

Mathematical Perspectives on the Federal Thrift Savings Plan (TSP)

*Military Operations Research Society Symposium
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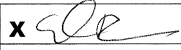
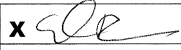
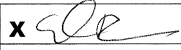
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Disclaimer

- *You will not receive any personal financial advice during this talk, as I am not officially qualified or certified to do so.*
- *However, my presentation is intended to get you to think mathematically about one of the retirement savings options available to many of you.*



Questions for Consideration

- Why might I be more risk tolerant than I currently believe?
- What are the L (Lifecycle) funds? How are they constructed? Why might they be of interest (or not) to me?
- What if stock and index fund returns are not normally distributed, as is commonly assumed?
- How does the choice of reward and risk measures affect optimal TSP portfolios?



Big Picture on Saving \$\$\$

“There is no scholarship for retirement!”

-Unknown

- Spouse's 401(k) with matching funds
- Roth IRA (for Soldier/civilian and spouse)
- Thrift Savings Plan (TSP)
- Spouse's 401(k) without matching funds
- Coverdale Educational Savings Accounts
- 529 Tuition Plans (prepaid or savings)

(ordering of these depends on tax considerations)



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Thrift Savings Plan (TSP) Overview

- Largest defined contribution retirement savings and investment plan
 - 3.7 million participants
 - \$210 billion in assets
- 401(k) equivalent for government employees and uniformed service members
- 5 non-traded core funds
- Can rebalance daily with no direct costs



Core TSP Funds

“RISKY” ASSETS

Fund	Description	Assets*	Mean Return [#]	Standard Deviation [#]
G	short-term, specially issued Treasury securities	\$66.6B (39.2%)	6.4%	1.5%
F	tracks Lehman Brothers U.S. Aggregate (LBA) Index	\$10.2B (6.0%)	7.3%	5.6%
C	tracks S&P 500 Index	\$66.7B (39.3%)	13.0%	17.9%
S	tracks Dow Jones Wilshire 4500 Completion Index	\$13.7B (8.1%)	13.3%	19.9%
I	tracks MSCI EAFE (Europe, Australia, Far East) Index	\$12.6B (7.4%)	7.8%	18.7%

* As of Dec 31, 2005

[#] For the period 1988-2005



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Returns / Investment Horizon

- Returns

- Arithmetic:

$$r_{i,t} = \frac{S_{i,t} - S_{i,t-1}}{S_{i,t-1}}$$

- Log :

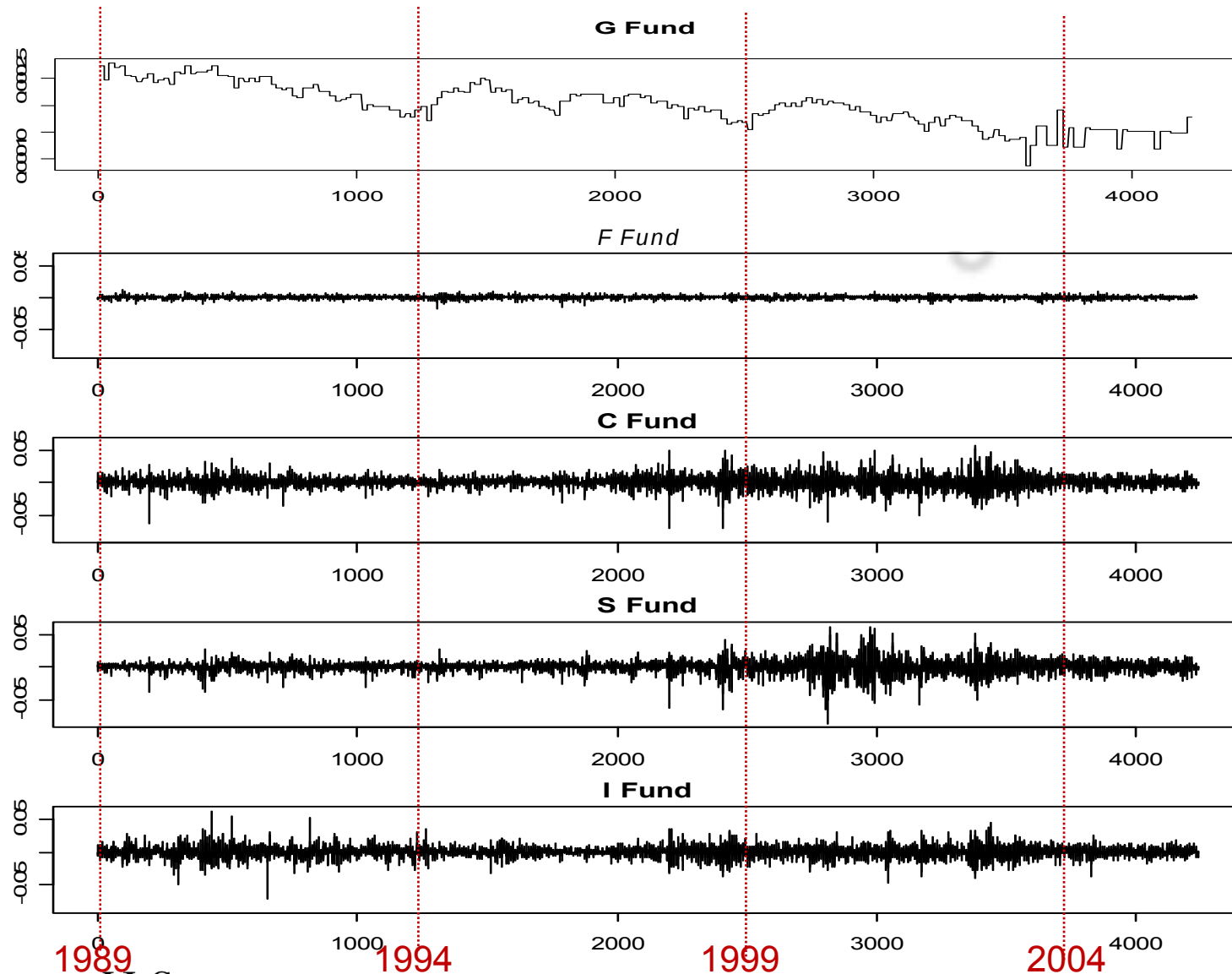
$$r_{i,t} = \ln(S_{i,t}) - \ln(S_{i,t-1}) = \ln\left(\frac{S_{i,t}}{S_{i,t-1}}\right)$$

- Investment Horizon: 20 years

- Point of military (not ultimate) retirement
 - System encourages 20 year careers
 - Employment options vary greatly
 - Can move TSP assets to other plans



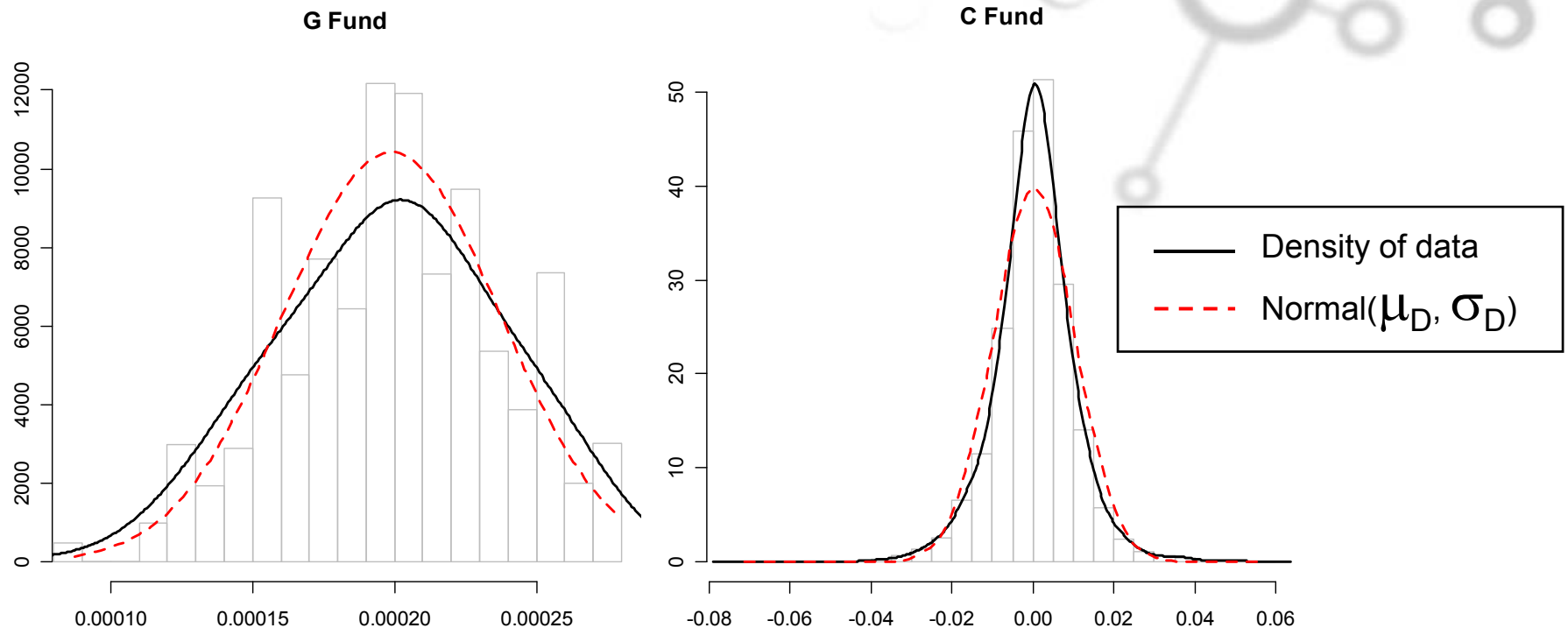
Daily Returns Time Series



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Daily Returns Distributions



- G fund appears approximately Gaussian
- C, S, I, and F funds are more peaked with heavy tails
- Goodness of Fit testing at common levels of significance rejects Normal for F, C, and S funds, even with batched means



Mean-Variance Portfolio Optimization (Markowitz, 1952)

Let X_i = fraction of funds invested in asset i

$\bar{R}_i$ = expected return of asset i

$\bar{R}_p$ = expected return of portfolio p

σ_i^2 = variance of return of asset i

σ_{jk} = covariance of return of asset j with asset k

$$\text{Minimize} \quad \sigma_p^2 = \sum_{j=1}^N X_j^2 \sigma_j^2 + \sum_{j=1}^N \sum_{\substack{k=1 \\ k \neq j}}^N X_j X_k \sigma_{jk}$$

$$\text{Subject to:} \quad \sum_{i=1}^N X_i = 1$$

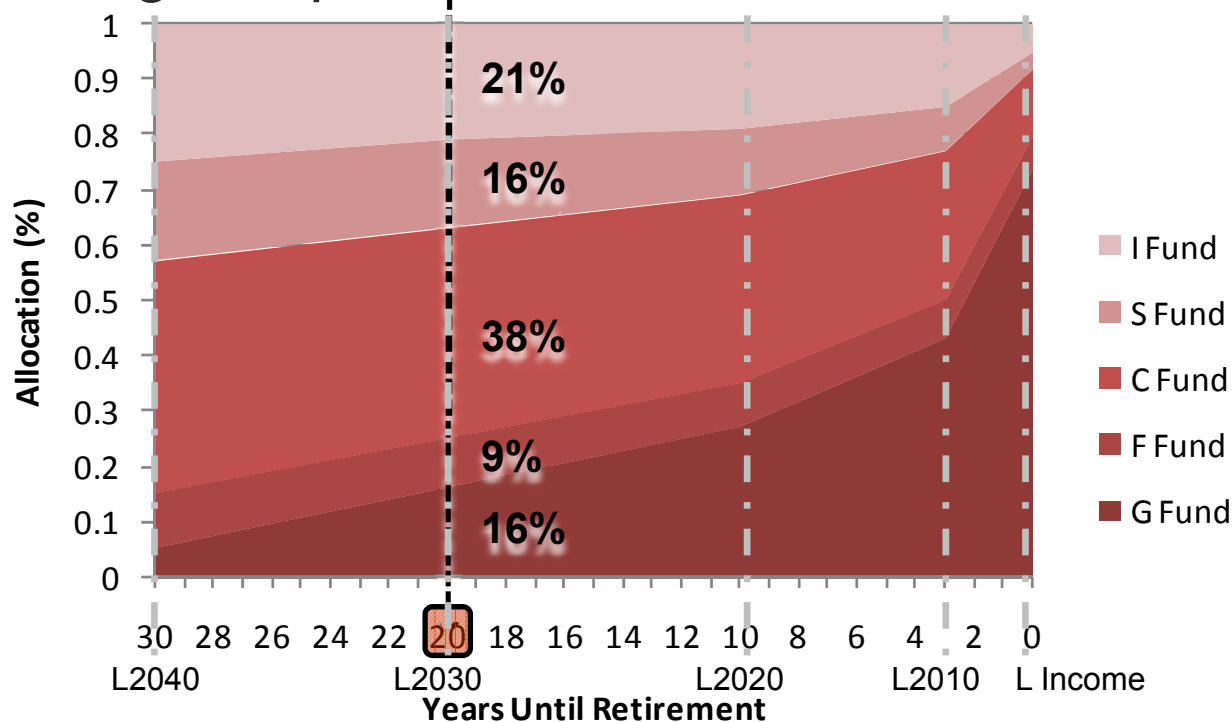
$$\bar{R}_p = \sum_{i=1}^N X_i \bar{R}_i$$

$$X_i \geq 0, \quad i = 1, \dots, N$$



L (Lifecycle) Funds

- Invest in 5 core TSP funds based on time horizon to provide highest possible rate of return for risk taken.



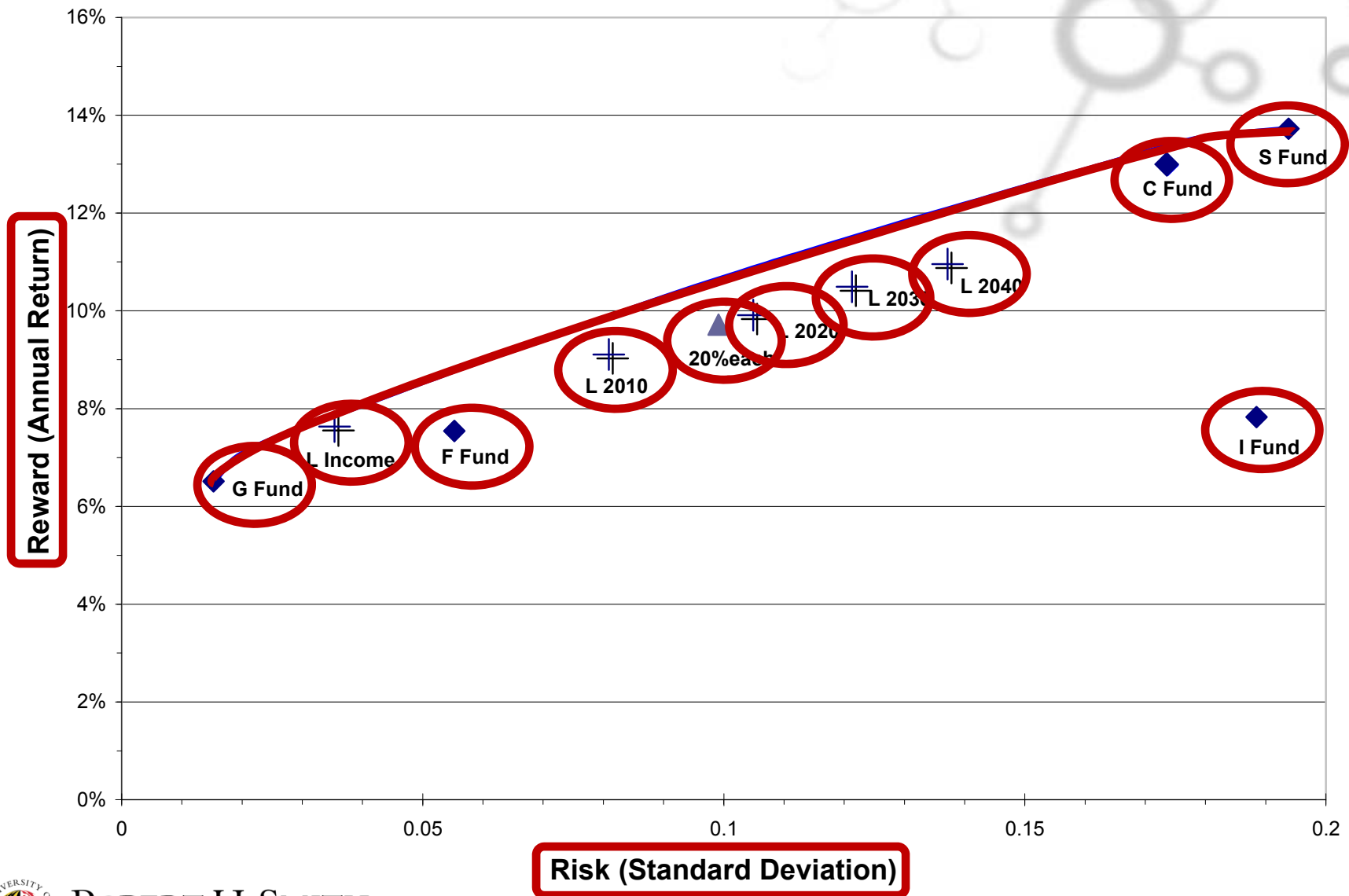
- Over time, investments shift away from stocks and into bonds.
- L Funds are great, but ...



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Reward-Risk Profile of TSP Funds



VG-ICA Factor Model

(Madan & Yen, 2004)

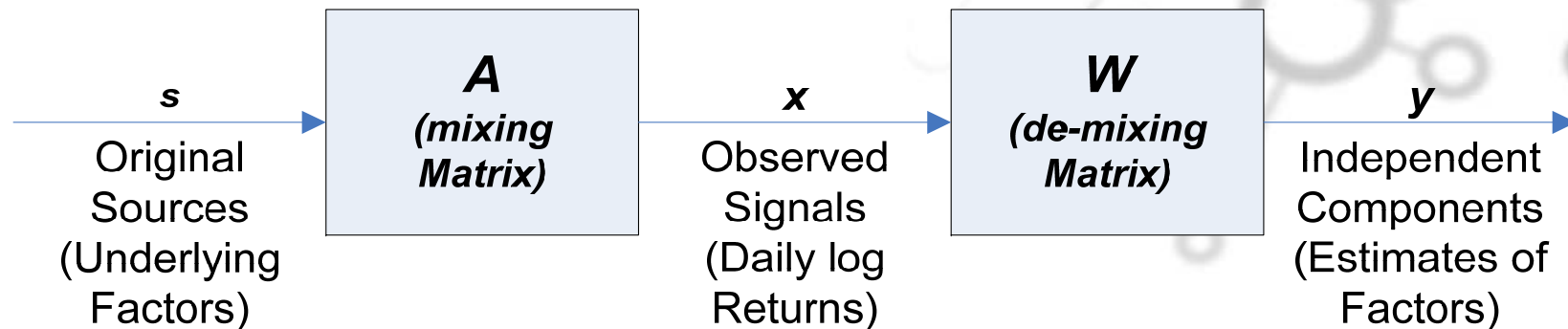
$$(R - \mu) = XB + \varepsilon$$

$$D = XB + \varepsilon$$

1. Use **Independent Component Analysis (ICA)** on asset returns D to identify underlying factors X
2. Fit the **Variance Gamma (VG)** distribution to each retained factor by MLE
3. Use Expected Utility to determine optimal portfolio of VG-ICA factors; convert back to optimal portfolio of assets (TSP funds)



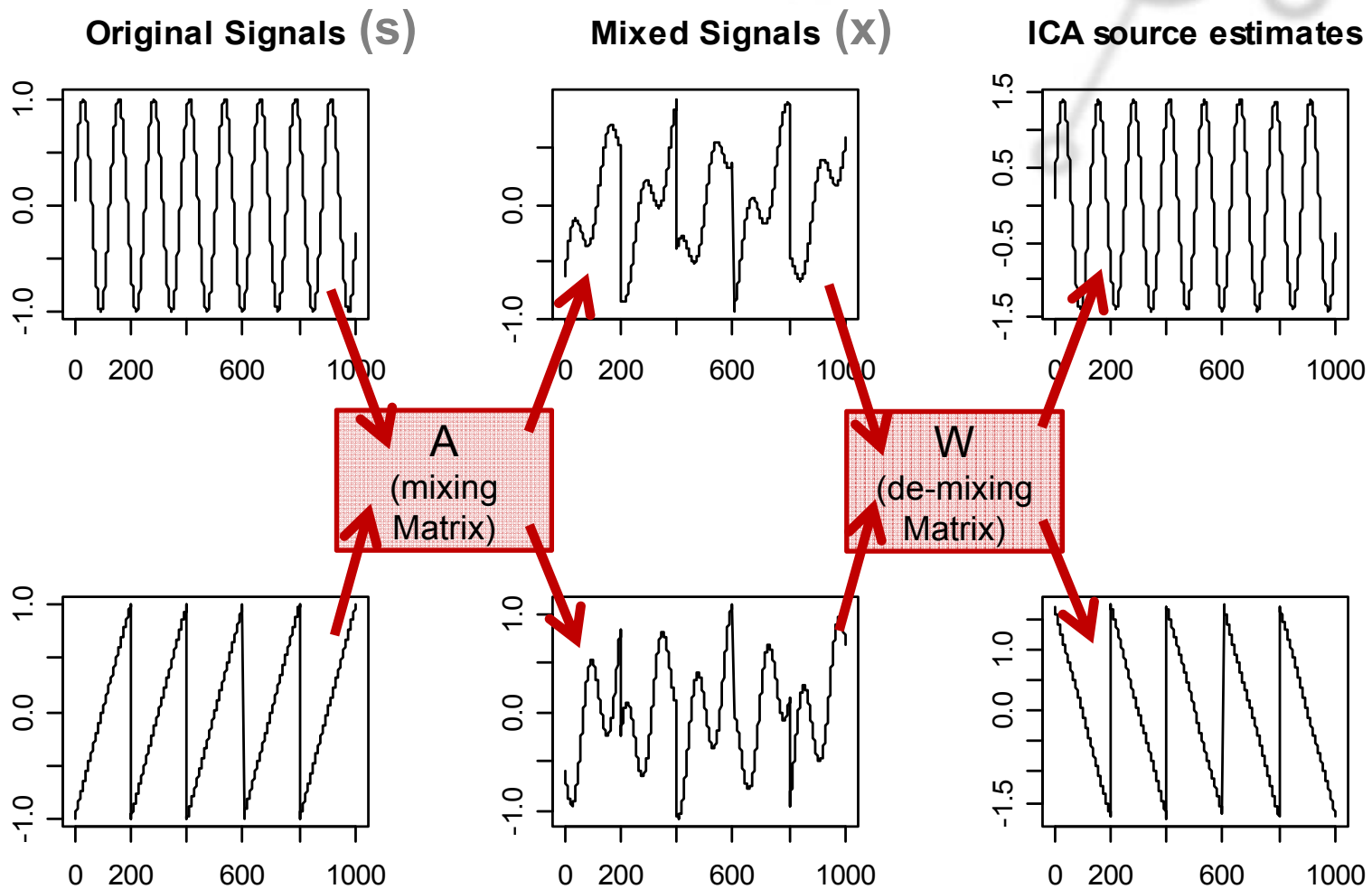
Independent Component Analysis (ICA)



- Principal Component Analysis (PCA)
 - Focus on finding **uncorrelated** components in Gaussian data
 - Maximizes explained variance
 - Uses second-order statistics
- Factor Analysis
 - Essentially PCA with extra terms to model noise
- ICA
 - Focus on **independent** and non-Gaussian components
 - Maximizes non-Gaussianity (to maximize information)
 - Uses higher-order statistics

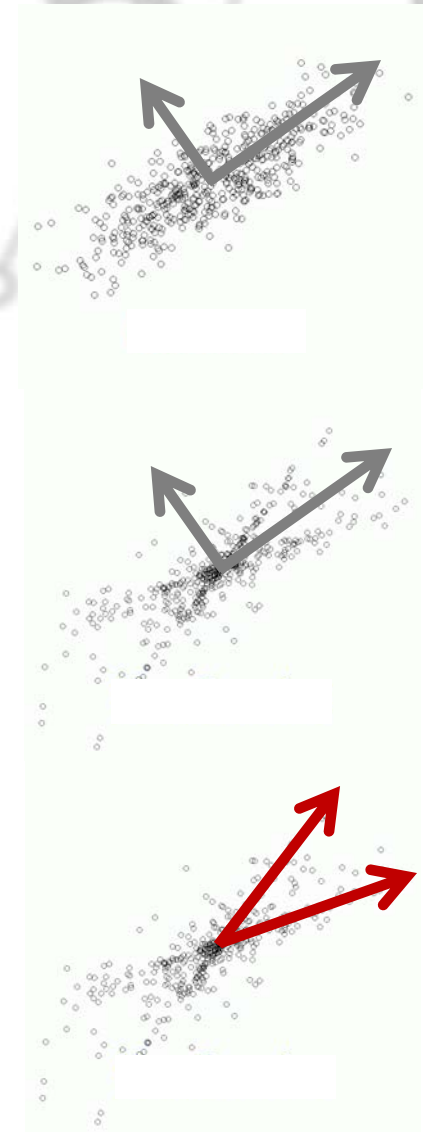


Another ICA Example



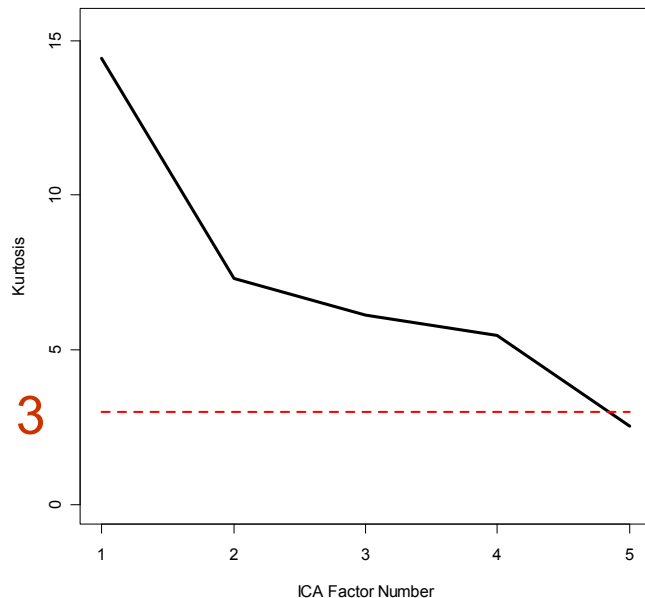
ICA versus PCA

- **Principal Component Analysis (PCA)** finds:
 - directions of maximal variance in Gaussian data (second-order statistics).
 - directions of maximal variance in non-Gaussian data (second-order statistics).
- **Independent Component Analysis (ICA)** finds directions of maximal independence in non-Gaussian data (higher-order statistics).



How Many ICs to Keep?

“Scree” Plot



R² Values from Regression

# ICs Kept	F Fund	C Fund	S Fund	I Fund
5	1	1	1	1
4	.9980	.9994	.9998	.9949
3	.0611	.8983	.9652	.9869
2	.0611	.8962	.9629	.1276

- Dropping more than one IC reduces fit on at least one fund
 - The first four have excess kurtosis
- Keep 4 Independent Components (ICs)



VG Process and Distribution

- **Pure jump process** with two representations

- Time-changed Brownian motion (Madan & Seneta, 1990)

$$X_{VG}(t; \nu, \theta, \sigma) = b(\gamma(t; 1, \nu), \theta, \sigma)$$

- Difference of 2 Gamma processes (Madan, Carr & Chang, 1998)

$$X_{VG}(t) = G_p(t) - G_n(t)$$

- **Parameters:** σ controls spread
 ν affects kurtosis
 θ impacts skewness

- **Density Function** (Madan, Carr & Chang, 1998)

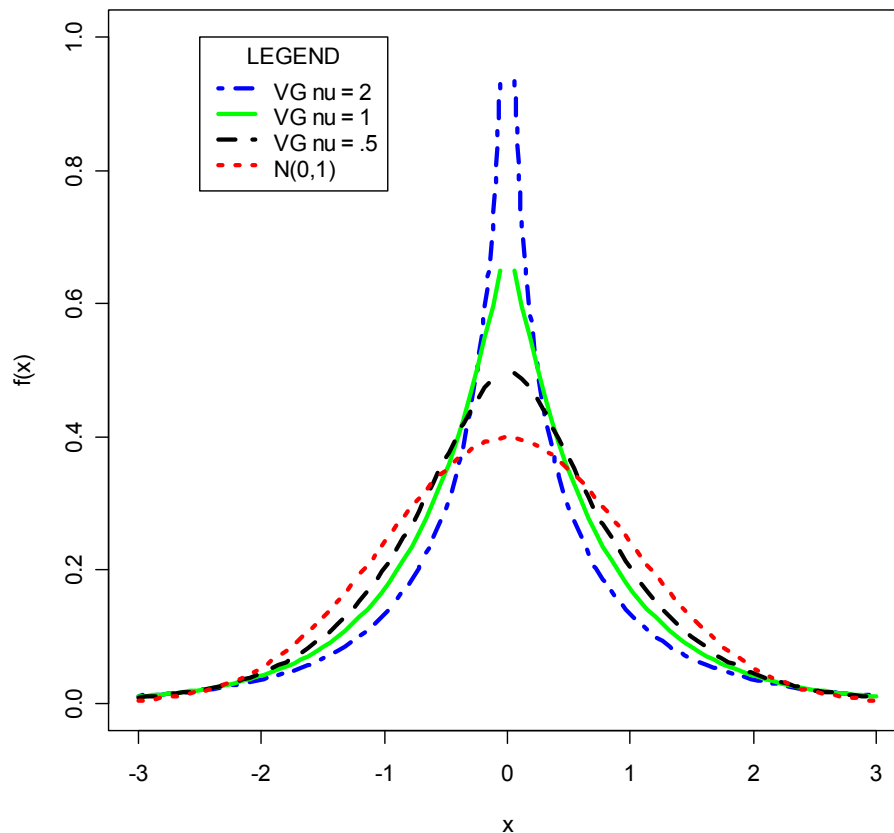
$$h(z) = \frac{2 \exp(\theta x / \sigma^2)}{\nu^{1/\nu} \sqrt{2\pi} \sigma \Gamma(\frac{1}{\nu})} \left(\frac{x^2}{2\sigma^2 / \nu + \theta^2} \right)^{\frac{1}{2\nu} - \frac{1}{4}} K_{\frac{1}{\nu} - \frac{1}{2}} \left(\frac{1}{\sigma^2} \sqrt{x^2 (2\sigma^2 / \nu + \theta^2)} \right)$$

with $x = z - \theta$ where $z = \ln(S(t) / S(t-1))$

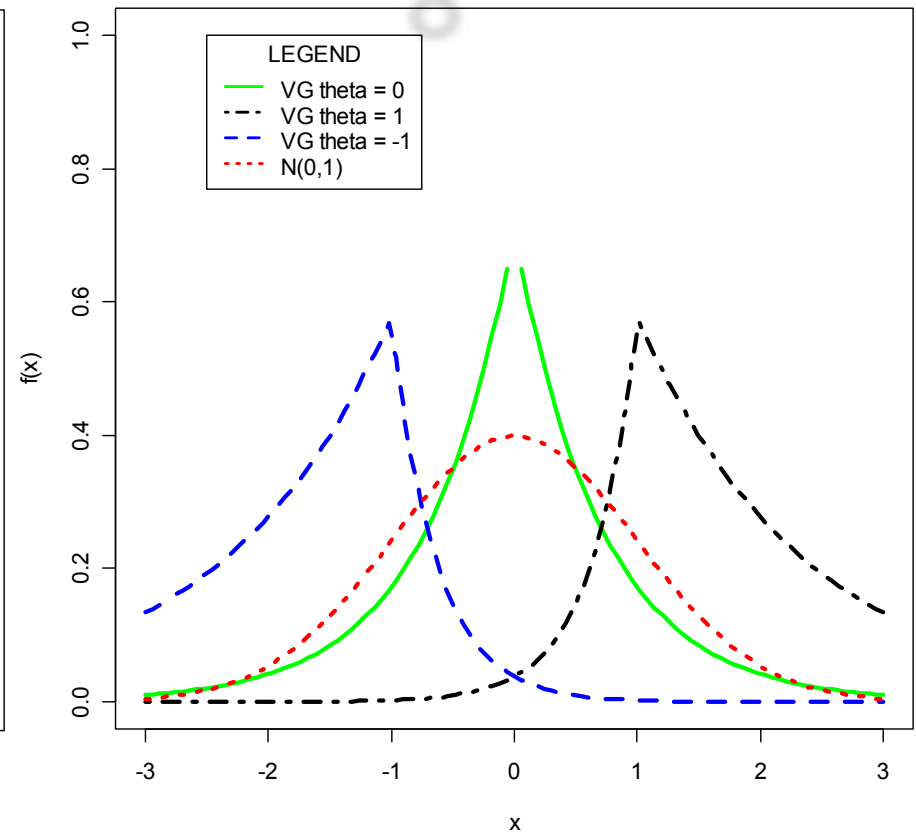


Examples of VG Distributions

Effect of ν



Effect of θ



Fitting VG by MLE

- Given observed IID data $X_1, X_2, \dots, X_n$, define the **likelihood function** as:

$$L(\theta) = f_{\theta}(X_1) f_{\theta}(X_2) \cdots f_{\theta}(X_n)$$

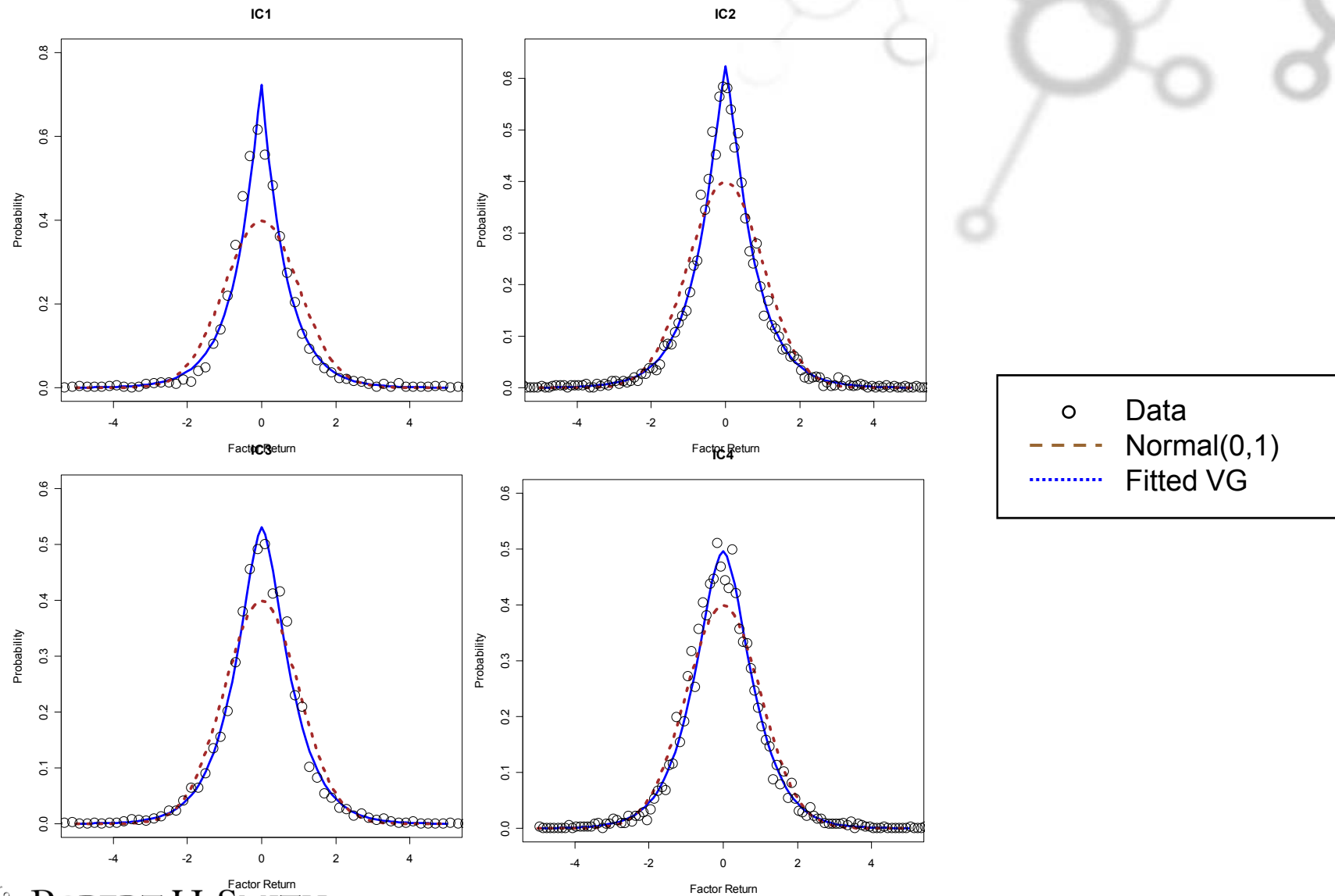
- The **MLE (maximum likelihood estimator)** $\hat{\theta}$ maximizes $L(\theta)$ over all permissible values of θ .
- Actually, maximizing the **log likelihood function** $\ln(L(\theta))$ is easier
- For the VG distribution with three parameters, this becomes:

$$l(\sigma, \nu, \theta) = \ln L(\sigma, \nu, \theta) = \sum_i f_{(\sigma, \nu, \theta)}(X_i)$$

(using pdf given before from Madan, Carr, and Chang, 1998)



Comparison of Fitted VG and Normal(0,1)



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Fitted VG Parameters / Chi-Square Statistics

IC#	Fitted VG Parameters - Daily (Annualized)			X ² Test Statistic (p-values) (X ² _{.01,17} = 33.41)	
	σ	ν	θ	VG(σ, ν, θ)	N(0,1)
IC1	0.933 (14.814)	0.969 (.00385)	-0.015 (-3.773)	99.01 (8.08E-13)	546.89 (7.83E-104)
IC2	0.980 (15.558)	0.820 (.00326)	-0.001 (-0.222)	13.37 (0.82)	295.73 (1.50E-51)
IC3	0.989 (15.703)	0.586 (.00232)	-0.004 (-1.019)	34.94 (0.014)	171.70 (1.32E-26)
IC4	0.991 (15.739)	0.468 (.00186)	-0.005 (-1.149)	25.29 (0.151)	118.07 (2.54E-16)

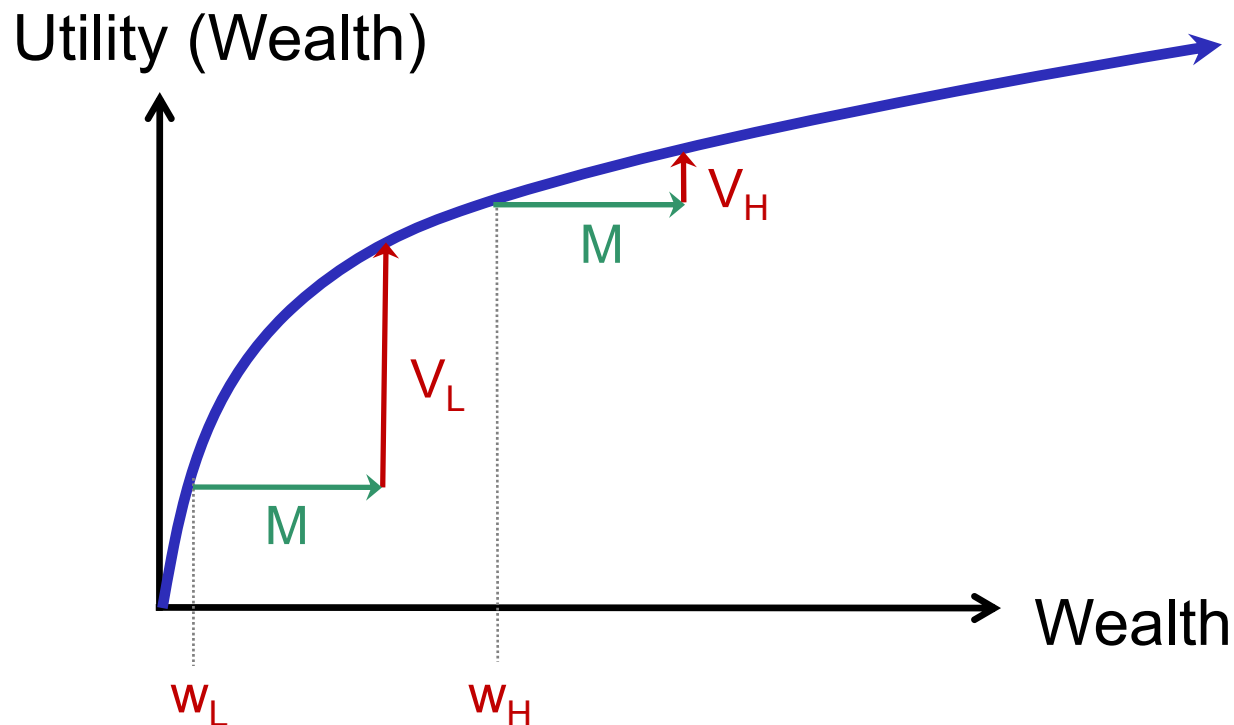
- Some excess kurtosis and slight negative skewness in each IC
- VG fits much better than Normal distribution



Utility Theory & Risk Aversion

Utility- a measure of relative satisfaction obtained

Risk Aversion- concave utility function, as shown below



Aside on Risk Aversion/Tolerance

(Jennings & Reichenstein, 2001)

- Pensions considered when planning retirement income..... but NOT when calculating asset allocation
- Pensions and investment portfolio generate retirement funds; why not consider both in total portfolio?
- Many similarities between inflation-indexed Treasury bonds (TIPS) and military retirement
 - Linked to Consumer Price Index (CPI)
 - Backed by federal government
- Suggest treating after-tax present value as a “pseudo-bond” in total portfolio
- Discounting can be at recent TIPS rates (3%-5%) or higher personal discount rate (18+%)
- Results in more aggressive (risk tolerant) portfolio in active investments than would otherwise result



NPV of Military Retirement

(Jennings & Reichenstein, 2001)

Rank at Retirement	Years of Service	After-Tax NPV
LTC	20	\$726,674
LTC	22	\$802,690
COL	24	\$994,468
COL	26	\$1,096,490
COL	28	\$1,166,125
COL	30	\$1,205,255

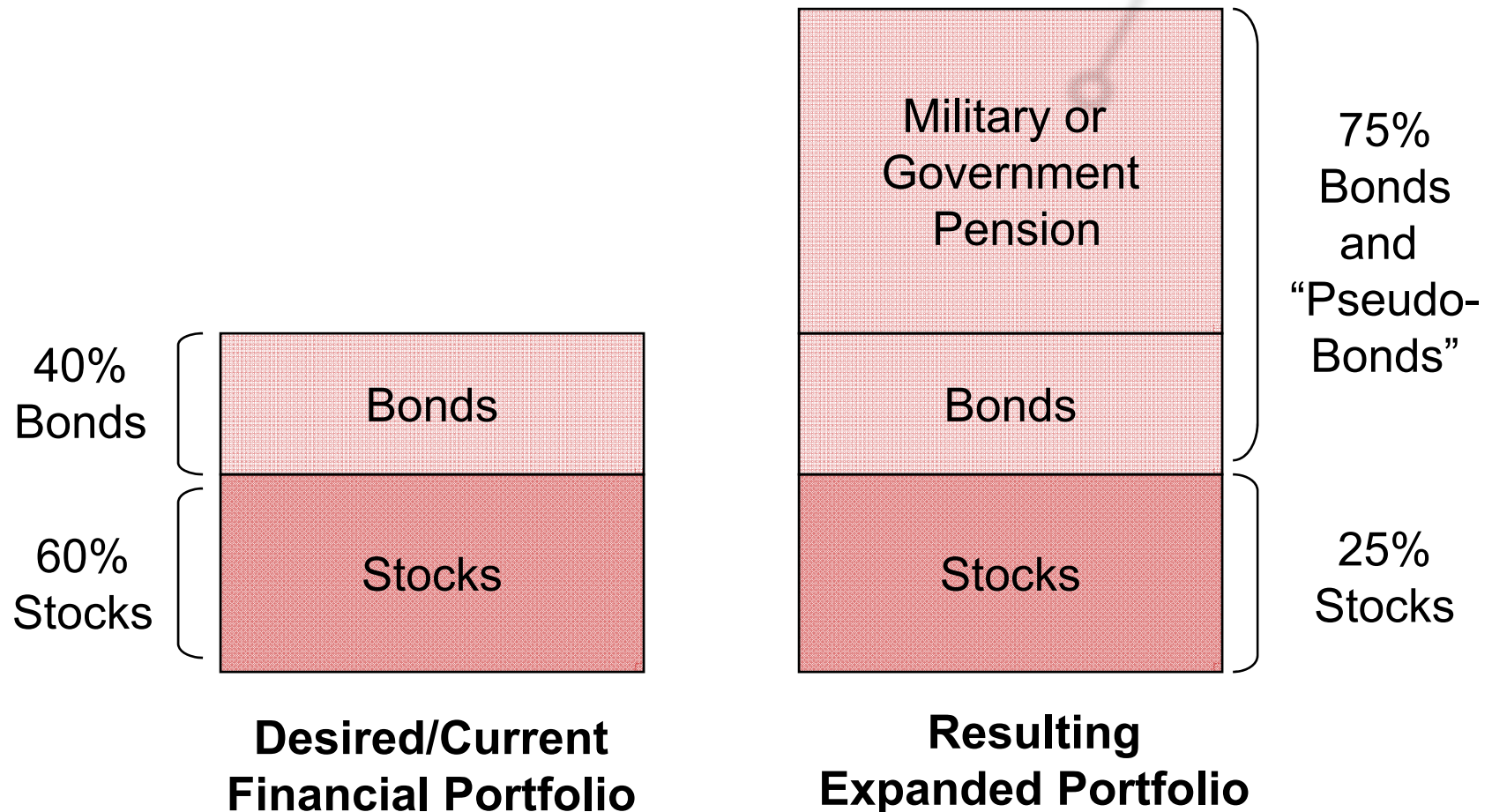
Assumptions:

- Officer currently at 18 years of service
- 28% tax bracket
- 4% TIPS rate / inflation



“Pseudo-Bond” Example

(Nestler, 2007)



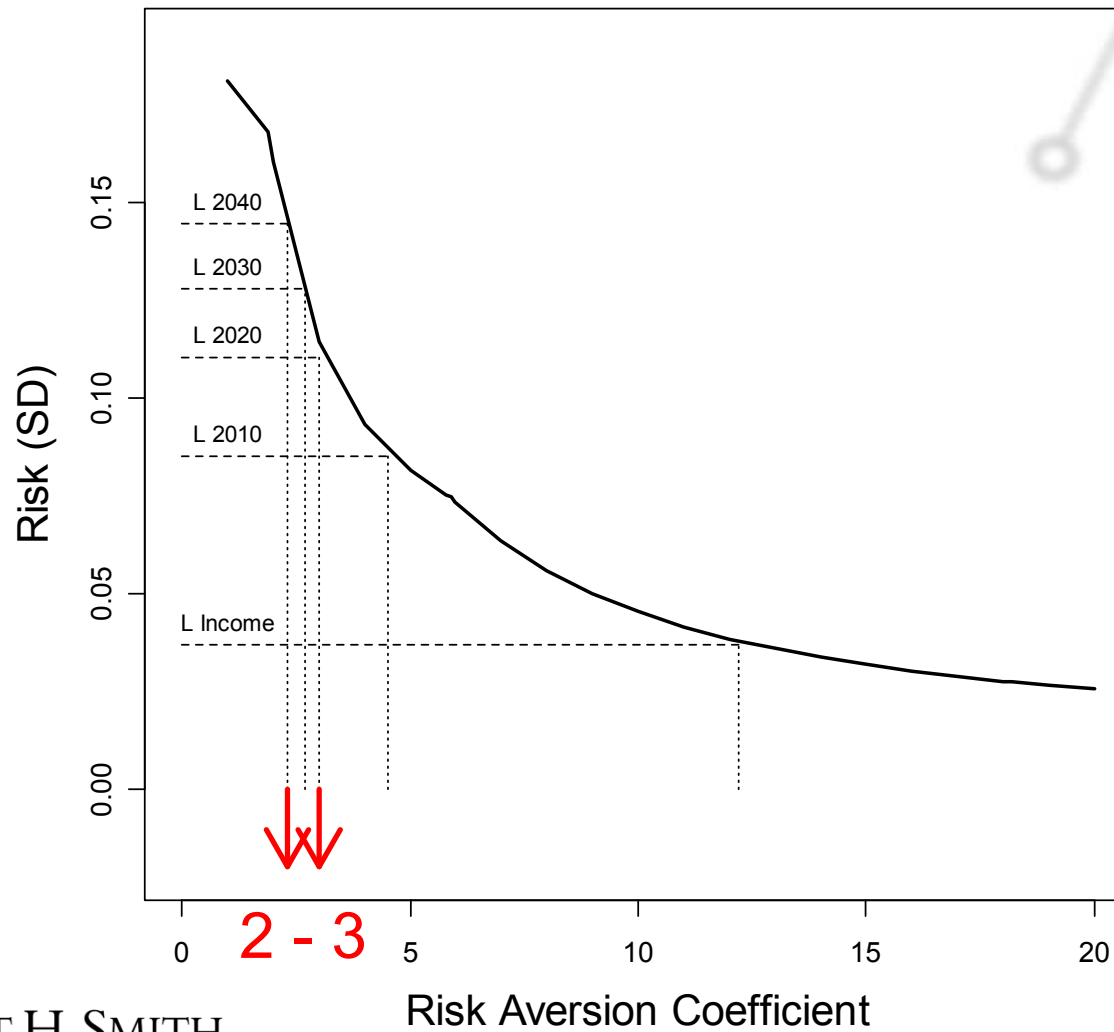
Negative Exponential Utility

$$U(w) = -e^{-cw}, \quad c > 0$$

- Constant Absolute Risk Aversion (CARA) -- no “wealth effect”
- Computational tractability advantage over other (log, power) utility functions
- Analytical solution to maximization problem is available using Certainty Equivalent (CE)
- CE is well-known for Normal and given for VG-ICA (Madan and Yen, 2004)



Implied Risk Aversion Coefficient



Portfolios for Comparison

Model	G Fund	F Fund	C Fund	S Fund	I Fund
VG-ICA (Daily)	0%	1%	43%	30%	26%
Riskless	100%	0%	0%	0%	0%
TSP "Market Portfolio"	39%	6%	39%	8%	8%
L 2030	16%	9%	38%	16%	21%
L 2040	5%	10%	42%	18%	25%

NOTE: These portfolios are created with returns assumed to be Normally distributed.



Stochastic Dominance

- Generalizes utility theory; don't need a specific utility function
- First-Order Stochastic Dominance (FOSD)
 - Assumes only monotonicity; strongest result
 - A FOSD B IFF $F_B(x) \geq F_A(x), \forall x$
- Second-Order Stochastic Dominance (SOSD)
 - Also assumes risk aversion
 - A SOSD B IFF $\int_{-\infty}^x [F_B(u) - F_A(u)] du \geq 0, \forall x$
- Easy to test with empirical data



Traditional Risk Measures

- Dispersion Measures
 - Variance (or Standard Deviation)
 - Treats gains and losses equally
 - Semi-Variance
 - Only considers observations below mean
 - Mean Absolute Deviation (MAD)
 - Average absolute deviation from the mean
- “Safety Risk” Measures
 - Value-at-Risk (VaR)
 - Expected Tail Loss (ETL)

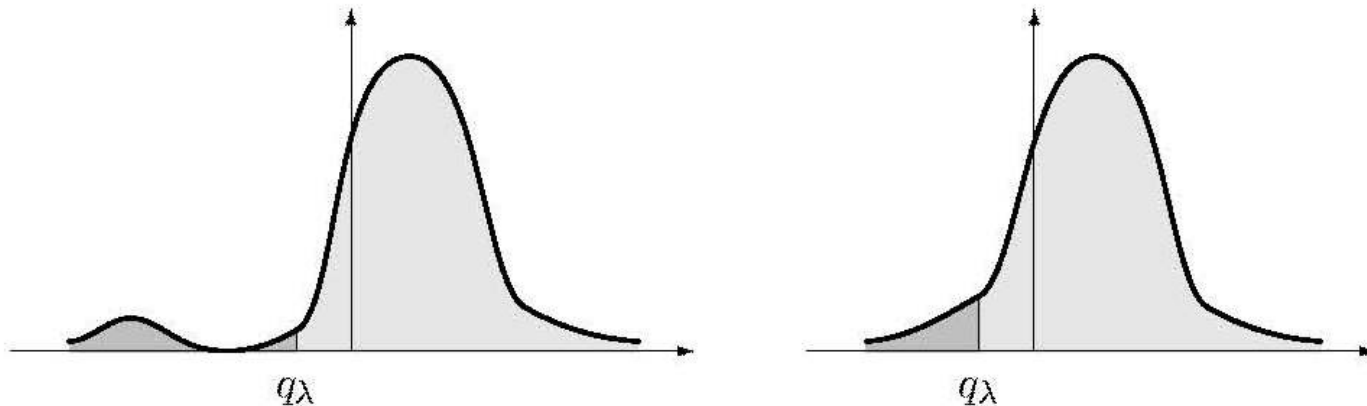


Value-at-Risk (VaR)

- “Expected maximum loss over a fixed horizon for a given confidence level”

$$P(X \geq VaR_{\lambda}(X)) = \lambda$$

- Standard risk measure for past 12 years
- Does not reward diversification
- Addresses size but not shape of tail



Coherent Measures of Risk

(Artzner, Delbaen, Eber, & Heath, 1999)

- Axioms for coherency:
 - Translation invariance $\rho(X - \alpha) = \rho(X) - \alpha$
 - Monotonicity $X > Y \Rightarrow \rho(X) > \rho(Y)$
 - Sub-additivity $\rho(X + Y) \leq \rho(X) + \rho(Y)$
 - Positive homogeneity $\rho(\lambda X) = \lambda \rho(X)$
- Variance: not monotonic or translation invariant
- VaR: not sub-additive in non-Gaussian world
- Other measures that are coherent exist.

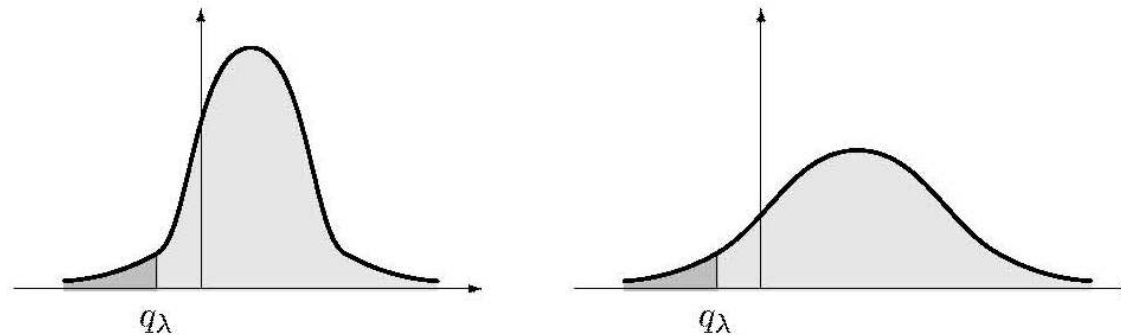


Conditional VaR

- “Expected value of all losses greater than VaR for a specified λ .”

$$CVaR_{\lambda}(X) = E[X \mid X > VaR_{\lambda}(X)]$$

- Also known as Expected Shortfall (Rockafellar & Uryasev, 2001) and Tail VaR (Acerbi, Nardio, et Al., 2001)
- Accounts for size and shape of left tail but ignores rest of distribution



Classes of Weighted VaR

(Cherny, 2006; Cherny & Madan, 2007)

$$WVaR_{\mu}(X) = \int_{[0,1]} CVaR_{\lambda}(X) \mu(dx)$$

- Beta VaR(α, β)

$$\mu_{\alpha, \beta}(dx) = B(\beta + 1, \alpha - \beta)^{-1} x^{\beta} (1 - x)^{\alpha - \beta - 1} dx, \quad x \in [0, 1]$$

- Expectation of average of the β biggest of α independent copies of portfolio loss
- Faster to estimate than CVaR

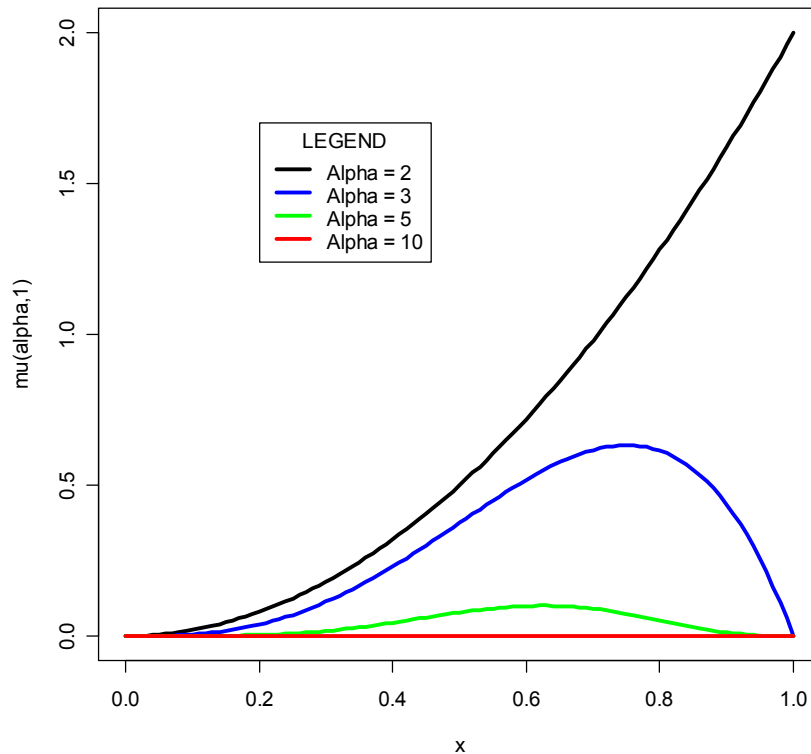
- Alpha VaR(α)

- Essentially Beta VaR with $\beta=1$
- Expectation of biggest of α copies of portfolio loss

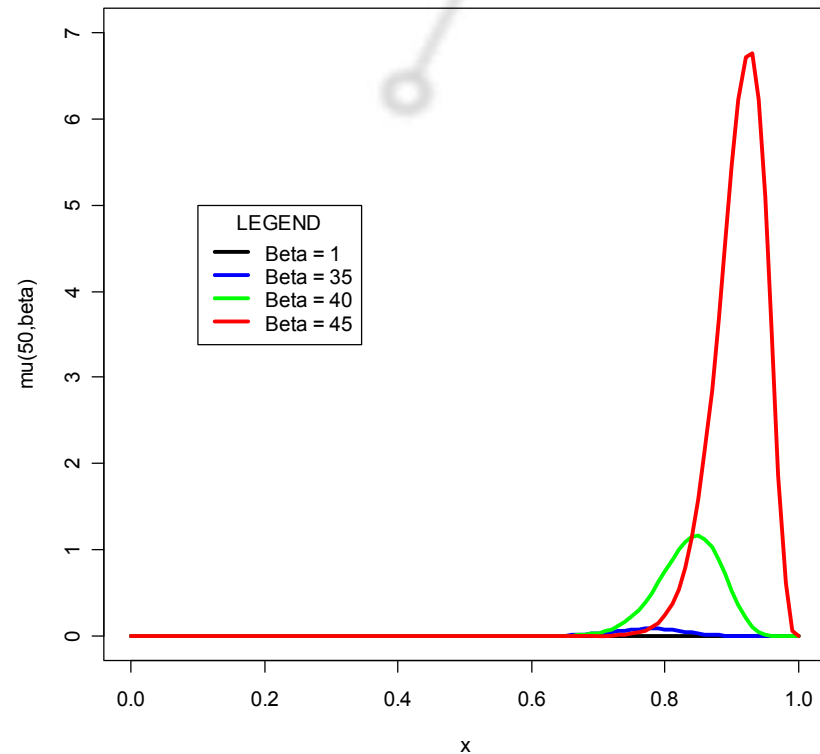


Effect of Alpha and Beta

Effect of Alpha With Beta = 1



Effect of Beta with Alpha = 50



Can allow for more risk by decreasing α or increasing β



Performance (Reward-Risk) Measures

- Sharpe Ratio

$$SR = \frac{E(X)}{\sigma_X}$$

- STARR Ratio

$$STARR = \frac{E(X)}{CVaR_{\lambda}(X)}$$

- R-Ratio
(Rachev)

$$R = \frac{CVaR_{\lambda_1}(-X)}{CVaR_{\lambda_2}(X)}$$



New Portfolio Performance Measures (Nestler, 2007b)

- Similar to R-Ratio but use Alpha-VaR and Beta-VaR in place of CVaR

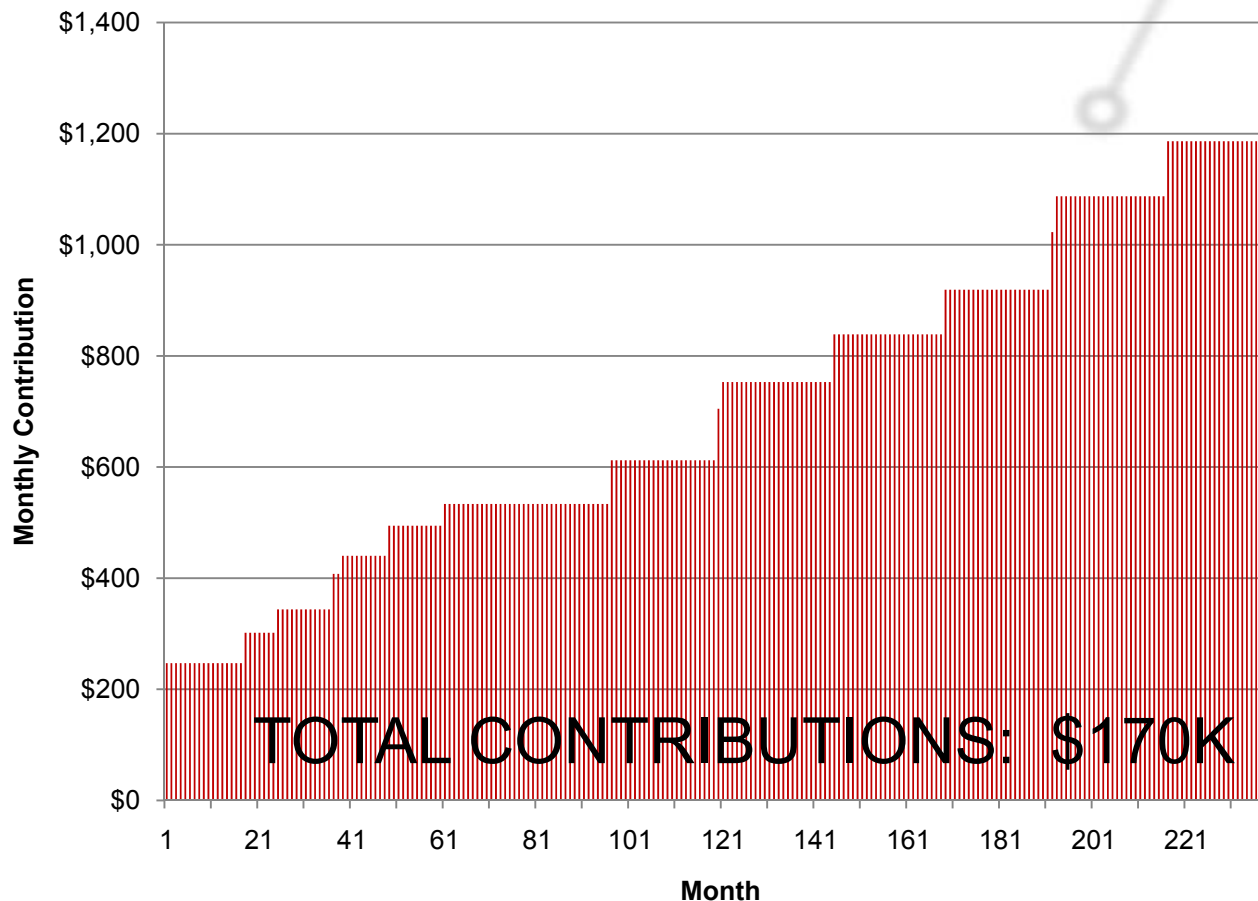
- AVaR-Ratio:
$$AVR = \frac{AVaR_{\alpha_1}(-X)}{AVaR_{\alpha_2}(X)}$$

- BVaR-Ratio:
$$BVR = \frac{BVaR_{\alpha_1, \beta_1}(-X)}{BVaR_{\alpha_2, \beta_2}(X)}$$



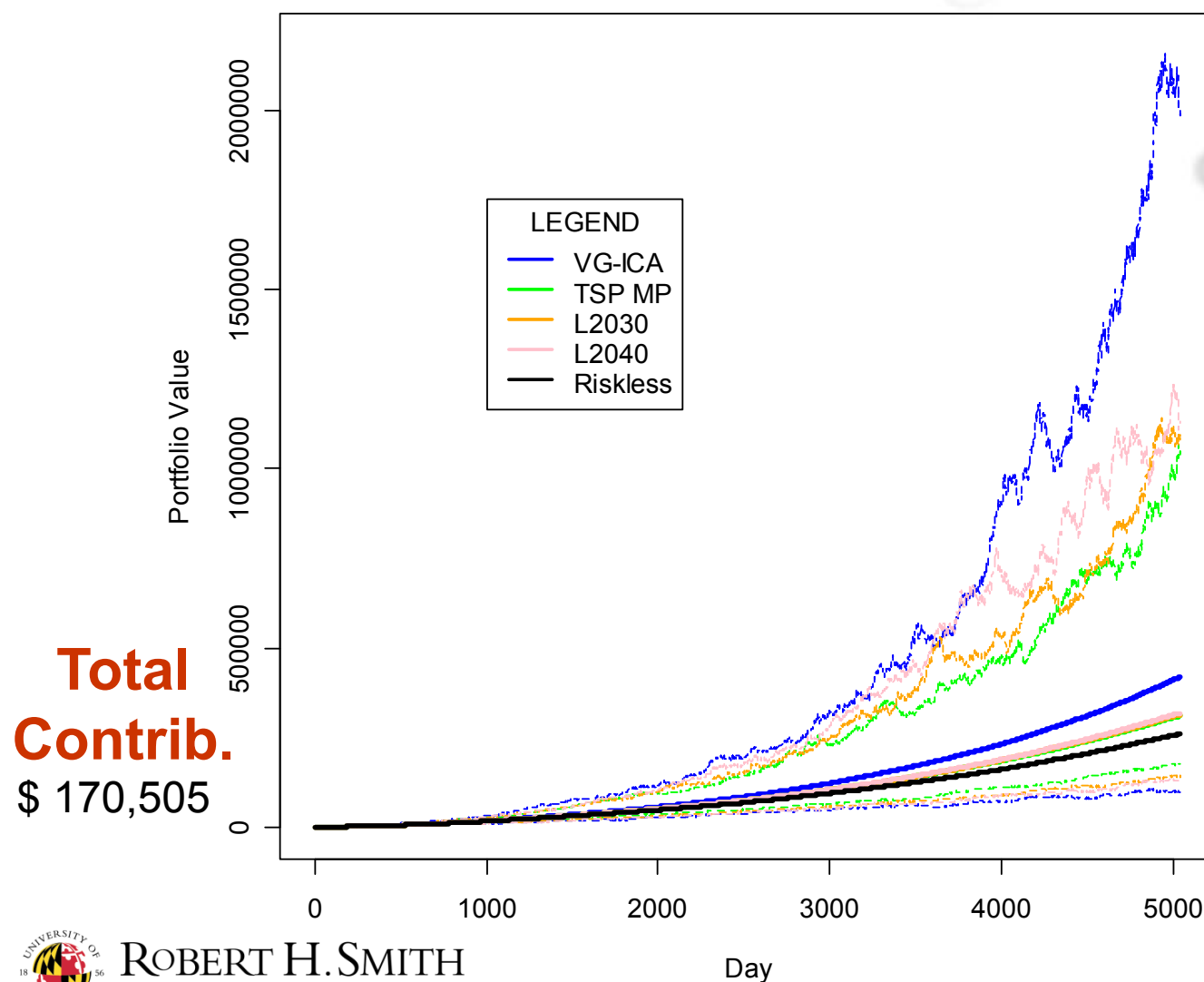
Monthly Contribution

- Assumes saving 10% of base pay each month (median for TSP)



Realistic Scenario: Portfolio Value

(5000 sample paths)



Upside Potential:

VG-ICA: \$ 1,992,133
 L2040: \$ 1,127,069
 L2030: \$ 1,093,643
 TSP MP: \$ 1,064,902

Expected Value:

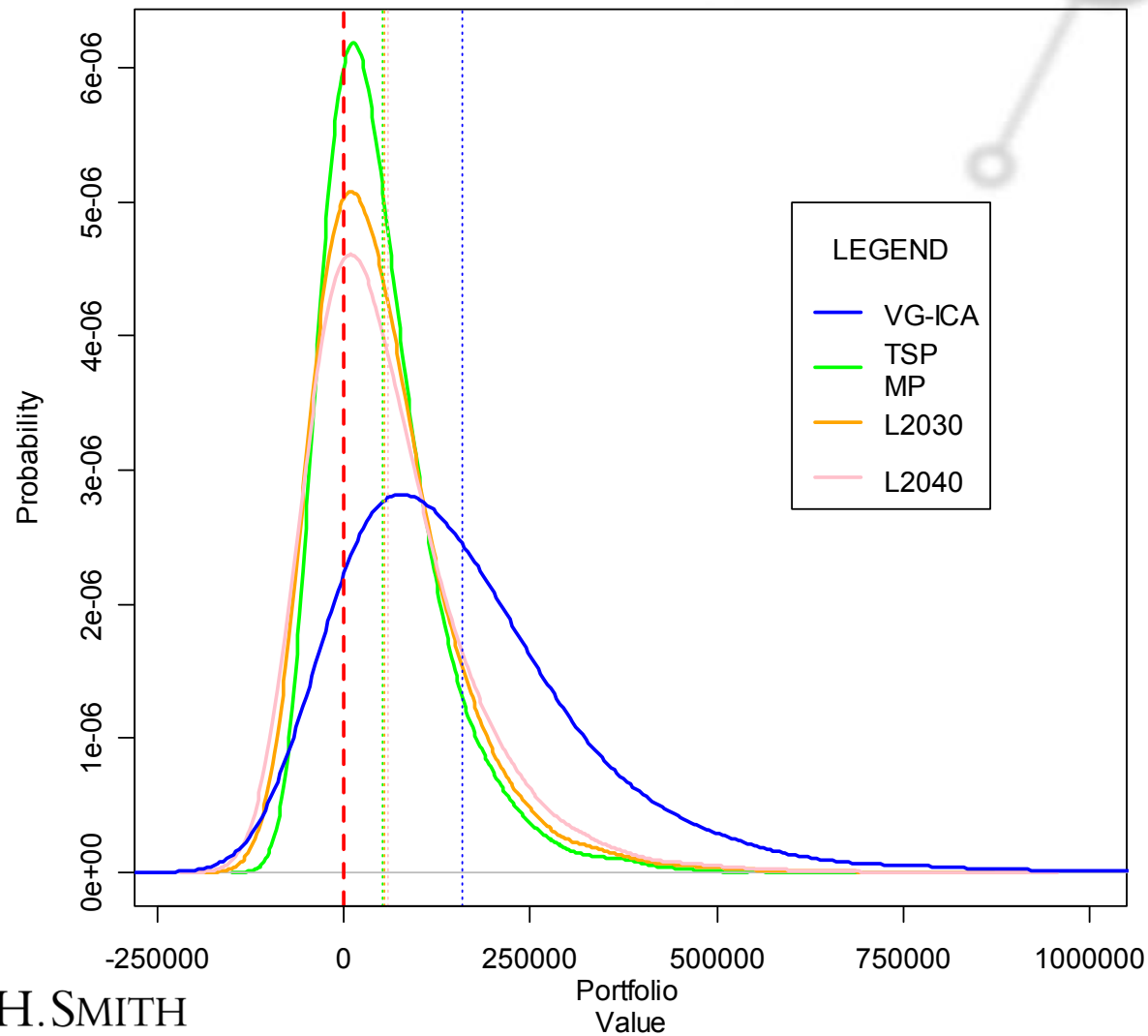
VG-ICA: \$ 418,381
 L2040: \$ 318,840
 L2030: \$ 313,936
 TSP MP: \$ 310,247
 Riskless: \$ 259,642



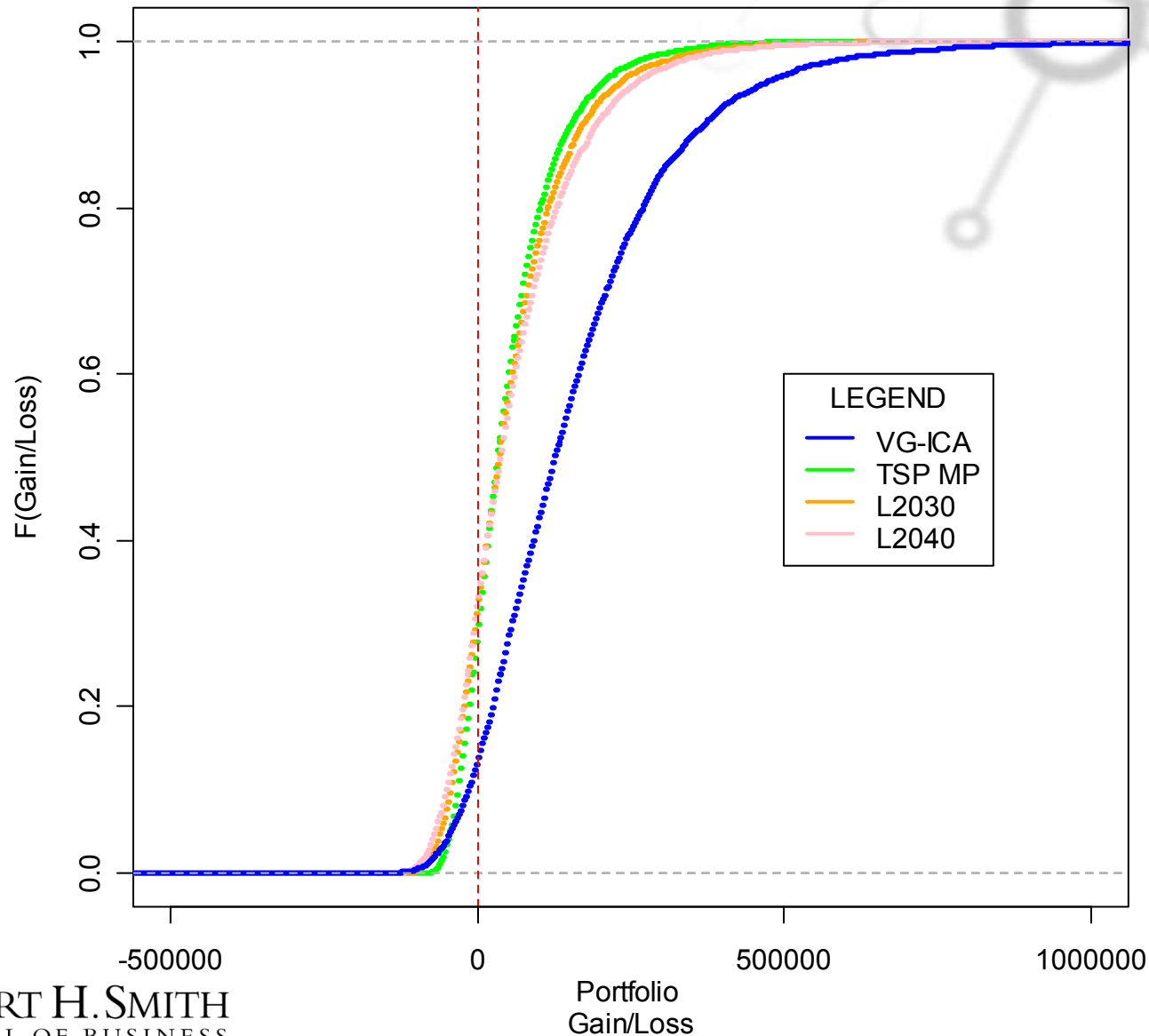
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PDF of Discounted Portfolio Value



Realistic Scenario: CDF Comparison



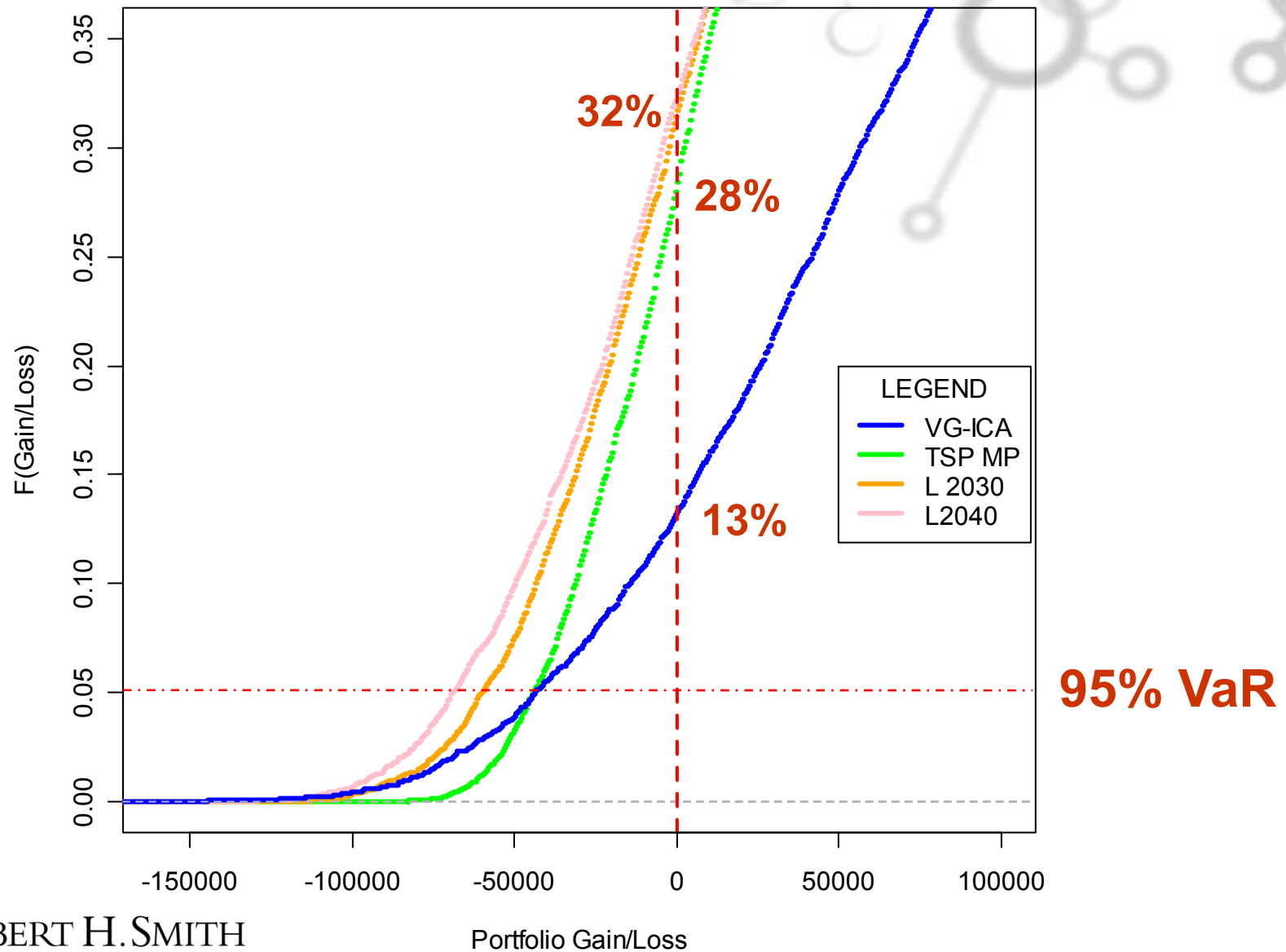
NOTE:
No SD.



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Realistic Scenario: Zoomed CDF Comparison



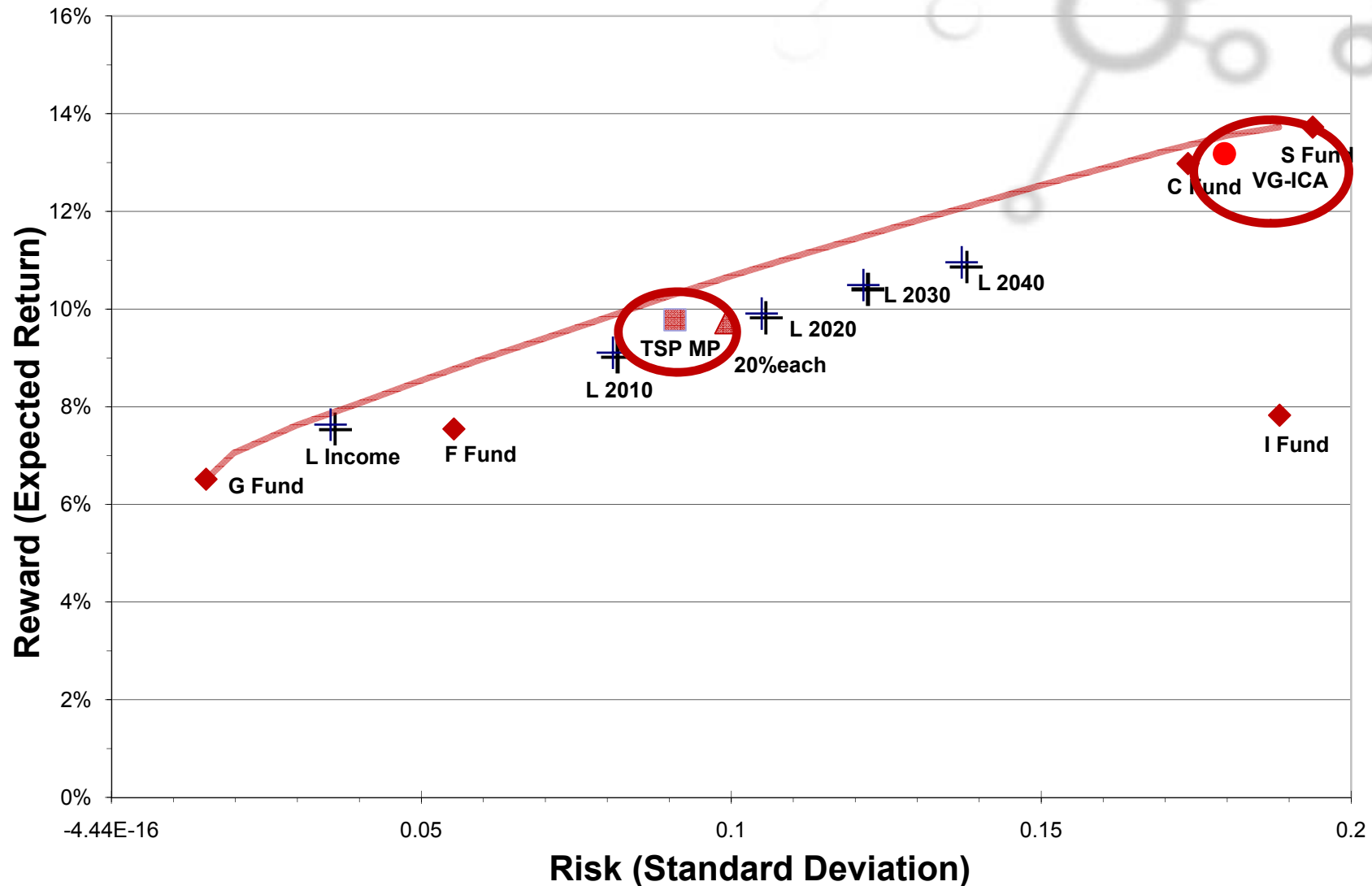
Realistic Scenario: Risk & Performance Measures

Risk Measure (↓ better)	VG-ICA	TSP MP	L 2030	L 2040
Std Dev	\$ 168,885	\$ 80,890	\$ 94,515	\$ 105,525
95% VaR	\$ 43,382	\$ 44,146	\$ 60,378	\$ 66,910
95% CVaR	\$ 68,056	\$ 54,789	\$ 74,684	\$ 82,783
Alpha VaR(50)	\$ 77,575	\$ 59,250	\$ 81,352	\$ 87,754
Beta VaR(50,5)	\$ 43,938	\$ 44,010	\$ 60,203	\$ 67,757

Performance Measure (↑ better)	VG-ICA	TSP MP	L 2030	L 2040
Sharpe Ratio	0.94	0.63	0.57	0.54
STARR Ratio	2.33	2.90	0.72	0.69
R-Ratio(.05,.05)	8.87	2.82	4.10	4.07
AVR	9.35	5.41	4.62	4.67
BVR	11.60	5.05	4.24	4.12



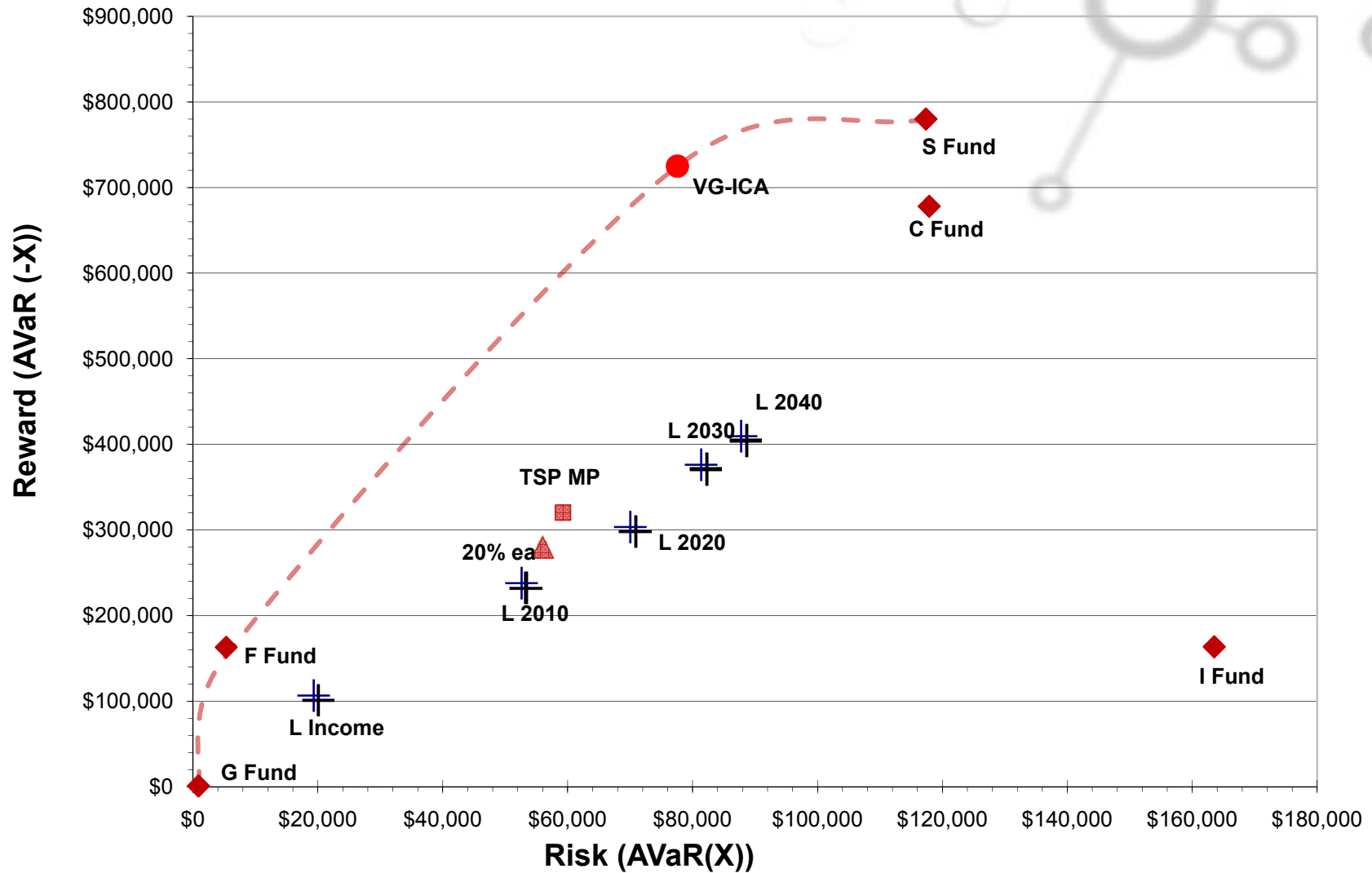
Traditional Reward-Risk Profile



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New Reward-Risk Profile



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Some Possible Answers

- Why might I be more risk tolerant than I currently believe?
 - Counting military or government pension as “pseudo-bonds” could change the target stock-bond asset mix.
- What are the L (Lifecycle) funds? How are they constructed? Why might they be of interest (or not) to me?
 - “Set it and forget it” funds built using mean-variance optimization with returns assumed to be distributed Normally.
 - Depends on an individual’s level of interest and involvement.
- What if stock and index fund returns are not normally distributed, as is commonly assumed?
 - Possible to take advantage of information contained in higher moments.
- How does choosing reward-risk measures affect optimal TSP portfolios?
 - Ability to capture information from entire distribution is useful.
 - Need to do further work on optimizing performance measures instead of using expected utility.





QUESTIONS?



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