Bank Risk Management with Value-at-Risk and Stress Testing: An Alternative to Conditional Value-at-Risk?

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I. Outline

1. Introduce Value-at-Risk (*VaR*) as a portfolio risk measure
2. Introduce Conditional Value-at-Risk (*CVaR*) as a portfolio risk measure
3. Introduce Stress Testing (*ST*)

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3. Introduce Stress Testing (*ST*)
4. Discuss Basle Committee on Bank Supervision
5. Present the issue at hand
6. Describe methodology

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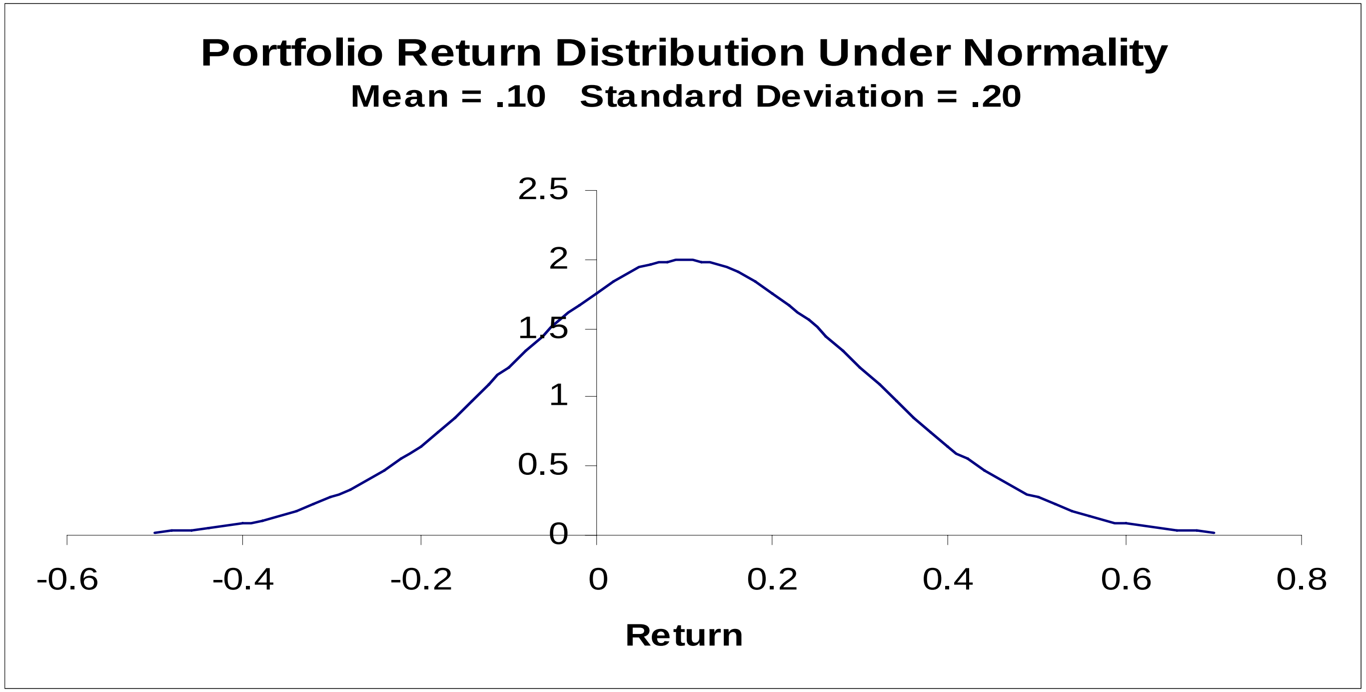
6. Describe methodology
7. Present no short selling results
8. Present short selling results
9. Conclude

II. *VaR*

Consider *99%* confidence level & normal distribution of *annual* returns



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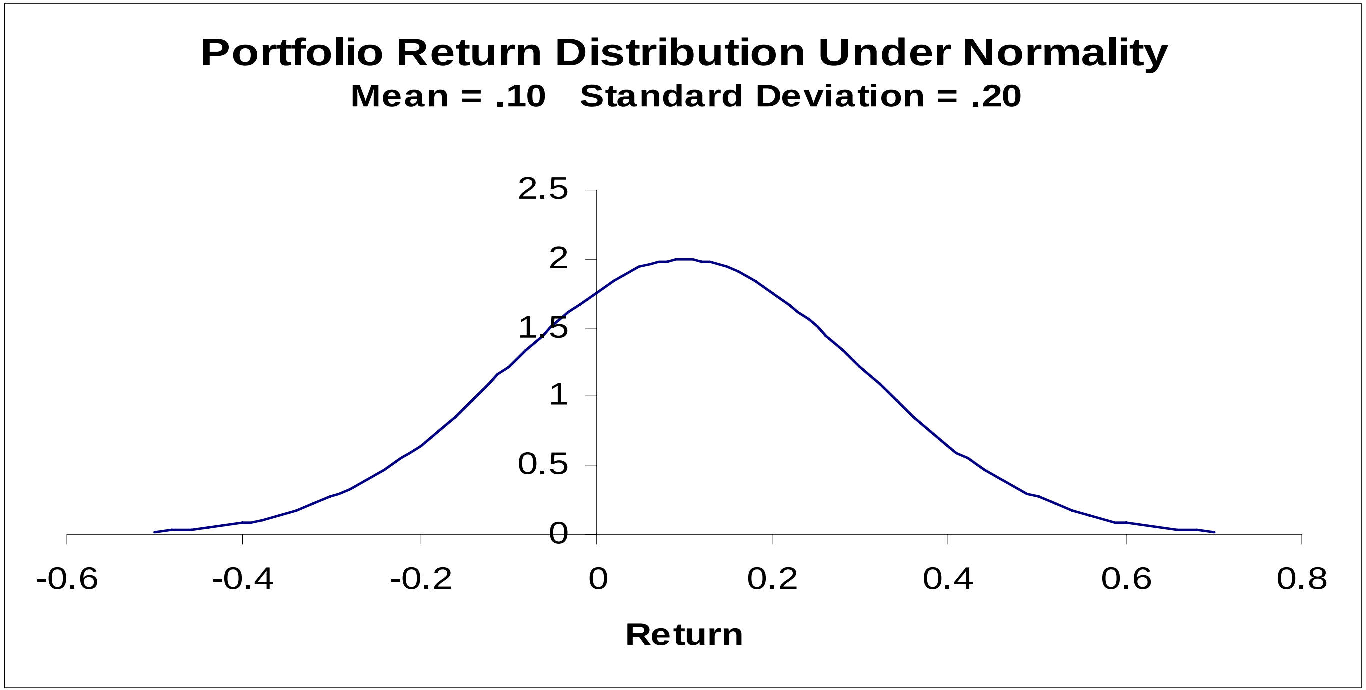

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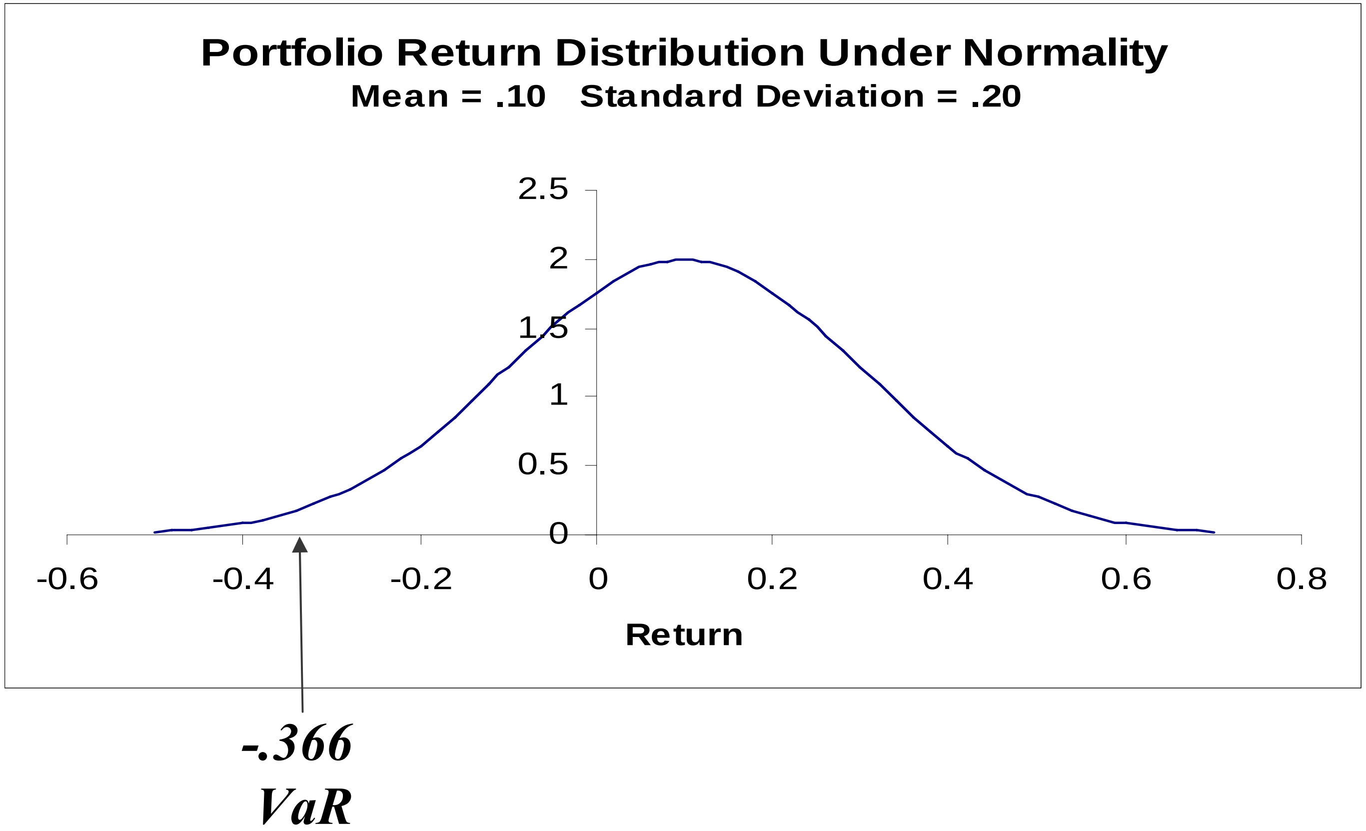

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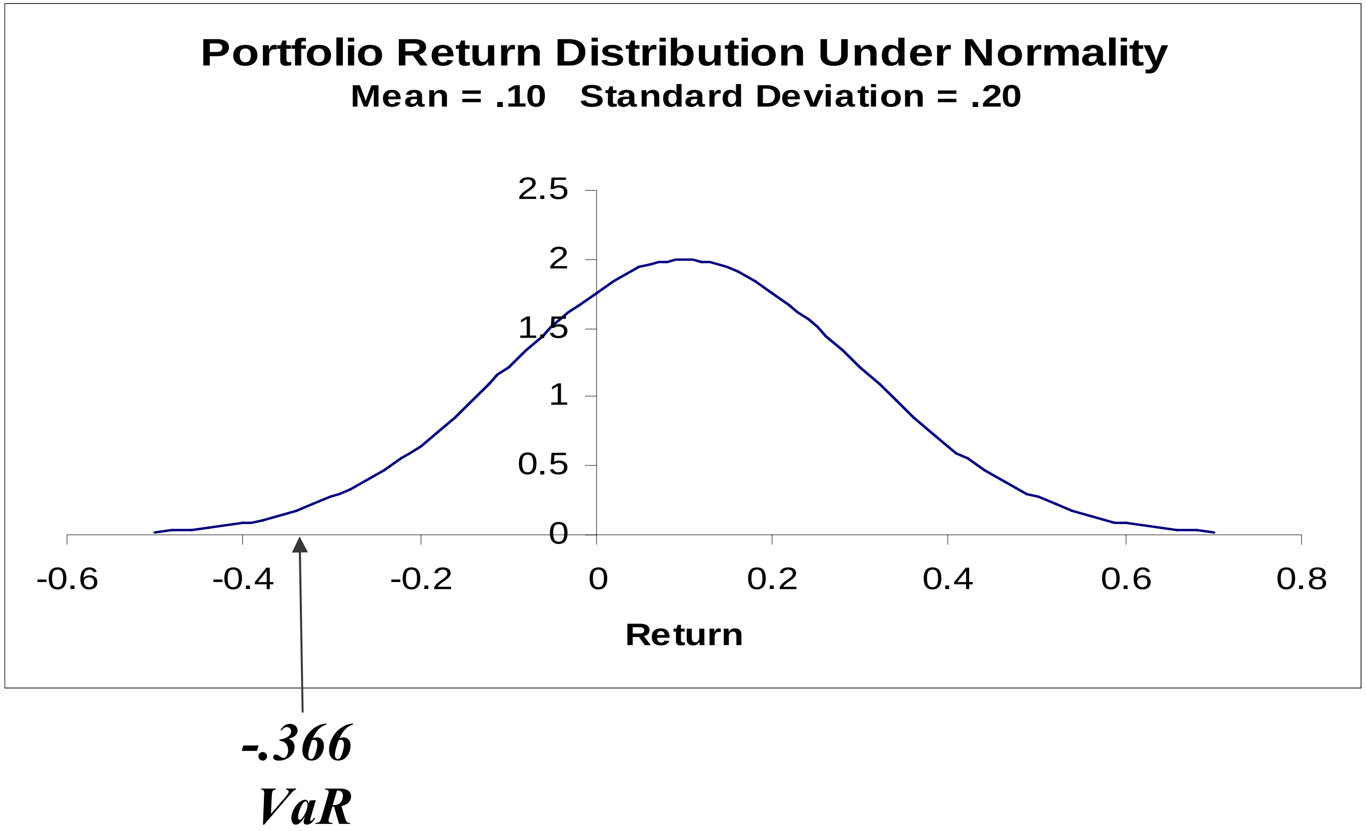

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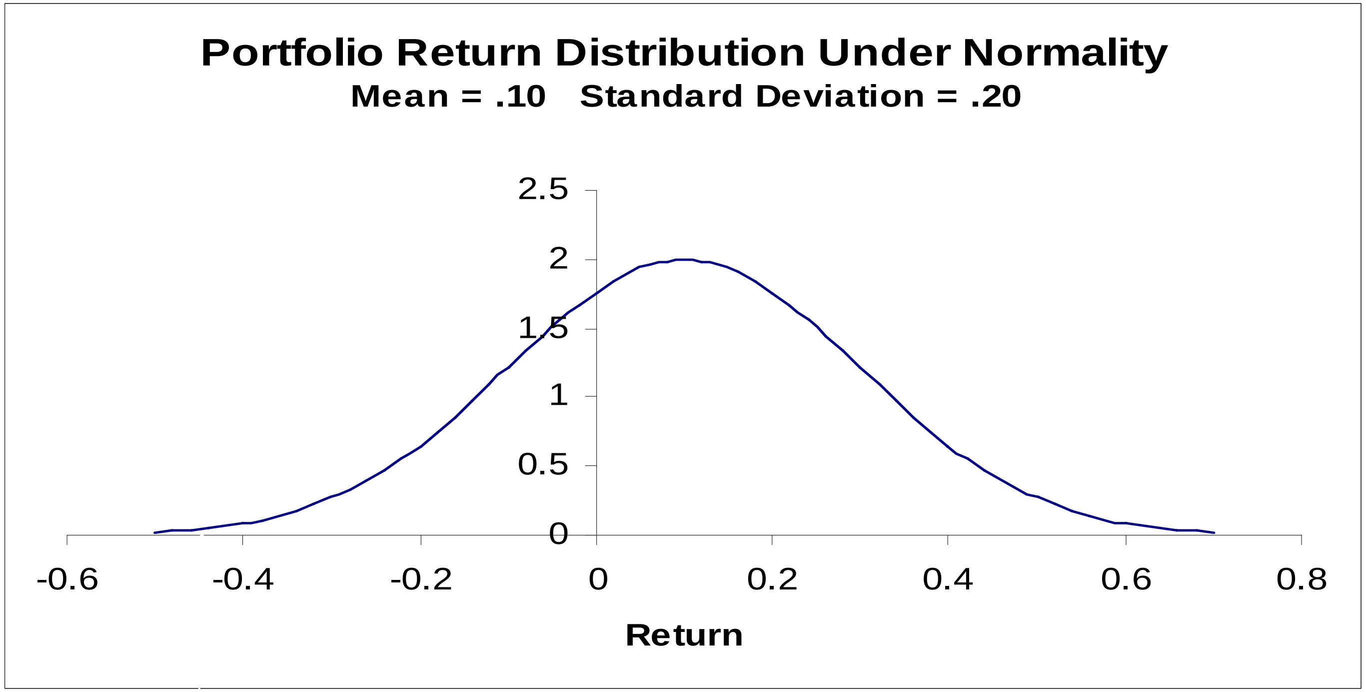
Trading portfolio of $1,000,000,000 is expected to lose <u>at least</u> $366,000,000 if a "bad event" occurs

III. *CVaR*

Consider a normal distribution of *annual* portfolio returns



- Expected return in the 1% tail is 2.665 standard deviations below the mean

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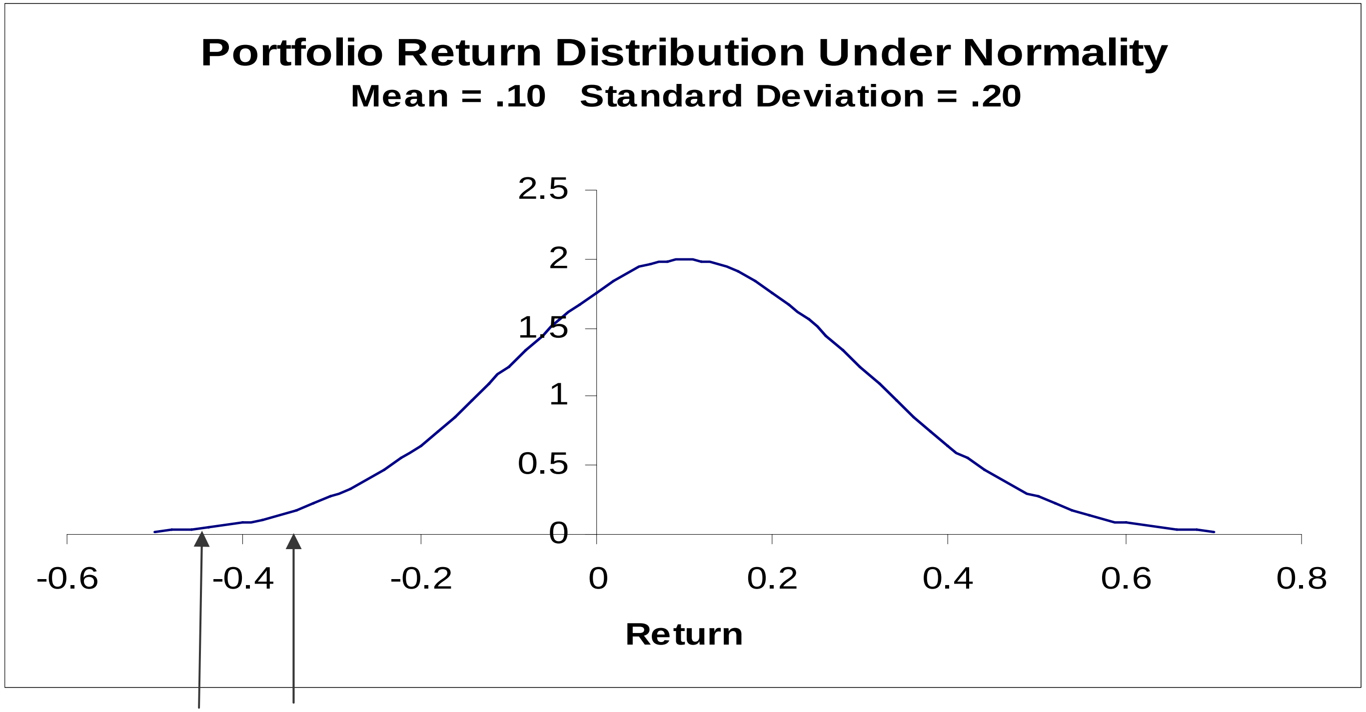

-.433 *-.366*

CVaR *VaR*

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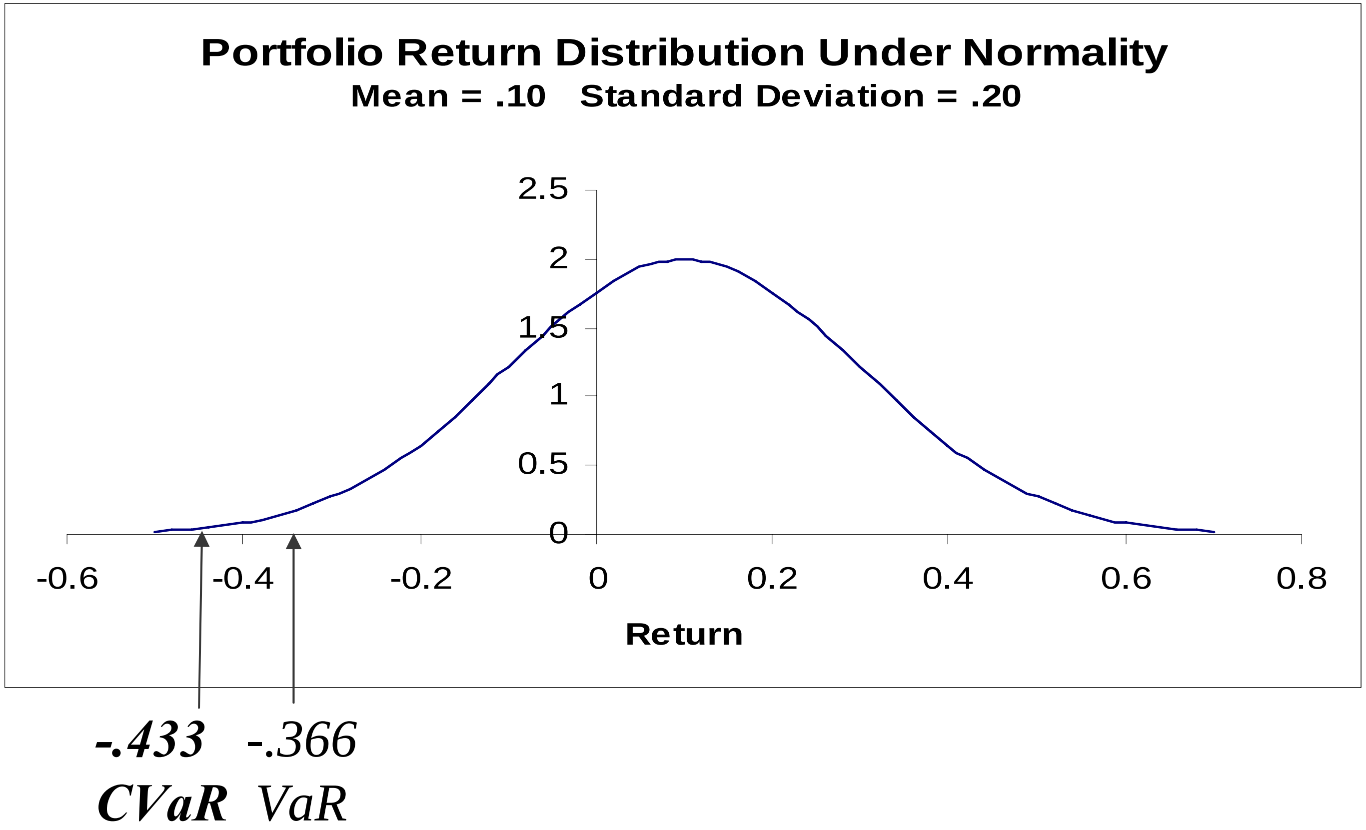

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- Black Monday 1987
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B. Emergence of Stress Testing (*ST*)

- Specify states (actual or hypothetical) where extreme events occur
- Specify security returns in these states
- Constrain portfolio loss to be equal to or less than T_i if stress event *i* occurs

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- Our concern: trading portfolios as regulated by BCBS
  - Focus on price risk of:
    - Equities, interest related securities, foreign exchange, commodities

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     - Average *VaR* over last 60 trading days multiplied by 3 (or up to 4 if regulators deem the *VaR* system to be deficient)
  5. Stress testing is required in reviewing capital adequacy
     - Viewed as a supplement to *VaR*
     - Risks are to be managed when tests show "particular vulnerability"

VI. The Issue at Hand

- Theory:
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Bounds must be "appropriate"

VII. Methodology

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  - Government bonds
  - Corporate bonds
  - Six size/value-growth portfolios of Fama-French
- *ST* events:
  - 1987 stock market crash
  - 9-11
- Time Period
  - 1982-2006
  - Monthly data (also use daily data for *ST*)

- # Data: Table 1 (in %)

	Treas. bills	Govt. bonds	Corp. bonds	Fama-French portfolios: Small Low	Small Inter.	Small High	Big Low	Big Inter.	Big High
Mean	0.43	0.73	0.83	0.82	1.44	1.58	1.10	1.22	1.27
Std. dev.	0.00	1.47	1.65	6.82	4.81	4.65	4.74	4.19	4.12
$VaR_{95\%}$	-0.43	1.66	1.61	9.13	5.46	5.53	6.92	4.52	5.60
$VaR_{99\%}$	-0.43	2.44	3.11	16.23	12.93	14.38	10.91	9.37	10.21
$CVaR_{95\%}$	-0.43	2.41	2.71	14.82	10.37	10.23	10.12	8.56	8.88
$CVaR_{99\%}$	-0.43	3.34	3.75	24.48	20.20	19.91	16.36	16.11	14.50
	Returns in ST events								
Crash of 87	0.04	0.34	-0.55	-13.03	-11.12	-10.97	-17.94	-18.60	-17.92
9/11	0.16	0.69	-0.60	-15.06	-13.14	-15.34	-11.72	-11.36	-11.72

Data is "normal" – note size, BV/MV, and return/risk relationships

- **Consider six cases**

  Case A. No short selling

  A1. *VaR* constraint

  A2. *ST* constraints

  A3. *VaR* + *ST* constraints

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Case A. No short selling

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Case B. Short selling

B1. *VaR* constraint

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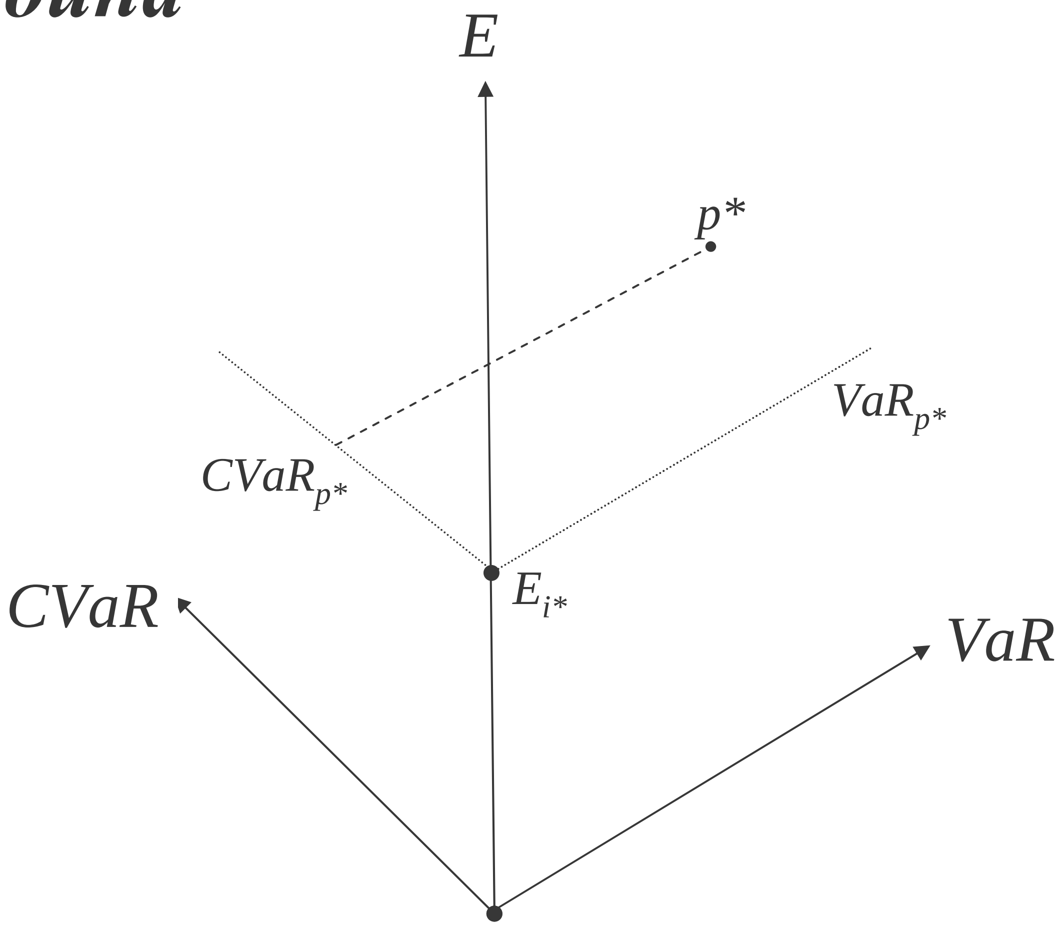
➔ Set constraints with either fixed or variable bounds in each case:

$$VaR_p \leqslant V$$
$$T_{1,p} \leqslant T_1$$
$$T_{2,p} \leqslant T_2$$

V*, *T1*, *T2* are bounds for constraints on portfolio *p

- **Graphical Representation:**

Fixed Bound



For given expected return E_{i*}, portfolio p* has minimum CVaR

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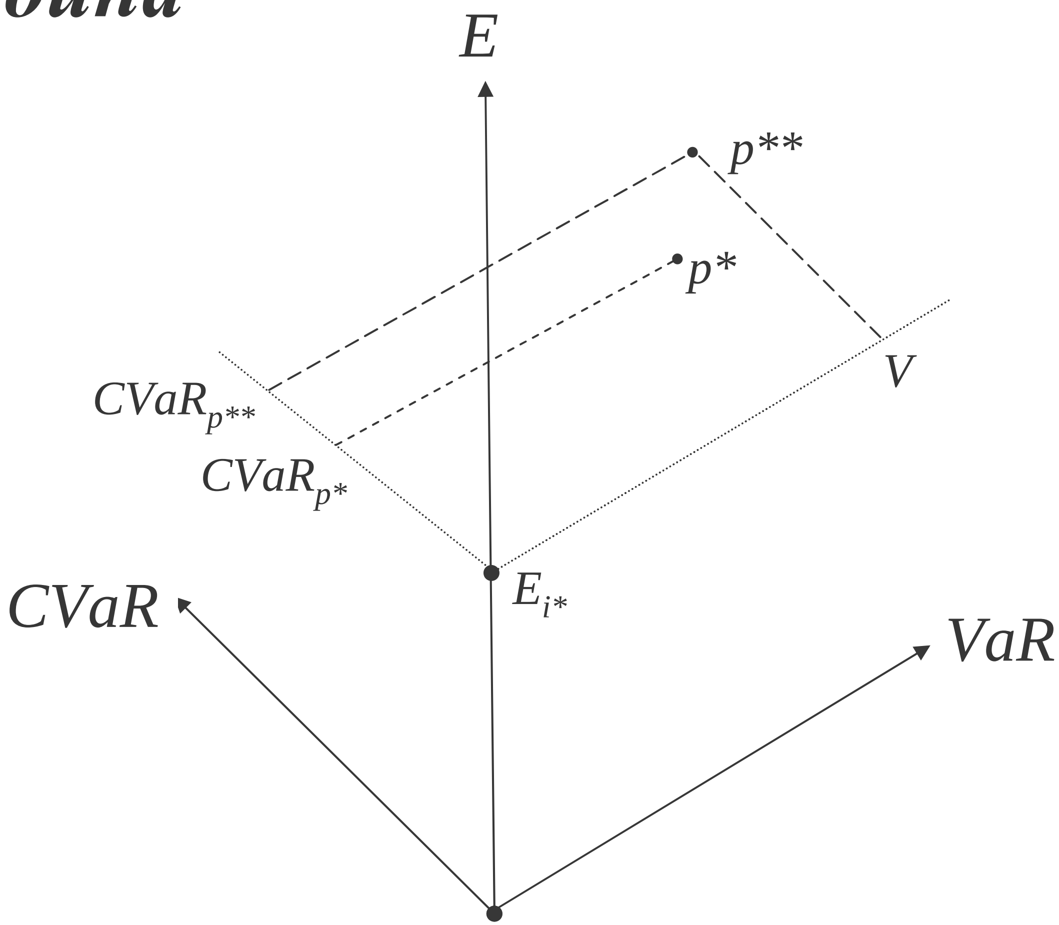
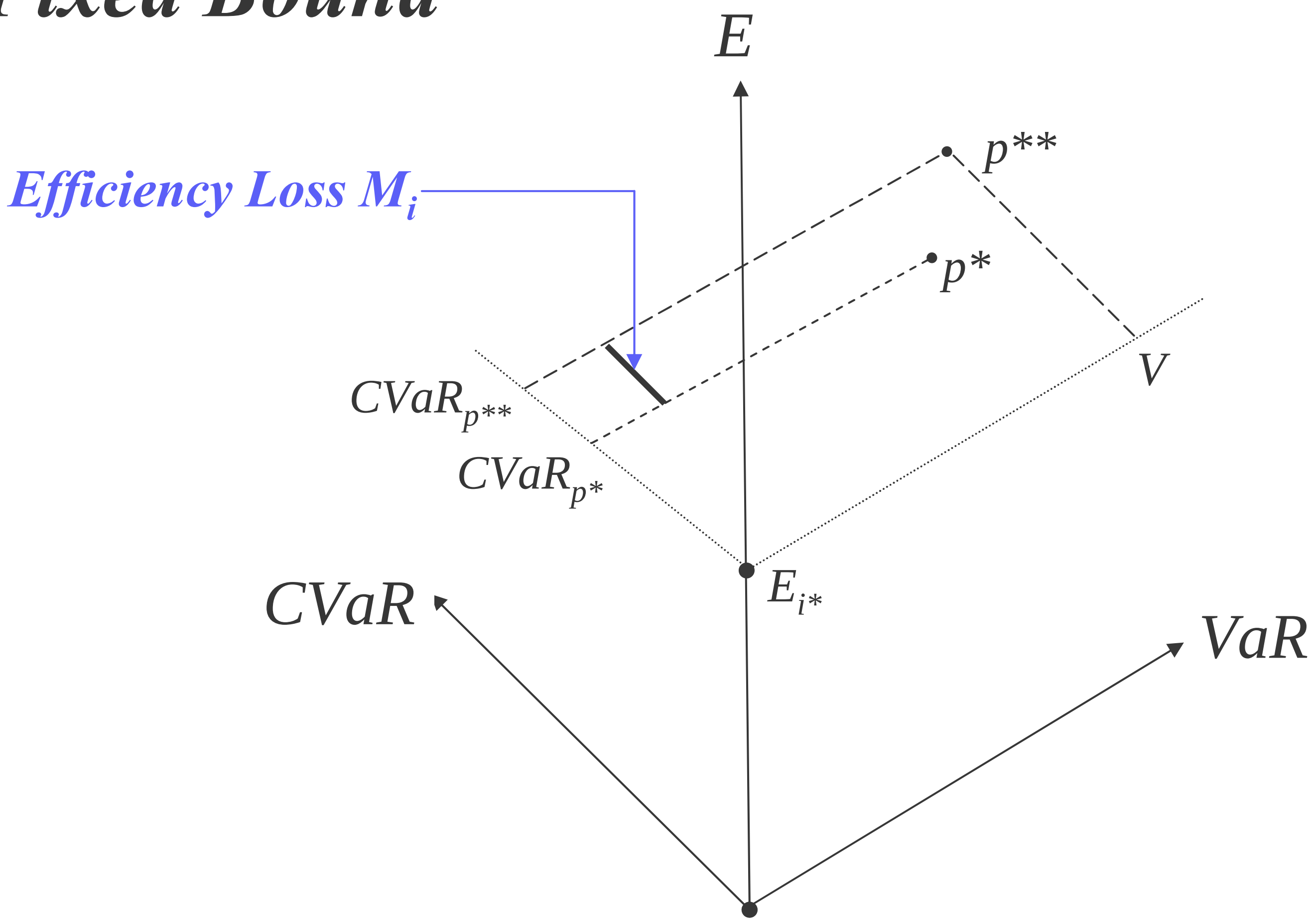


Of all portfolios with expected return E_{i*} and VaR ≤ V, portfolio p** has maximum CVaR

• Graphical Representation:

Fixed Bound



Efficiency loss of portfolio p** is equal to $CVaR_{p^{**}} - CVaR_{p^*}$

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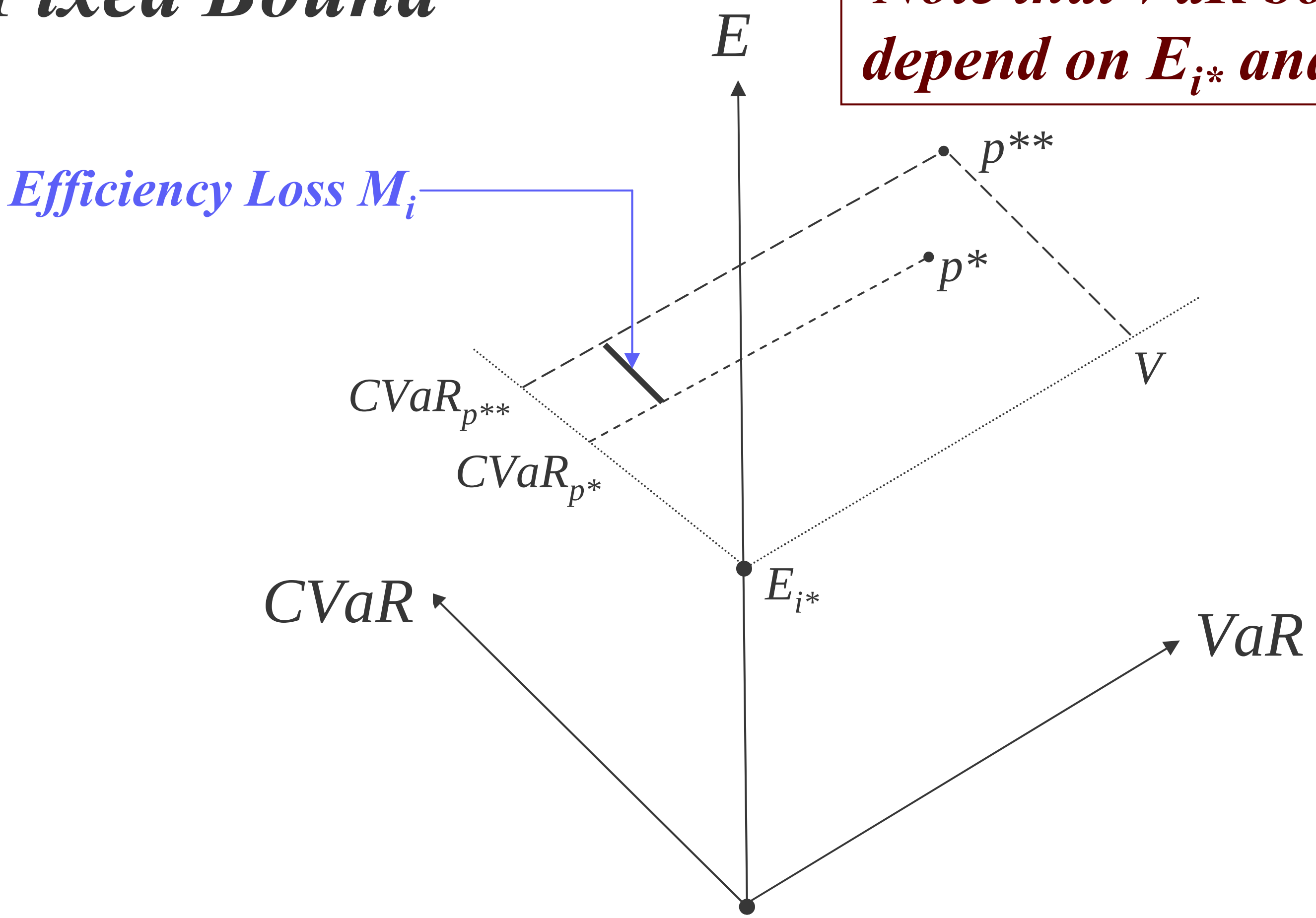
Note that VaR bound V does not depend on E_{i*} and is thus "fixed"



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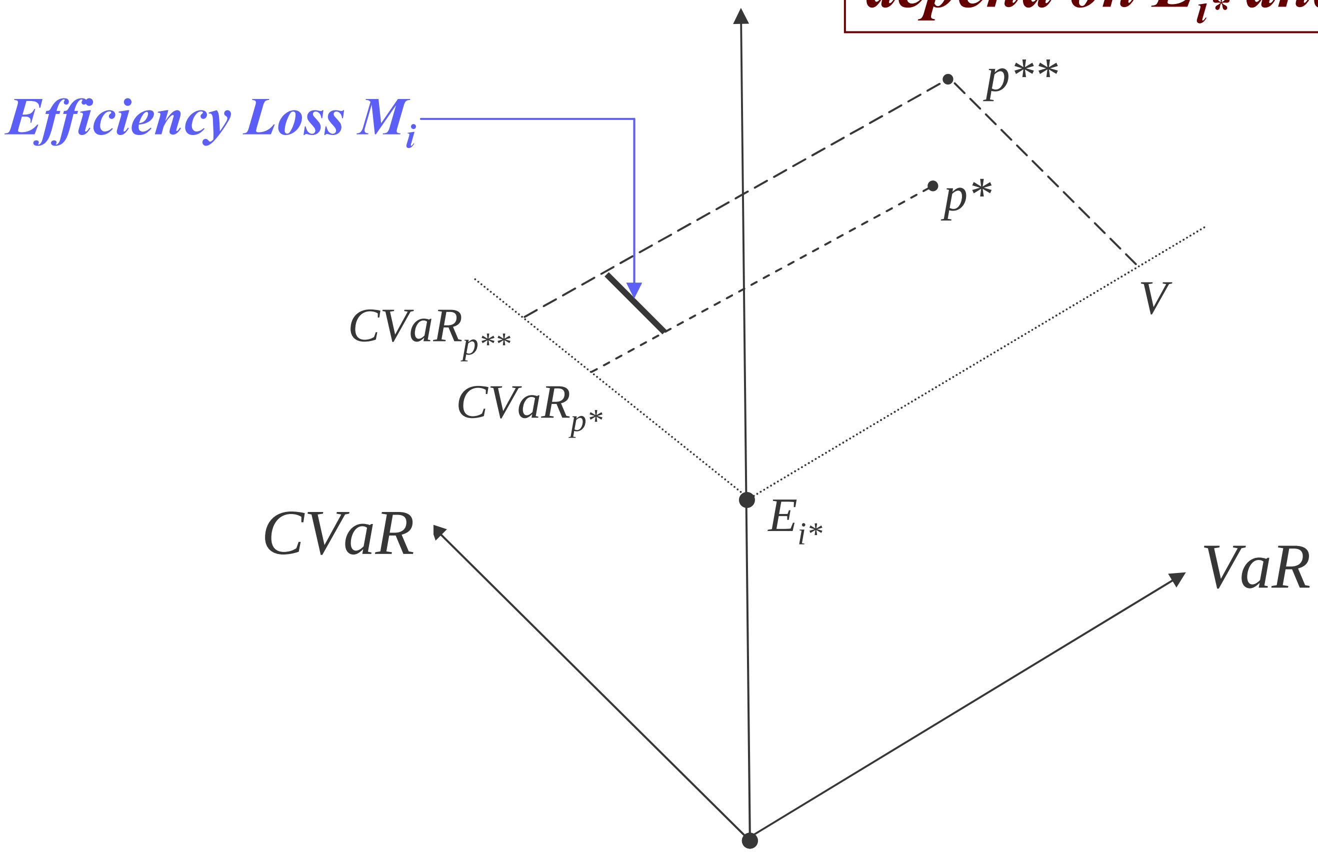
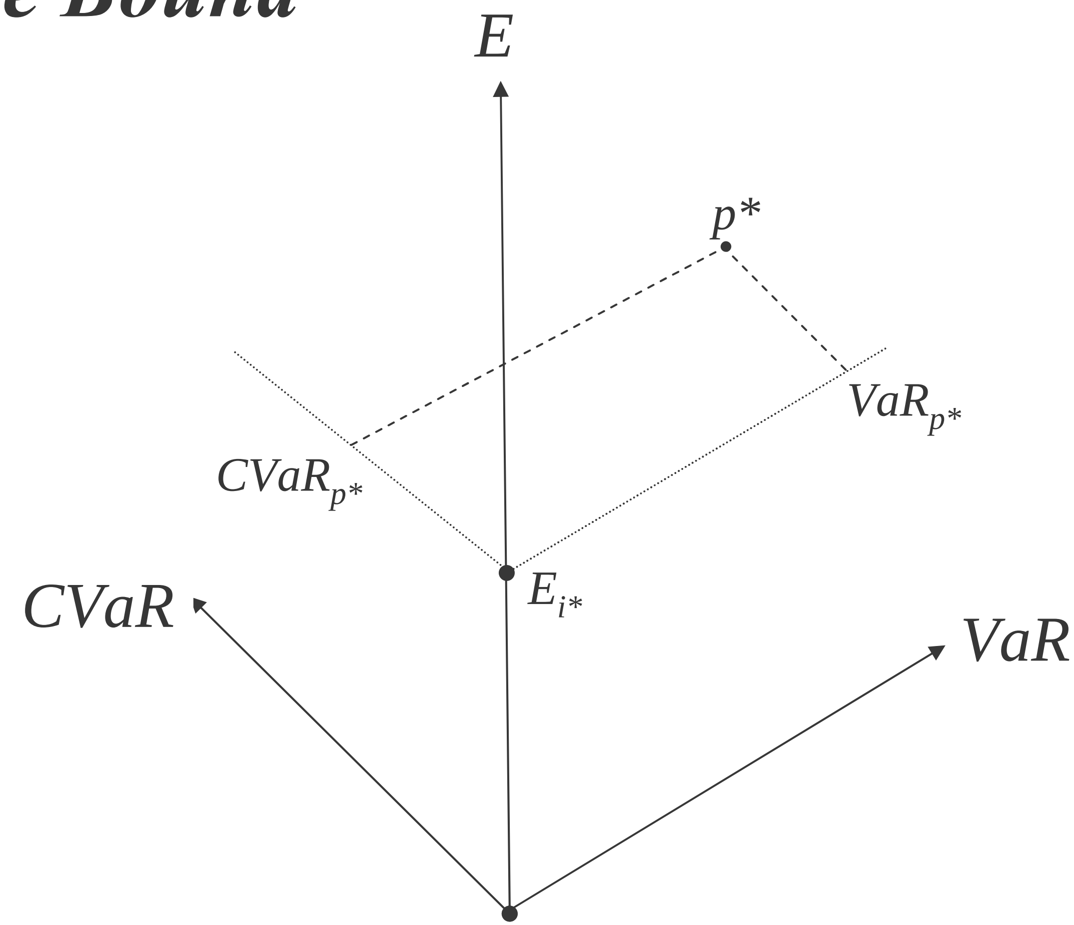


Determine average efficiency loss (AL) and global efficiency loss (GL) from 101 values of M_i

- **Graphical Representation:**
  Variable Bound



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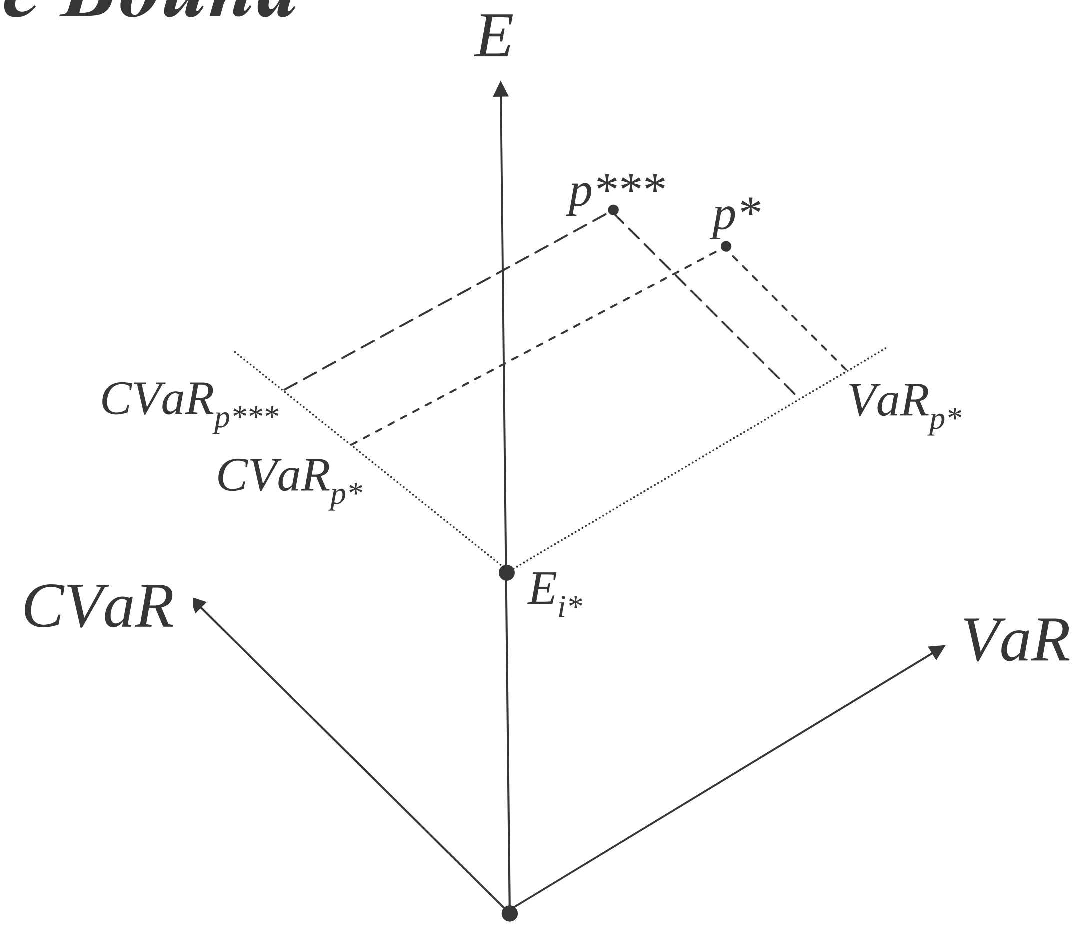

Of all portfolios with expected return E_{i*} & $VaR \leq VaR_{p*}$, portfolio p has maximum CVaR***

- **Graphical Representation:**

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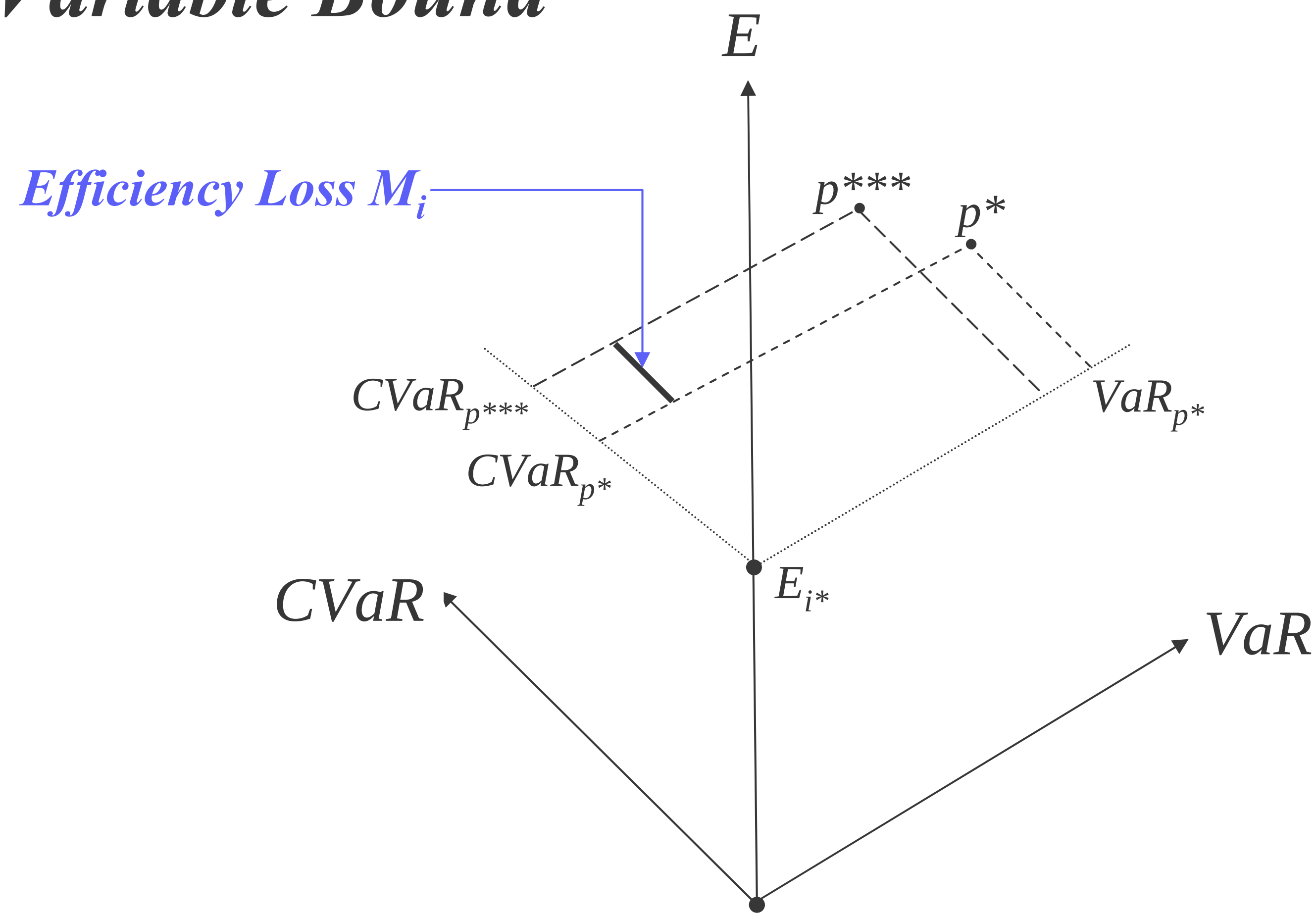

Efficiency loss of portfolio p is equal to*** $CVaR_{p^{***}} - CVaR_{p^{*}}$

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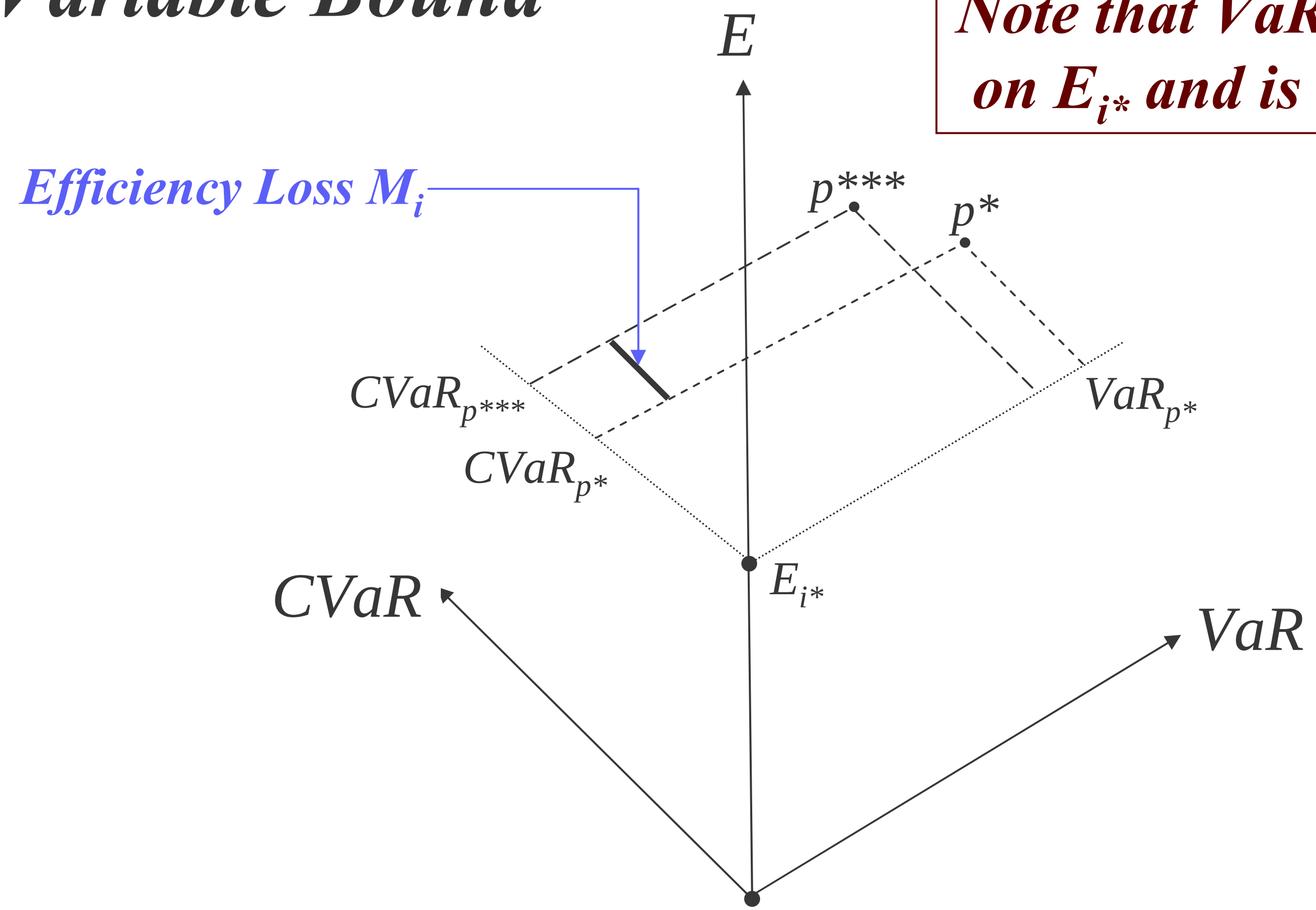
Note that VaR bound depends on E_{i*} and is thus "variable"



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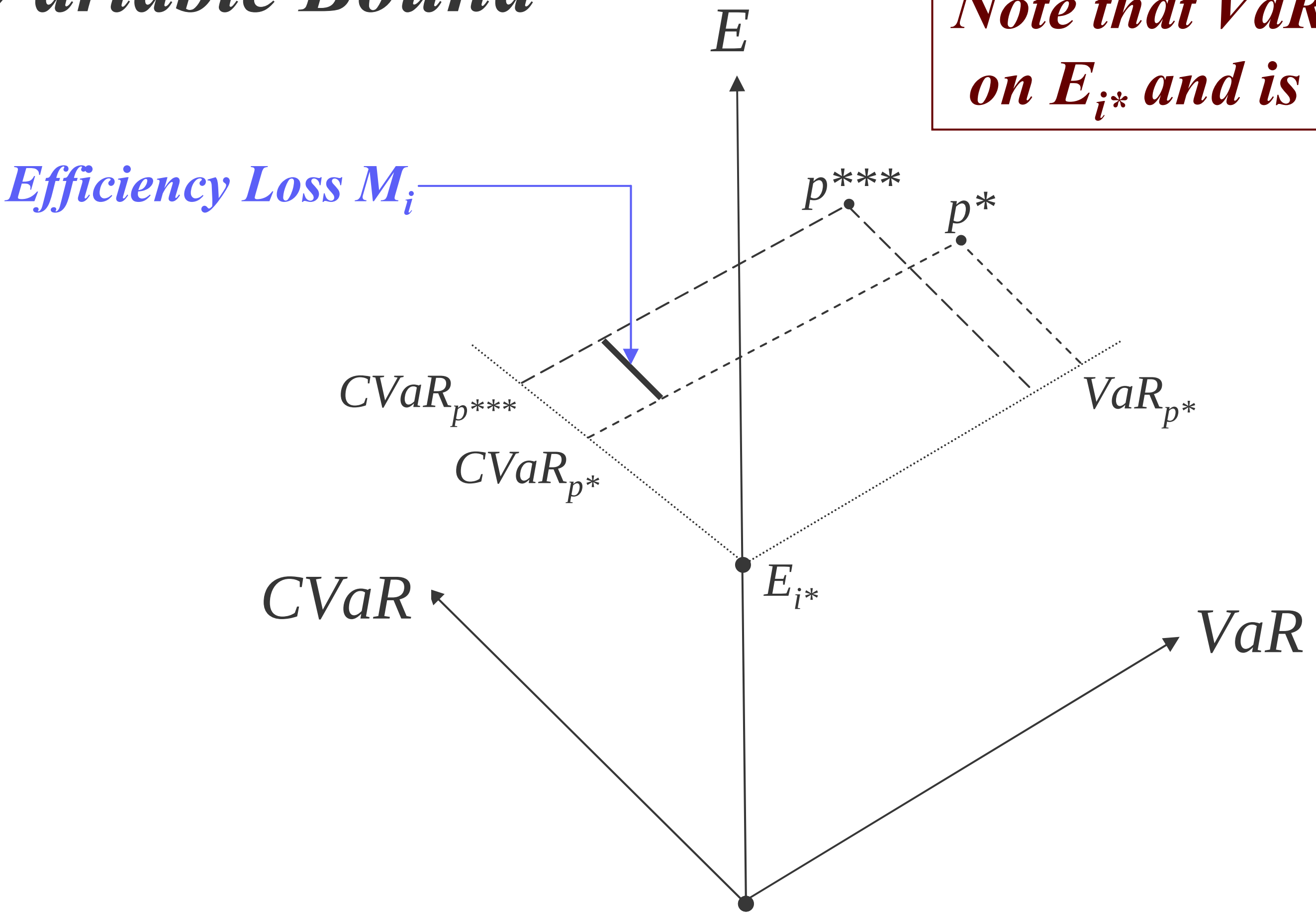


Determine average efficiency loss (AL) and global efficiency loss (GL) from 101 values of M_i

• Figure 1: Determining Efficiency Losses

Step 1 : Choose confidence level and bound(s)

↓

Step 2 : Find maximum feasible expected return $\bar{E}$ given the constraint(s)

↓

Step 3 : Calculate $\delta = (\bar{E} - \underline{E})/100$ where $\underline{E}$ is the risk-free rate

↓

Step 4 : Determine grid of 101 expected returns $E_1 = \underline{E}$; $E_2 = \underline{E} + \delta$; $E_3 = \underline{E} + 2\delta$; ... ; $E_{101} = \bar{E}$

↓

Step 5 : Solve for maximum efficiency loss M_i for each expected return E_i

↓

Step 6 : Find Average and Global Maximum Efficiency Losses *AL* and *GL* from the 101 values of M_i

We are agnostic about the model used to select portfolios, as our focus is on controlling CVaR

VIII. Case A1: No Short Selling, *VaR*

- Constraint with fixed bound: $VaR_p \leqslant 2\%$ and $VaR_p \leqslant 4\%$

α	95%		99%	
V	2%	4%	4%	8%
Average maximum efficiency loss	2.03	3.97	4.46	8.38
Global maximum efficiency loss	3.27	5.91	6.20	11.79
Maximum feasible expected return	1.10	1.38	1.03	1.26

VIII. Case A1: No Short Selling, *VaR*

- Constraint with fixed bound: $VaR_p \leqslant 2\%$ and $VaR_p \leqslant$ 4

α	95%		99%	
V	2%	4%	4%	8%
Average maximum efficiency loss	2.03	3.97	4.46	8.38
Global maximum efficiency loss	3.27	5.91	6.20	11.79
Maximum feasible expected return	1.10	1.38	1.03	1.26

- Set bound $V = VaR$ of each minimum $CVaR$ portfolio with expe

α	95%	99%
Average maximum efficiency loss	0.65	1.29
Global maximum efficiency loss	1.89	2.65
Maximum feasible expected return	1.58	1.58

IX. Case A2: No Short Selling, *ST*

- Constraints with fixed bounds: $T_{1,p} = T_{2,p} \leqslant 4\%$ and 8%

α	95%		99%	
$T_1 = T_2$	4%	8%	4%	8%
Average maximum efficiency loss	2.06	4.03	3.52	7.54
Global maximum efficiency loss	3.51	6.88	5.98	11.72
Maximum feasible expected return	1.01	1.21	1.01	1.21

IX. Case A2: No Short Selling, *ST*

- Constraints with fixed bounds: $T_{1,p} = T_{2,p} \leqslant 4\%$ and 8%

α	95%		99%	
$T_1 = T_2$	4%	8%	4%	8%
Average maximum efficiency loss	2.06	4.03	3.52	7.54
Global maximum efficiency loss	3.51	6.88	5.98	11.72
Maximum feasible expected return	1.01	1.21	1.01	1.21

- Set each bound equal to loss on each minimum *CVaR* portfolio with expected return *E* during that event

α	95%	99%
Average maximum efficiency loss	0.27	0.41
Global maximum efficiency loss	1.06	1.52
Maximum feasible expected return	1.58	1.58

X. Case A3: No Short Selling, *VaR*+*ST*

- Fixed-bound constraints on *VaR*, $T_{1,p}$, and $T_{2,p}$ as before

α	95%				99%			
V	2%		4%		4%		8%	
$T_1 = T_2$	4%	8%	4%	8%	4%	8%	4%	8%
Average maximum efficiency loss	1.77	2.04	2.06	3.79	3.52	4.43	3.52	7.51
Global maximum efficiency loss	3.25	3.27	3.51	5.94	5.91	6.20	5.98	11.42
Maximum feasible expected return	1.01	1.10	1.01	1.21	1.01	1.03	1.01	1.21

X. Case A3: No Short Selling, *VaR+ST*

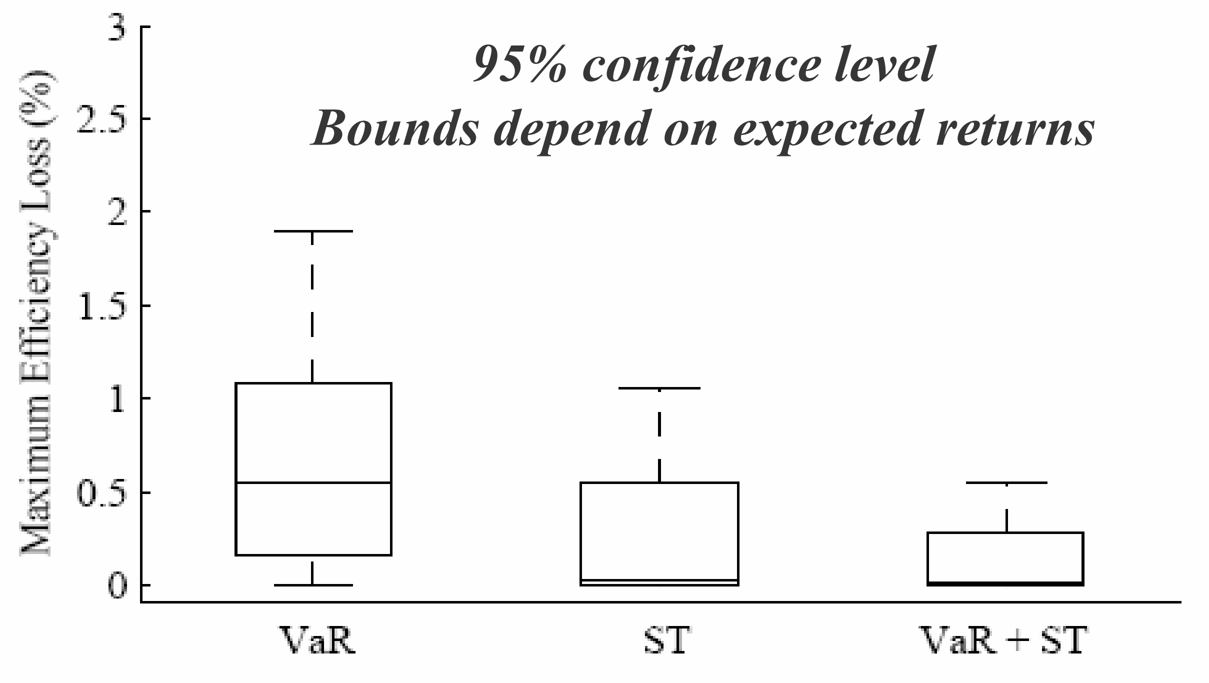
- Fixed-bound constraints on *VaR*, $T_{1,p}$, and $T_{2,p}$ as before

α	95%				99%			
V	2%		4%		4%		8%	
$T_1 = T_2$	4%	8%	4%	8%	4%	8%	4%	8%
Average maximum efficiency loss	1.77	2.04	2.06	3.79	3.52	4.43	3.52	7.51
Global maximum efficiency loss	3.25	3.27	3.51	5.94	5.91	6.20	5.98	11.42
Maximum feasible expected return	1.01	1.10	1.01	1.21	1.01	1.03	1.01	1.21

- Set each bound equal to loss on minimum *CVaR* portfolio with expected return *E* during that event

α	95%	99%
Average maximum efficiency loss	0.14	0.21
Global maximum efficiency loss	0.55	0.83
Maximum feasible expected return	1.58	1.58

XI. Comparison of Cases



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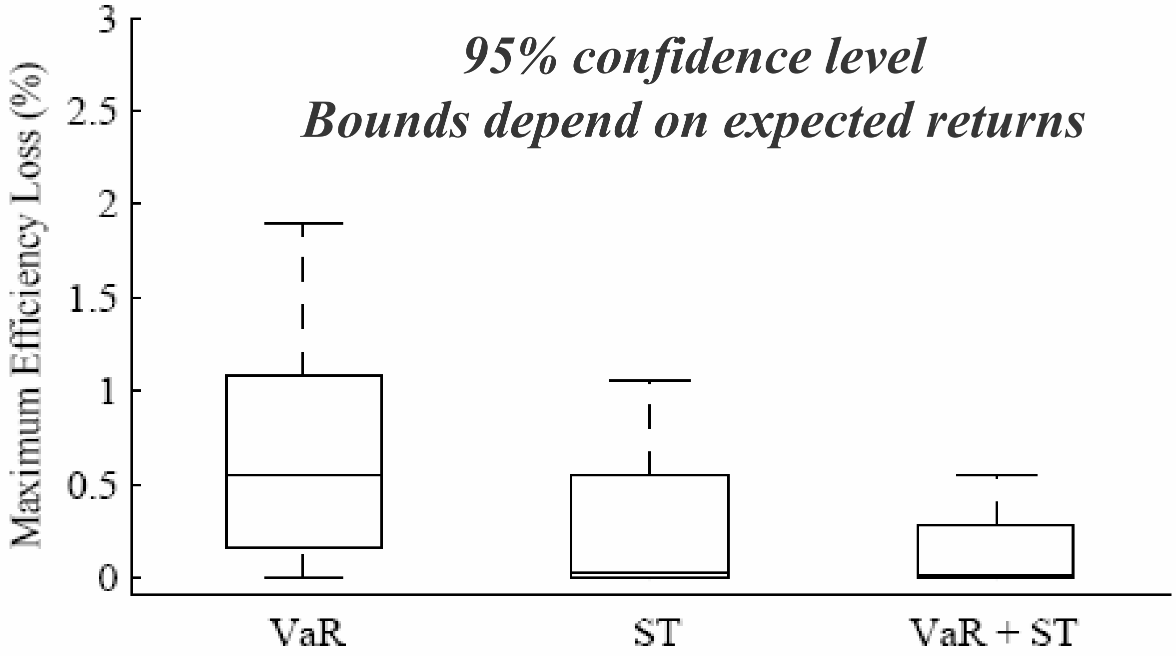
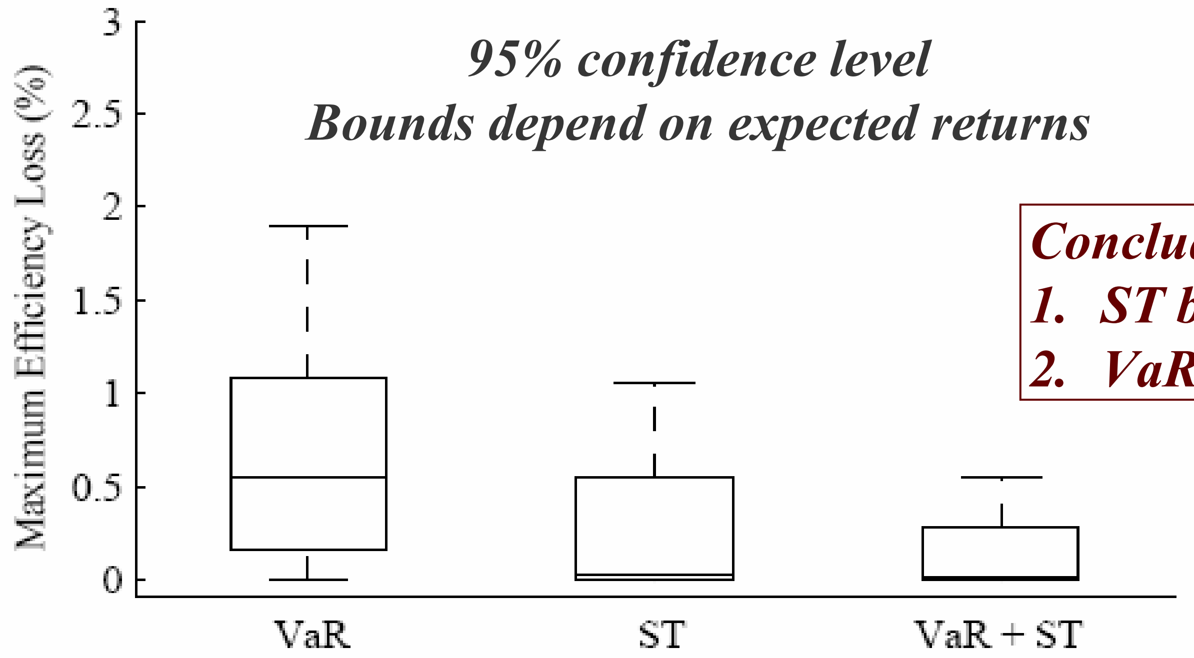


Test hypotheses	α	
	95%	99%
(a) H_0: cdfs of losses are equal (Kolmogorov-Smirnov test)		
H_A: cdf(VaR, short selling disallowed) < cdf(ST, short selling disallowed)	0.46*	0.48*
H_A: cdf(VaR, short selling allowed) > cdf(ST, short selling allowed)	0.73*	0.68*
(b) H_0: medians of losses are equal (Wilcoxon rank sum test)		
H_A: median(VaR, short selling disallowed) > median(ST, short selling disallowed)	6.09*	7.67*
H_A: median(VaR, short selling allowed) < median(ST, short selling allowed)	−9.99*	−10.38*

XI. Comparison of Cases



Conclude:

1. ***ST better than VaR***
2. ***VaR+ST is effective***

Test hypotheses	α	
	95%	99%
(a) H_0: cdfs of losses are equal (Kolmogorov-Smirnov test)		
H_A: cdf(VaR, short selling disallowed) $<$ cdf(ST, short selling disallowed)	0.46*	0.48*
H_A: cdf(VaR, short selling allowed) $>$ cdf(ST, short selling allowed)	0.73*	0.68*
(b) H_0: medians of losses are equal (Wilcoxon rank sum test)		
H_A: median(VaR, short selling disallowed) $>$ median(ST, short selling disallowed)	6.09*	7.67*
H_A: median(VaR, short selling allowed) $<$ median(ST, short selling allowed)	−9.99*	−10.38*

XII. Case B1: Short Selling, *VaR*

- Constraint with fixed bound: $VaR_p \leqslant 2\%$ and $VaR_p \leqslant 4\%$

α	95%		99%	
V	2%	4%	4%	8%
Average maximum efficiency loss	3.80	7.01	8.25	14.94
Global maximum efficiency loss	5.36	9.49	11.11	20.97
Maximum feasible expected return	1.64	2.06	1.59	2.07

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- Constraint with fixed bound: $VaR_p \leqslant 2\%$ and $VaR_p \leqslant 4\%$

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Average maximum efficiency loss	3.80	7.01	8.25	14.94
Global maximum efficiency loss	5.36	9.49	11.11	20.97
Maximum feasible expected return	1.64	2.06	1.59	2.07

- Set bound V = *VaR* of each minimum *CVaR* portfolio with expect

α	95%	99%
Average maximum efficiency loss	3.02	3.79
Global maximum efficiency loss	7.44	9.56
Maximum feasible expected return	2.16	2.16

XIII. Case B2: Short Selling, *ST*

- Constraints with fixed bounds: $T_{1,p} = T_{2,p} \leqslant 4\%$ and 8%

α	95%		99%	
$T_1 = T_2$	4%	8%	4%	8%
Average maximum efficiency loss	9.89	10.91	16.52	17.80
Global maximum efficiency loss	14.84	17.96	24.18	28.19
Maximum feasible expected return	1.84	2.04	1.84	2.04

XIII. Case B2: Short Selling, *ST*

- Constraints with fixed bounds: $T_{1,p} = T_{2,p} \leqslant 4\%$ and 8%

α	95%		99%	
$T_1 = T_2$	4%	8%	4%	8%
Average maximum efficiency loss	9.89	10.91	16.52	17.80
Global maximum efficiency loss	14.84	17.96	24.18	28.19
Maximum feasible expected return	1.84	2.04	1.84	2.04

- Set each bound equal to loss on each minimum *CVaR* portfolio with expected return *E* during that event

α	95%	99%
Average maximum efficiency loss	9.67	15.50
Global maximum efficiency loss	17.39	26.97
Maximum feasible expected return	2.16	2.16

XIV. Case B3: Short Selling, *VaR+ST*

- Fixed-bound constraints on *VaR*, $T_{1,p}$, and $T_{2,p}$ as before

α	95%				99%			
V	2%		4%		4%		8%	
$T_1 = T_2$	4%	8%	4%	8%	4%	8%	4%	8%
Average maximum efficiency loss	3.13	3.70	5.85	6.08	6.59	7.91	12.34	12.22
Global maximum efficiency loss	5.06	5.32	9.53	9.53	10.35	10.89	17.54	17.54
Maximum feasible expected return	1.52	1.64	1.82	1.93	1.59	1.59	1.78	1.95

XIV. Case B3: Short Selling, *VaR+ST*

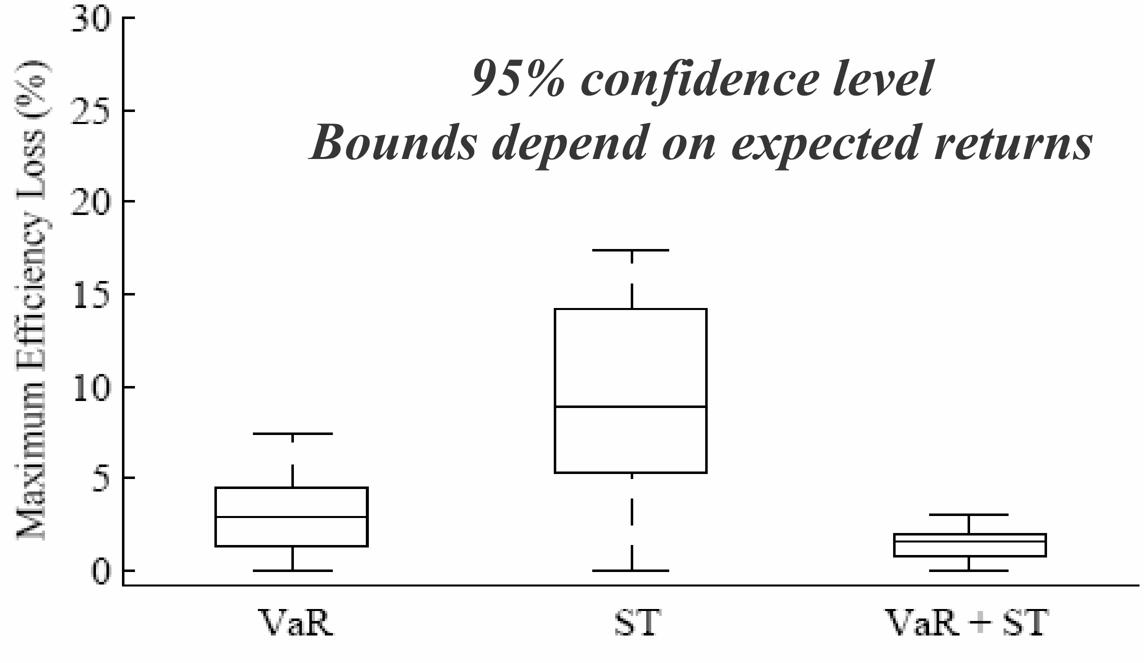
- Fixed-bound constraints on *VaR*, $T_{1,p}$, and $T_{2,p}$ as before

α	95%				99%			
V	2%		4%		4%		8%	
$T_1 = T_2$	4%	8%	4%	8%	4%	8%	4%	8%
Average maximum efficiency loss	3.13	3.70	5.85	6.08	6.59	7.91	12.34	12.22
Global maximum efficiency loss	5.06	5.32	9.53	9.53	10.35	10.89	17.54	17.54
Maximum feasible expected return	1.52	1.64	1.82	1.93	1.59	1.59	1.78	1.95

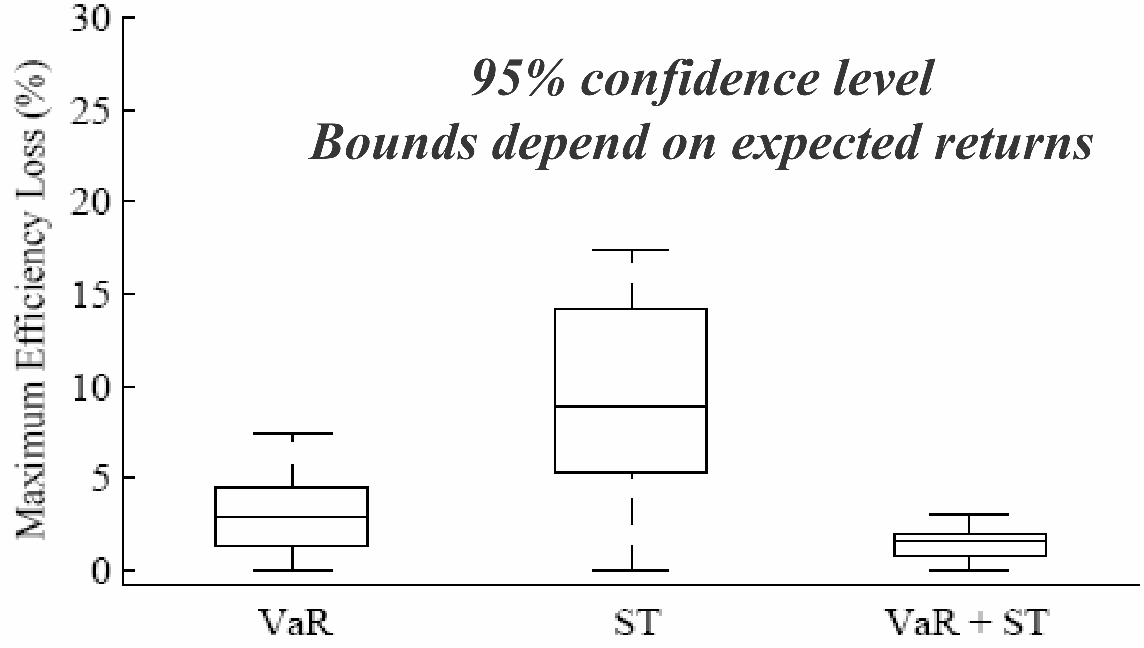
- Set each bound equal to loss on minimum *CVaR* portfolio with expected return *E* during that event

α	95%	99%
Average maximum efficiency loss	1.44	1.94
Global maximum efficiency loss	3.08	4.03
Maximum feasible expected return	2.16	2.16

XV. Comparison of Cases



XV. Comparison of Cases



Test hypotheses	α	
	95%	99%
(a) H_0: cdfs of losses are equal (Kolmogorov-Smirnov test)		
H_A: cdf(VaR, short selling disallowed) < cdf(ST, short selling disallowed)	0.46*	0.48*
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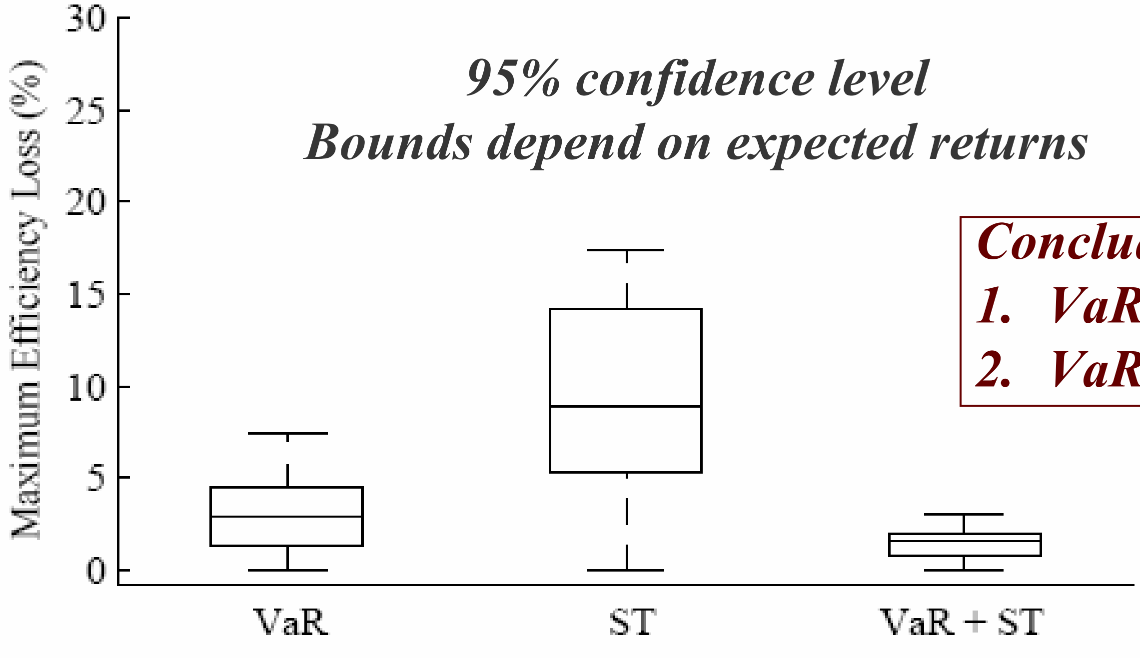
XV. Comparison of Cases



Conclude:
1. ***VaR better than ST***
2. ***VaR+ST not effective***

Test hypotheses	α	
	95%	99%
(a) H_0: cdfs of losses are equal (Kolmogorov-Smirnov test)		
H_A: cdf(VaR, short selling disallowed) < cdf(ST, short selling disallowed)	0.46*	0.48*
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XVI. Conclusion

- No short selling:
  - *ST* works better than *VaR* in controlling tail risk
  - With appropriate bounds, *VaR* plus *ST* effectively controls tail risk

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  - *VaR* plus *ST* does not effectively control tail risk

XVI. Conclusion

- No short selling:
  - *ST* works better than *VaR* in controlling tail risk
  - With appropriate bounds, *VaR* plus *ST* effectively controls tail risk
- Short selling:
  - *VaR* works better than *ST* in controlling tail risk
  - *VaR* plus *ST* does not effectively control tail risk
- Since bank trading books typically have short positions, the joint use of *VaR* and *ST* to set minimum capital requirements is unreliable