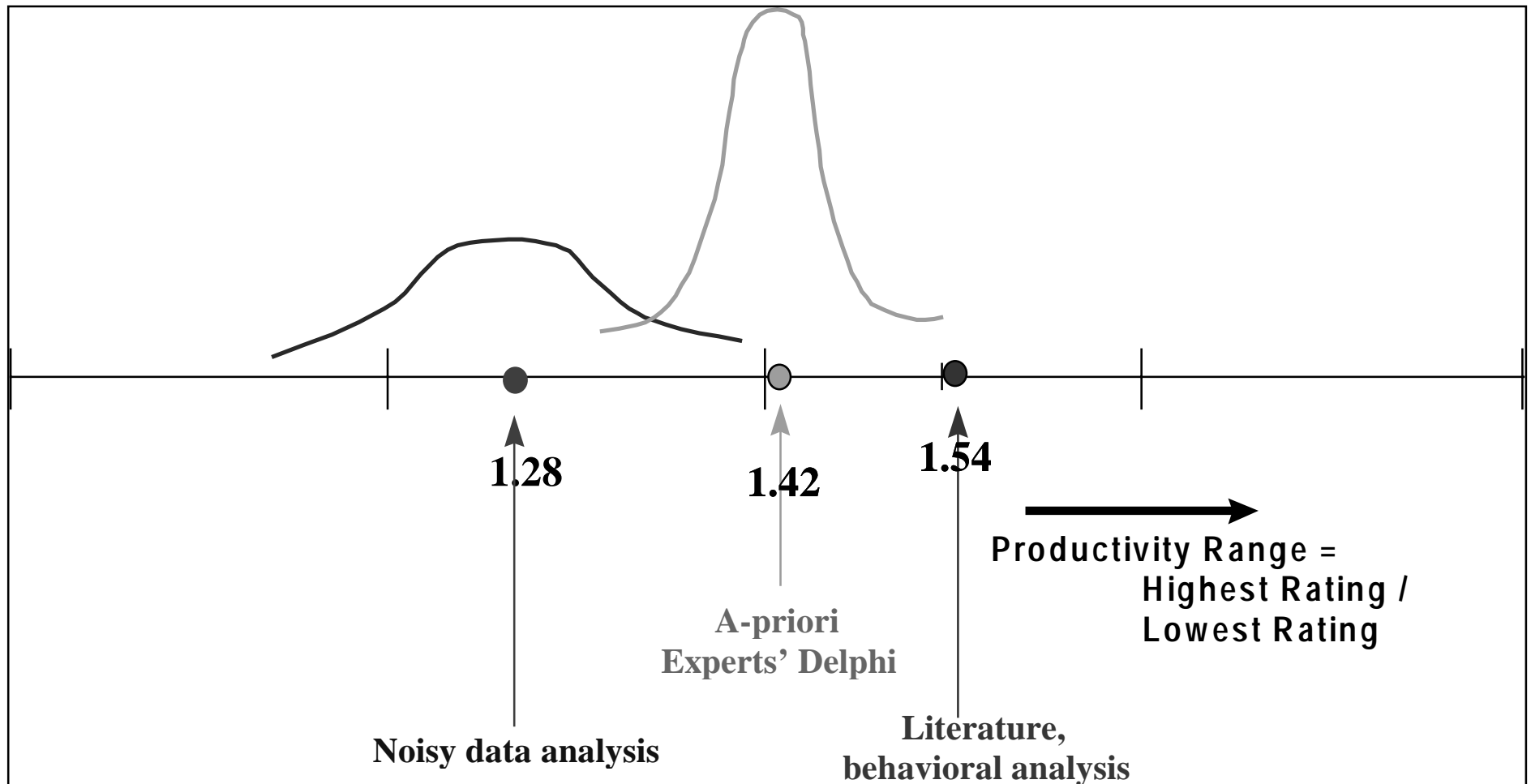
Literature, Behavioral Analysis (Steps 1-3)



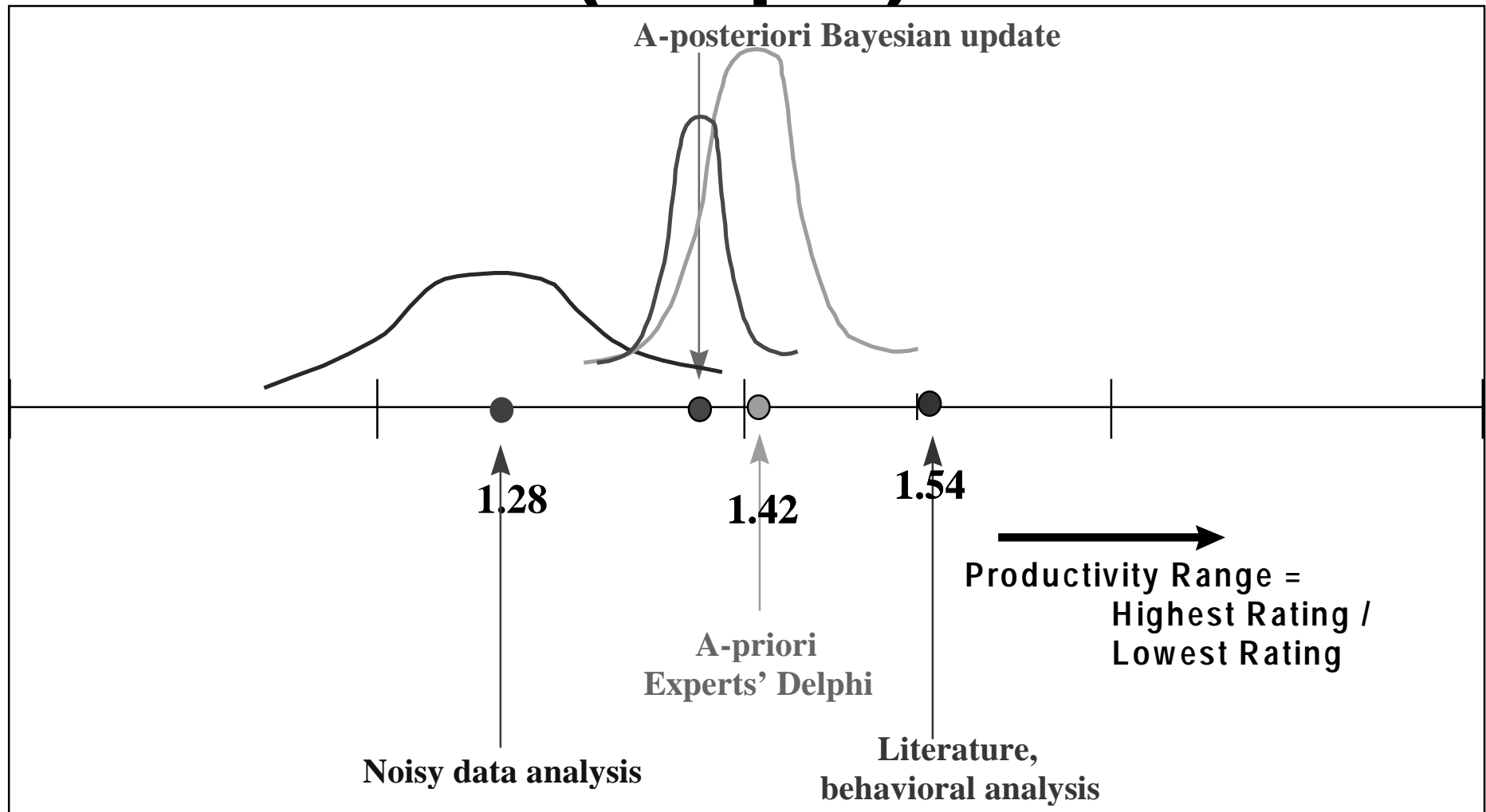
Results of Delphi (Step 4)



Results of Sampling Data (Step 5)



Results of Bayesian Update: Using Prior and Sampling Information (Step 6)



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COCOMO II Calibration Process

- ◆ **Began with expert-determined a-priori model parameters**
 - Iterated with Affiliates (Result => Original Post Architecture Model)
- ◆ **Collected Data**
- ◆ **Identified and consolidated highly correlated model parameters**
- ◆ **Statistically determined estimates of consolidated model parameters from data**
 - Using logarithms to linearize regression
- ◆ **Used data determined model parameters to adjust a-priori model parameters**
 - Experimented with weighting factors

Consolidated Highly Correlated Parameters

TIME	1.0000	0.6860	-0.2855	-0.2015
STOR	0.6860	1.0000	-0.0769	-0.0027
ACAP	-0.2855	-0.0769	1.0000	0.7339
PCAP	-0.2015	-0.0027	0.7339	1.0000
TIME	STOR	ACAP	PCAP	

- What do we do? \Rightarrow Combine :

TIME & STOR to give RCON (Resource Constraints)

ACAP & PCAP to give PERS (Personnel Factors)

Thus, 15 effort multipliers instead of 17 for calibration

Statistical Data Analysis

Variable	Minimum	Maximum	Ratio (Max/Min)
EFFORT	6	11400	1900
SIZE	2.6	1292.8	497

Thus, we took log transforms to normalize the response variable. Also, we took log transforms to linearize the parametrized model.

COCOMO II Calibration Model

- **Needed linear model for regression:**

$$Y = B_0 + B_1X_1 + B_2X_2 + \dots + B_pX_p$$

- **COCOMO II Post-Architecture is non-linear**

$$Y = B_0X^{B_1}$$

- **What did we do?**
 - **Expanded COCOMO II model**
 - **Transformed products with logarithms to produce sums**

Expanded COCOMO II

- Distributed the Scale Factors
- Resulted in 21 predictor variables i.e. 15 Effort Multipliers + 5 Scale Factors + (Size)^{1.01}

$$PM_{est} = A \cdot (Size)^{1.01} \cdot (Size)^{SF_1} \cdot (Size)^{SF_2} \dots EM_1 \dots EM_{15}$$

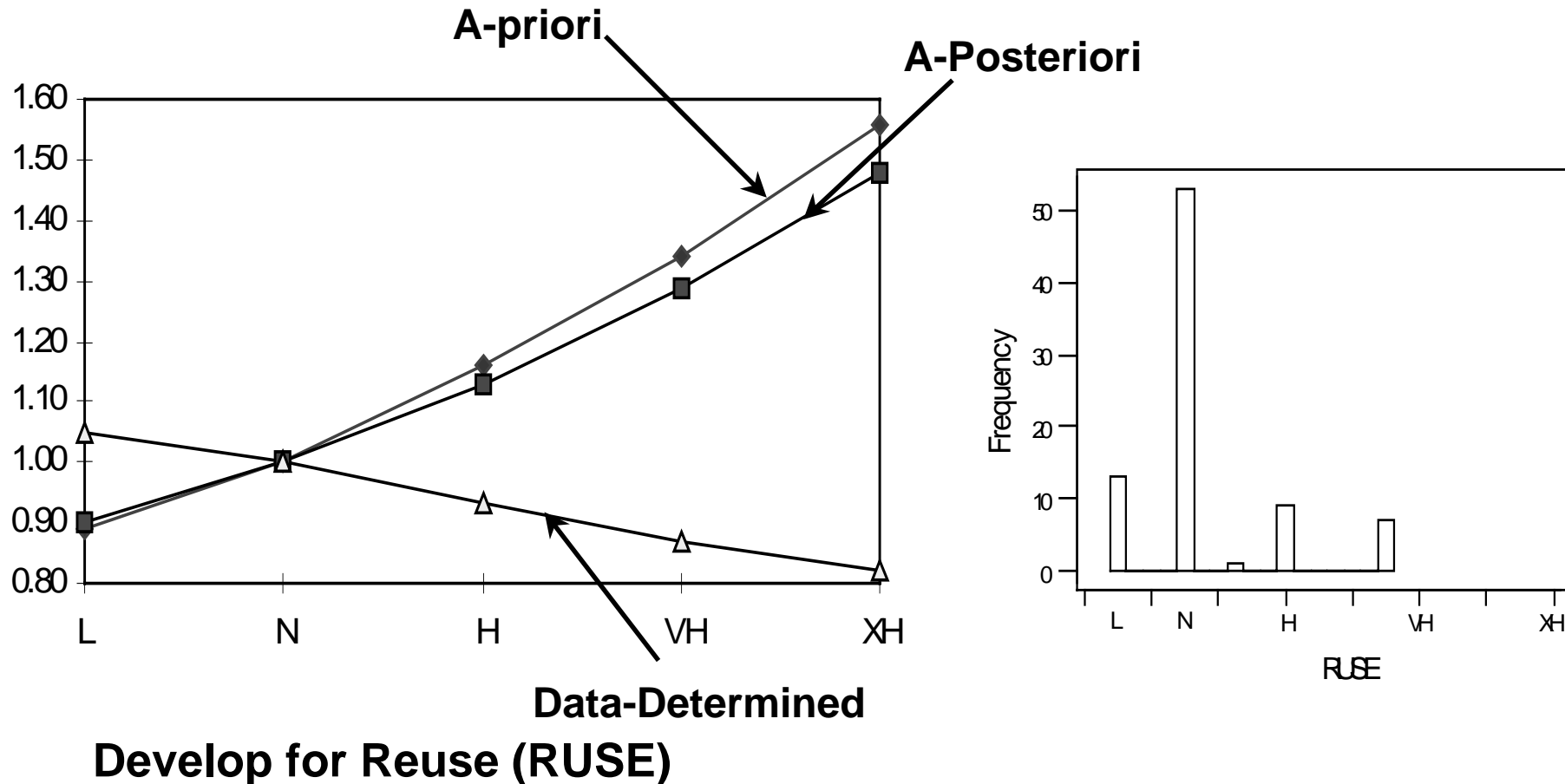
Log Transformed COCOMO:

$$\ln(PM_{est}) - \ln(Size)^{1.01} = \ln(A) + SF_1 \ln(Size) + \dots + \ln(EM_{15})$$

- Regression analysis derived the coefficients, B_i , for each factor

COCOMO II.1997 Calibration

- ◆ 83 projects
- ◆ Multiple Linear Regression
 - 10% weighted average between a-priori values and data-determined values



Accuracy Results

Effort Prediction	Before Stratification By Organization	After Stratification By Organization
PRED(.20)	46%	49%
PRED(.25)	49%	55%
PRED(.30)	52%	64%

Schedule Prediction	Before Stratification By Organization	After Stratification By Organization
PRED(.20)	48%	52%
PRED(.25)	54%	61%
PRED(.30)	61%	62%

COCOMO '81 & COCOMO II.1997

◆ **COCOMO '81: Pred (.20) = 68%**

◆ **COCOMO II.1997: Pred (.20) = 46%**

- **Challenges faced in calibrating COCOMO II**
 - ❖ **GUI builders, COTS, 4GL's, reuse, requirements breakage**
 - **Need to rethink size metrics**
 - ❖ **Distributed interactive applications**
 - **Web-based, object-oriented, event-based**
 - **Middleware effects**
 - ❖ **New process models (evolutionary, incremental, spiral)**
 - **Phases overlap**
 - **Where are cost measurement endpoints?**
 - ❖ **Lack of good data**
 - **not enough data (i.e. very little degrees of freedom)**
 - **lack of dispersion**
 - **heteroskedasticity**

Multiple Linear Regression Well-Suited When...

- ◆ lot of data is available
- ◆ no data items are missing
- ◆ there are no outliers
- ◆ the predictor variables are not highly correlated
- ◆ the predictor variables have an easy interpretation when used in model

most are violated by current software engineering data



Bayesian Analysis: COCOMO II.1998

A Simple Cost Model

- ◆ Suppose we have a simple software cost model

$$Effort = \alpha \cdot Size^{\beta_1} \vartheta$$

- ◆ Linearizing, we get

$$\ln(Effort) = \ln(\alpha) + \beta_1 \cdot \ln(Size) + \ln(\vartheta)$$

$$\ln(Effort) = \beta_0 + \beta_1 \cdot \ln(Size) + \varepsilon$$

- ◆ We need to determine the values of β_0 and β_1

Bayesian Analysis on a Simple Cost Model

- ◆ Suppose we have a simple software cost model

$$Effort = \alpha \cdot Size^{\beta_1} \delta$$

- ◆ Linearizing, we get

$$\ln(Effort) = \ln(\alpha) + \beta_1 \cdot \ln(Size) + \ln(\delta)$$

$$\ln(Effort) = \beta_0 + \beta_1 \cdot \ln(Size) + \varepsilon$$

- ◆ We need to determine the values of β_0 and β_1

Modeling Under Complete Prior Uncertainty - Statistical Analysis

Coefficient Label	Estimates Estimate	Std. Error	t-value
β_0	1.206	0.199	6.062
β_1	1.03	0.407	21.93

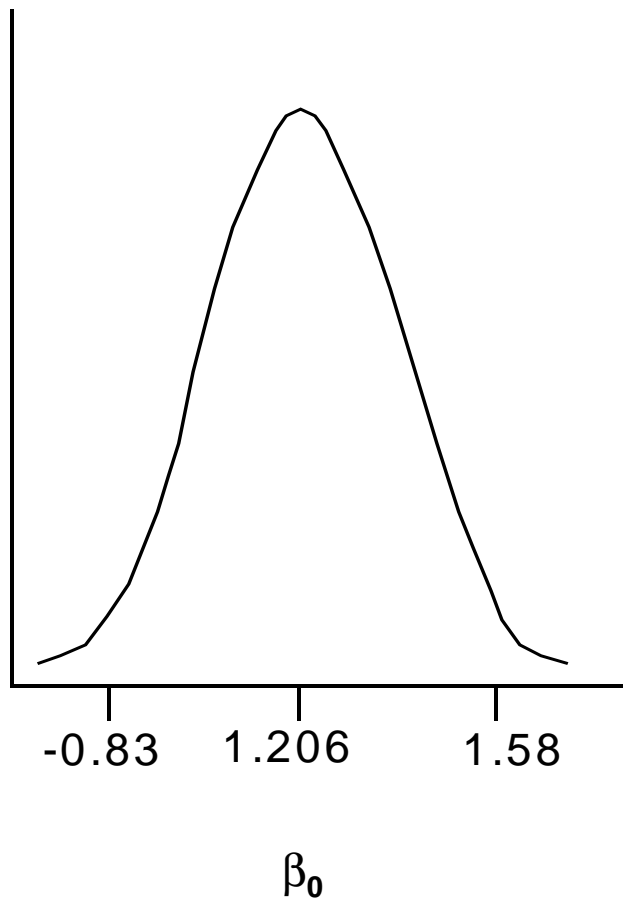
$$\ln(\textit{Effort}) = 1.206 + 1.03 \ln(\textit{Size})$$

$$\textit{Effort} = 3.3 \cdot \textit{Size}^{1.03}$$

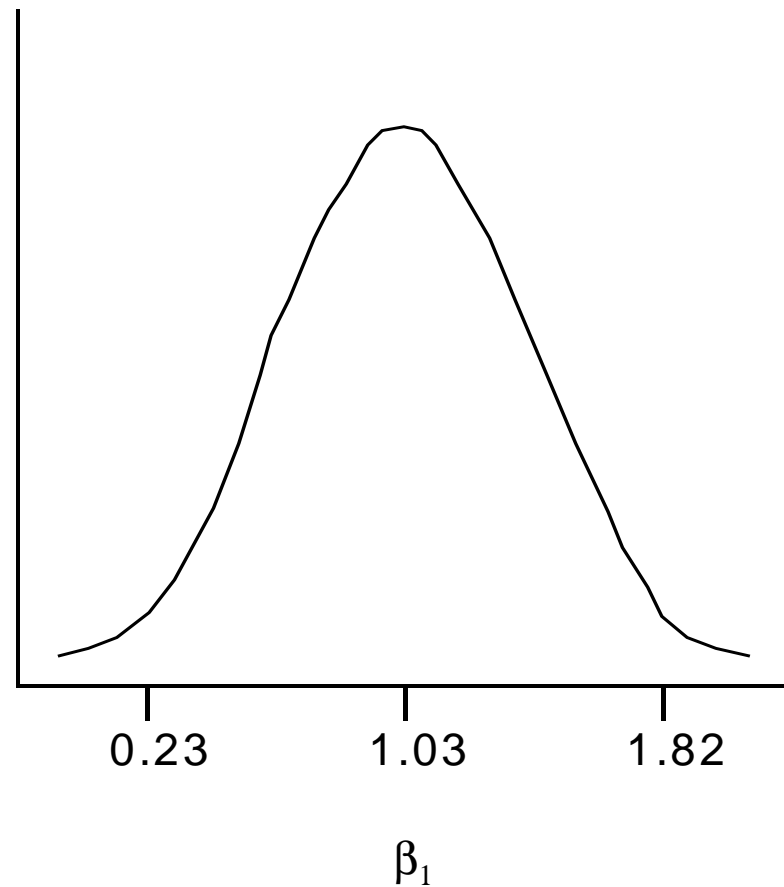
$$\textit{where } 3.3 = e^{1.206}$$

Posterior Density Functions - Noninformative Prior

$f(\beta_0 | \ln(\text{Effort}))$



$f(\beta_1 | \ln(\text{Effort}))$



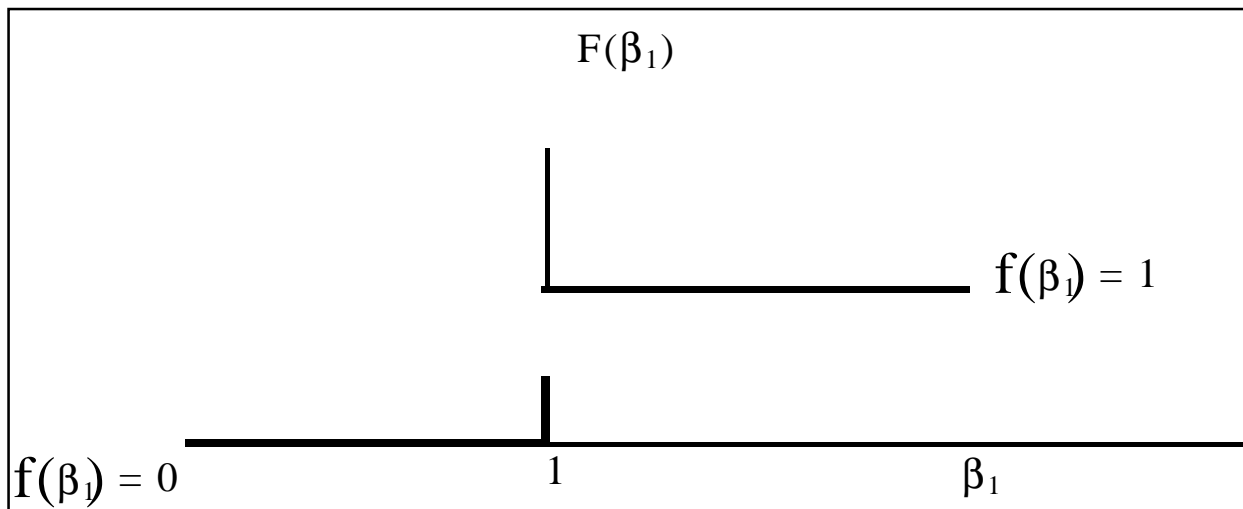
But, can $B < 1$? (i.e. economies of scale?)

Some Prior Knowledge on β_1

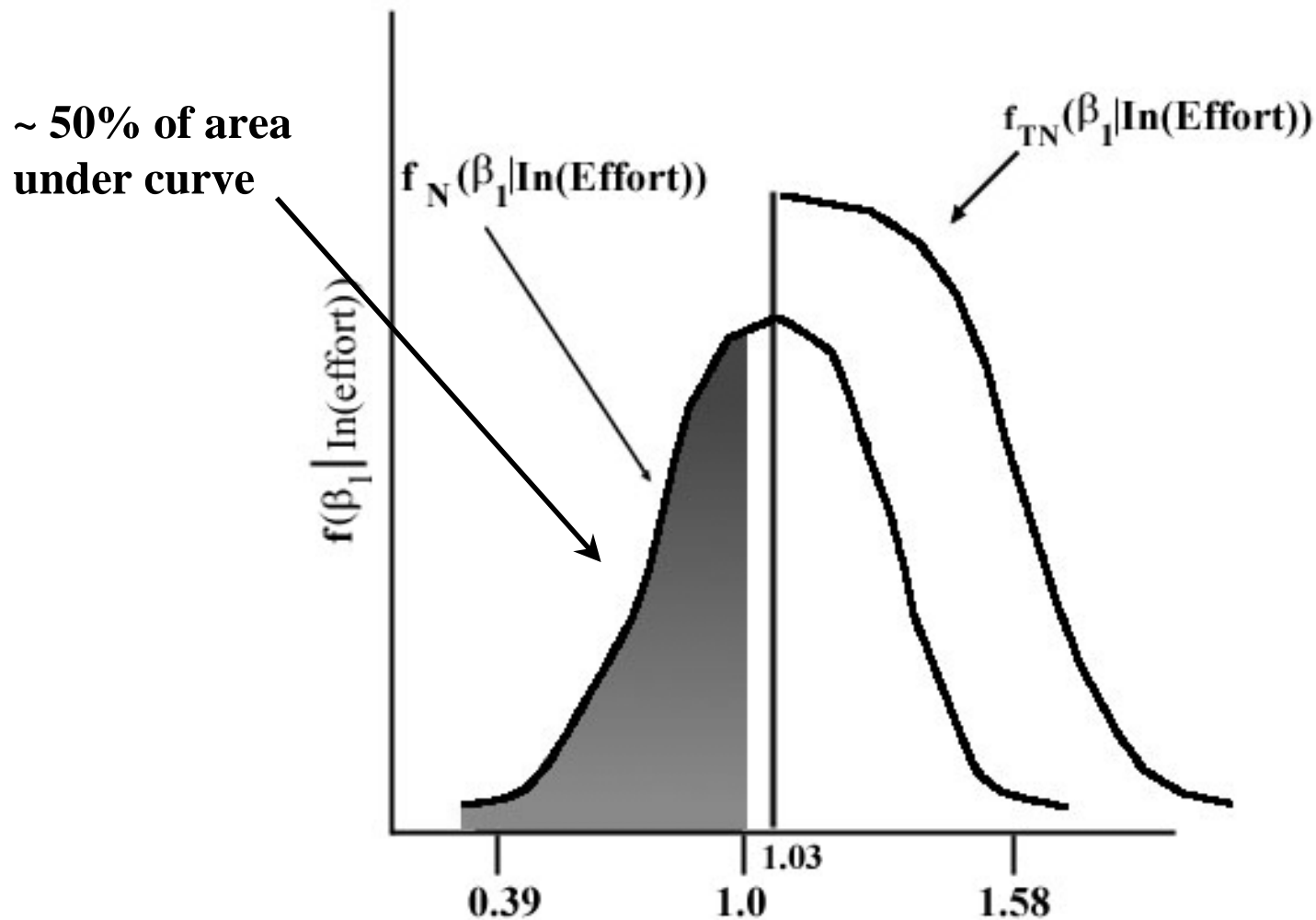
- ◆ Experience indicates that Software exhibits diseconomies of scale

[Banker94, Gulledge93].

- ❖ Suppose we believe that $\beta_1 \geq 1$
- ❖ $f(\beta_1) = 1$ if $\beta_1 > 1.0$
 $= 0$ if $\beta_1 \leq 1.0$



Post Sample Density Functions - Inclusion of Prior Information



Bayes Theorem

$$g(\beta / y) = \frac{f(y / \beta) g(\beta)}{f(y)}$$

$$g(\beta / y) \propto l(\beta / y) g(\beta)$$

posterior information \propto sample information X prior information



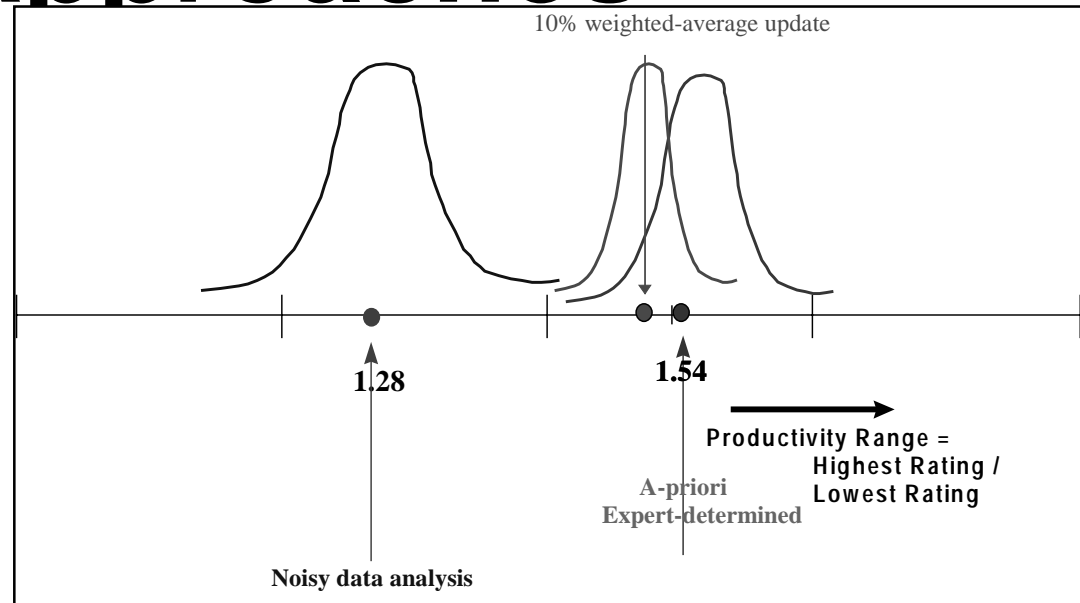
Prediction Accuracies*

Effort Prediction	Bayesian Approach 159 observations	COCOMO II.1997 83 observations
PRED(.20)	49%	46%
PRED(.25)	57%	49%
PRED(.30)	64%	52%

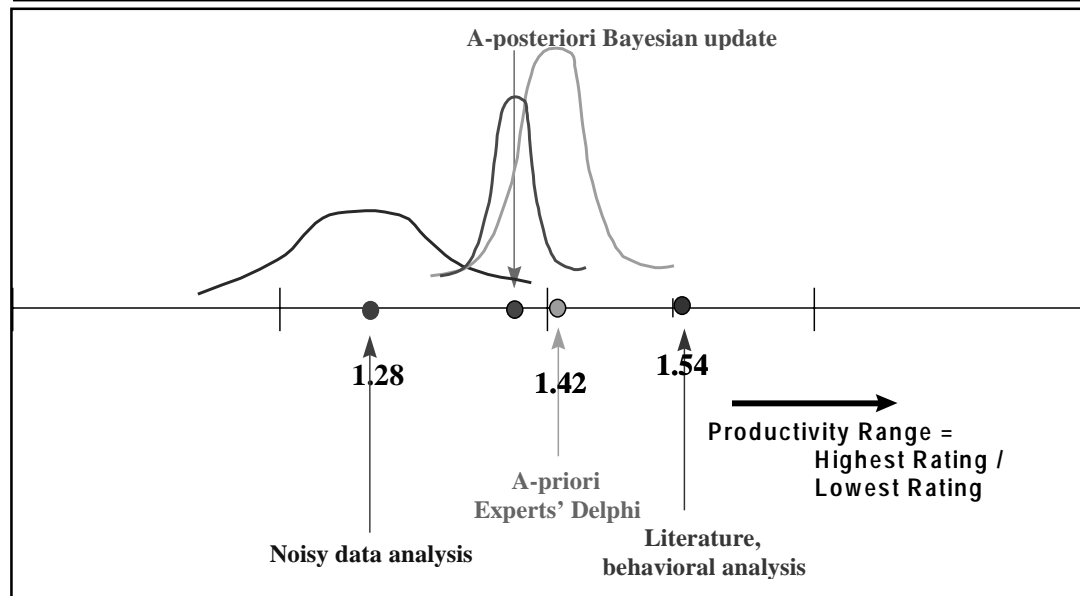
* Please note that the COCOMO II.1998 calibration is not yet complete. Hence these results may be different for the COCOMO II.1998 final calibration

COCOMO II Calibration Approaches

**COCOMO II.1997
10% weighed-
average approach**



**Bayesian approach -
weight determined by
data and prior
significance**



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COCOMO II Research Group's Aim

