Advanced Cost Analysis

- Inflation
- Cost Discounting
- Return on Investment
- Cost/Benefit Ratios
- Life Cycle Costing
- Cost Spreading
- Cost Estimating Relationships

Inflation

- As money supply and economy expand, buying power of money decreases
- A fixed sum of money is worth less from year to year
- "Real year dollars" - what specific year the money is quoted for (e.g., "$M2000")
- "Constant year dollars" - costing multiyear program based on buying power in single specified year (inflation added later)

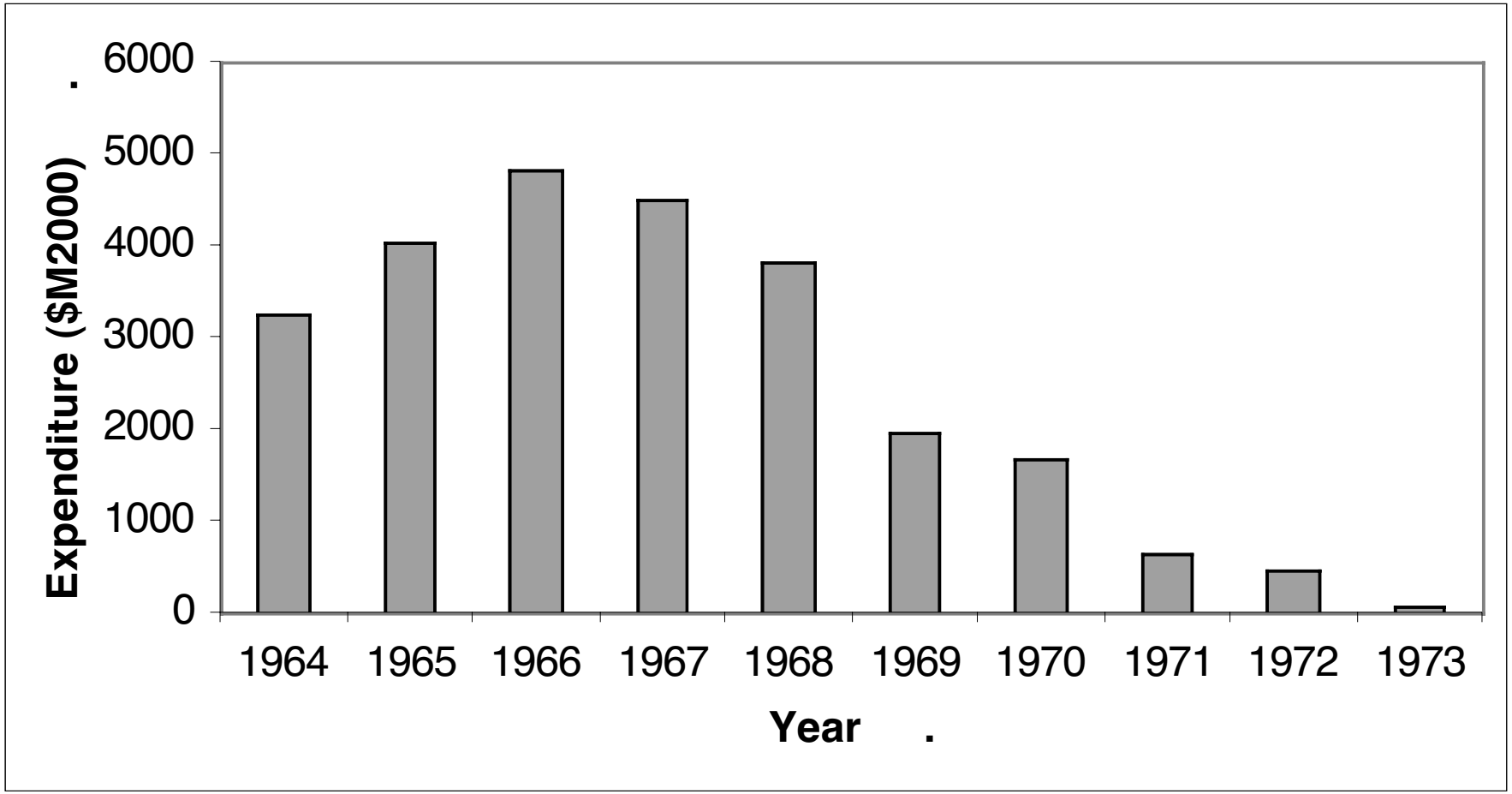
GDP Deflation Factors

Year	GDP factor	2002 value	Year	GDP factor	2002 value	Year	GDP factor	2002 value
1940	0.1032	$10.68	1963	0.2315	$4.76	1985	0.7382	$1.49
1941	0.1077	$10.23	1964	0.2345	$4.70	1986	0.7558	$1.46
1942	0.1155	$9.54	1965	0.2385	$4.62	1987	0.7758	$1.42
1943	0.1228	$8.97	1966	0.2437	$4.52	1988	0.8008	$1.38
1944	0.1275	$8.64	1967	0.2515	$4.38	1989	0.8318	$1.32
1945	0.1308	$8.42	1968	0.2608	$4.22	1990	0.8634	$1.28
1946	0.1401	$7.86	1969	0.2724	$4.04	1991	0.8953	$1.23
1947	0.1568	$7.03	1970	0.287	$3.84	1992	0.916	$1.20
1948	0.1695	$6.50	1971	0.3019	$3.65	1993	0.9392	$1.17
1949	0.1766	$6.24	1972	0.3165	$3.48	1994	0.9608	$1.15
1950	0.1738	$6.34	1973	0.331	$3.33	1995	0.9811	$1.12
1951	0.184	$5.99	1974	0.3545	$3.11	1996	1	$1.10
1952	0.1906	$5.78	1975	0.3898	$2.83	1997	1.017	$1.08
1953	0.1941	$5.68	1976	0.4179	$2.64	1998	1.03	$1.07
1954	0.1961	$5.62	TQ	0.432	$2.55	1999	1.0434	$1.06
1955	0.1982	$5.56	1977	0.4505	$2.45	2000	1.059	$1.04
1956	0.2036	$5.41	1978	0.4811	$2.29	2001	1.0802	$1.02
1957	0.2113	$5.21	1979	0.5186	$2.12	2002	1.1018	$1.00
1958	0.2167	$5.08	1980	0.5632	$1.96	2003	1.1238	$0.98
1959	0.2209	$4.99	1981	0.6174	$1.78	2004	1.1463	$0.96
1960	0.223	$4.94	1982	0.6596	$1.67	2005	1.1692	$0.94
1961	0.226	$4.88	1983	0.6892	$1.60			
1962	0.2288	$4.82	1984	0.715	$1.54			

Inflation Example: Saturn V Costs

Year	Real year $M	$M2000
1964	763.4	3255.4
1965	964.9	4045.8
1966	1177.3	4831.0
1967	1135.6	4515.3
1968	998.9	3830.1
1969	534.5	1962.0
1970	484.4	1687.9
1971	189.1	626.2
1972	142.5	450.1
1973	26.3	79.5
	6416.8	25283.4

Saturn V Annual Expenditures



Cost Spreading Estimation

- Programs very seldom occur in a single funding year
- Costs are not constant from year to year
  - Low start-up costs
  - High costs during vehicle development and fabrication
  - Low end-of-life costs
- Costs are estimated using a beta function
- Calculation worksheet at http://www.jsc.nasa.gov/bu2/beta.html

Beta Function for Cost Spreading

- Cumulative normalized cost function

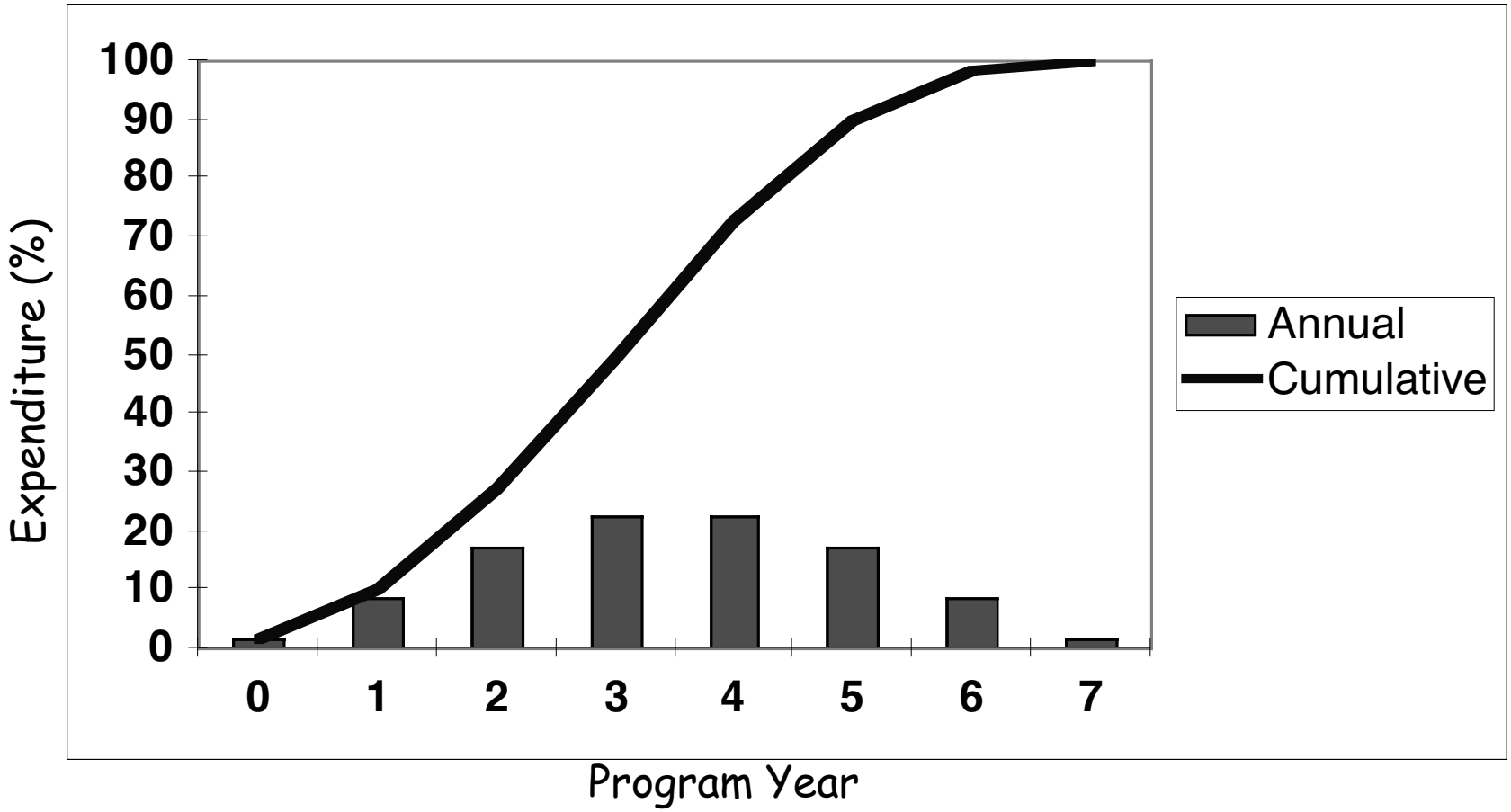
$$C(\tau) = 10\tau^2(1-\tau)^2(A + B\tau) + \tau^4(5 - 4\tau)$$

where

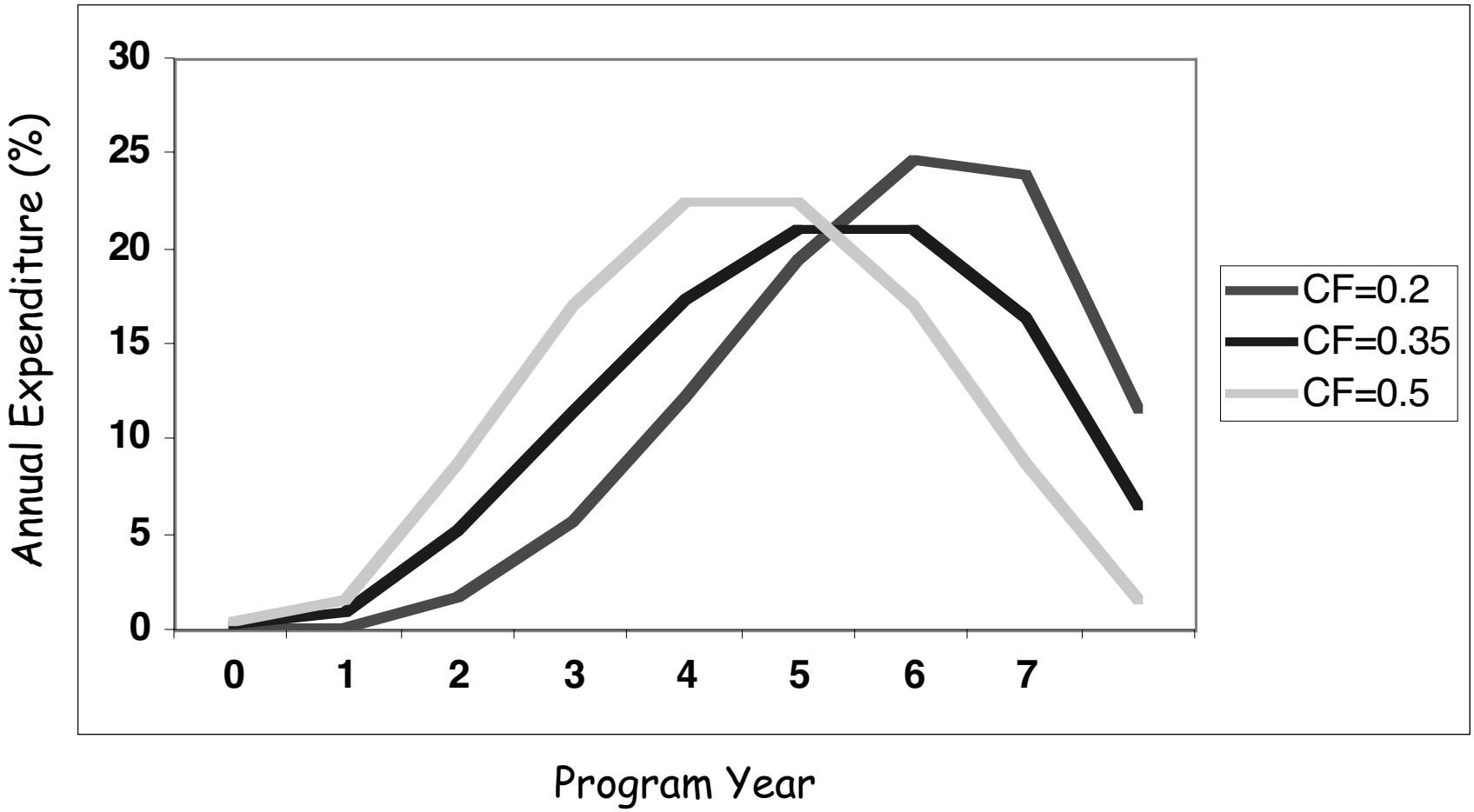
  - C = fraction of total program cost ($0 \le C \le 1$)
  - τ = fraction of total program time ($0 \le \tau \le 1$)
  - A and B = shape parameters ($0 \le A+B \le 1$)
  - Can also define equivalent parameters c_f (location of maximum) and P (width of peak) $0 \le P \le 1$; $0.1875 \le c_f \le 0.8125$

$$c_f < 0.5: \quad A = \frac{(1-P)(c_f - 0.1875)}{0.625}; \quad B = P\frac{c_f - 0.1875}{0.3125} \qquad c_f \ge 0.5: \quad A = \frac{P(c_f - 0.8125) + (c_f - 0.1875)}{0.625}; \quad B = P\frac{0.1875 - c_f}{0.3125}$$

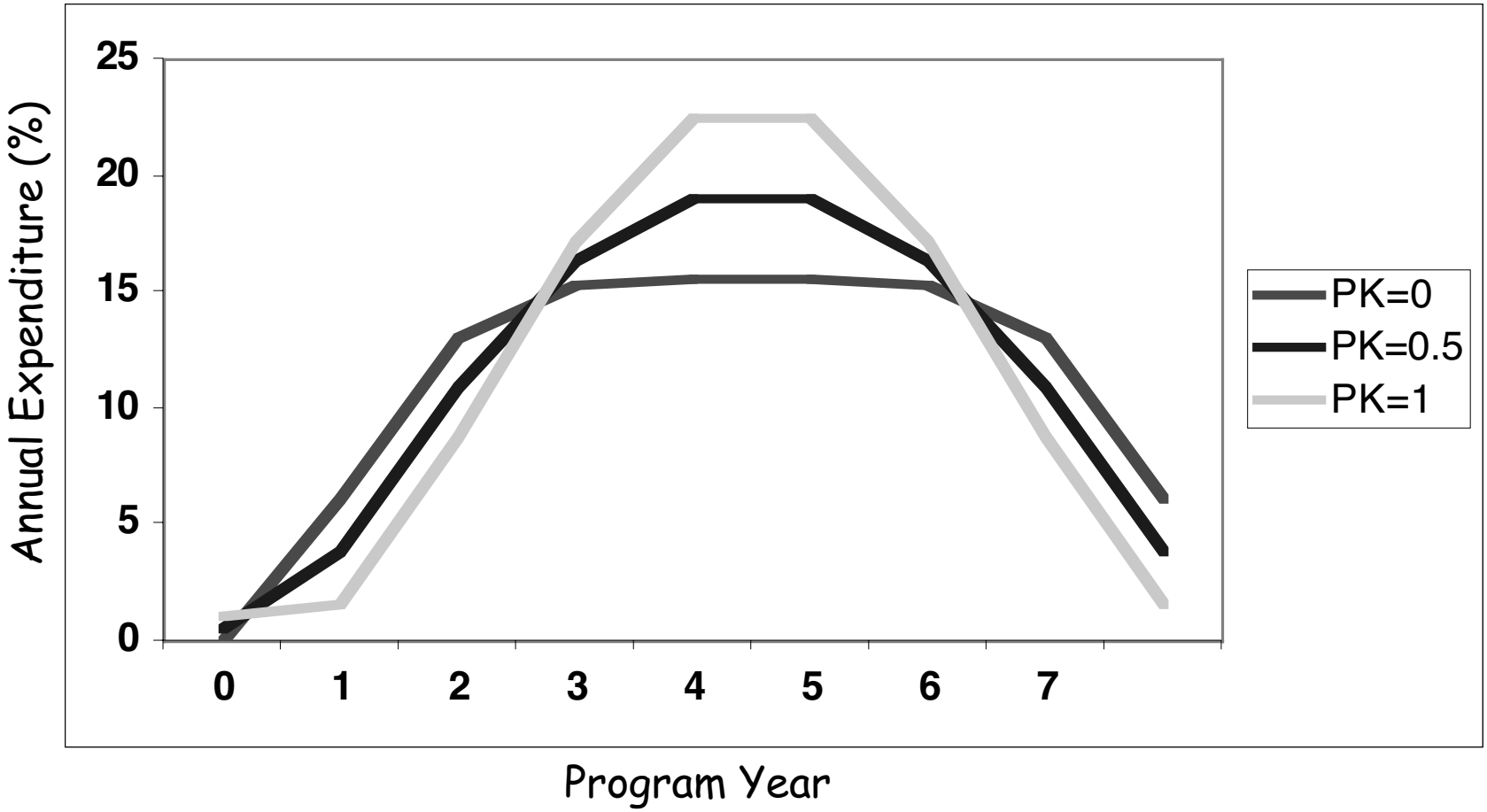
Sample of Beta Function



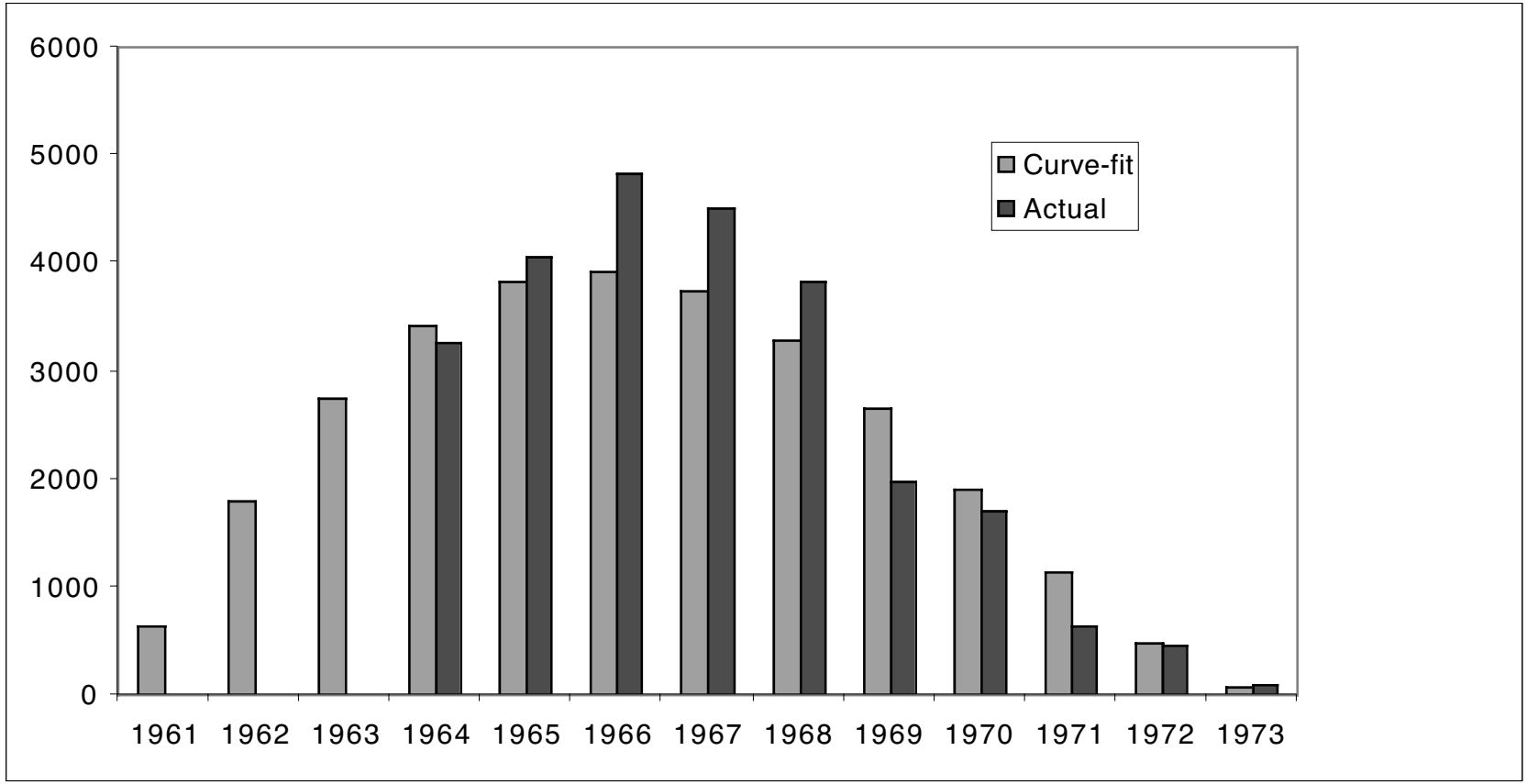
Cost Fraction in Beta Function



Peakedness in Beta Function



Beta Curve Fit to Saturn V Data



A=0.371; B=0.629

Cost Discounting

- Opportunity costs of money
- Analogous to compound interest at a bank
- ***Not*** the same thing as inflation
- Basic Definitions:
  - Net Present Value (NPV) - value of future sum today
  - Net Future Value (NFV) - value of sum today in the future
  - Discount Rate (r) - annual interest rate
- Provides a method of comparing costs across multiple years

Basic Equations of Cost Discounting

- Net Present Value (NPV)

$$C_i = C_{i+n}(1+r)^{-n}$$

- Net Future Value (NFV)

$$C_{i+n} = C_i(1+r)^{n}$$

- NPV of constant annual payments of R

$$C_i = R\frac{1-(1+r)^{-n}}{r}$$

- NFV of constant annual payments of R

$$C_{i+n} = R\frac{(1+r)^{n}-1}{r}$$

Cost Discounting Example: Saturn V Costs

Year	$M2000	NPV (2000) (r=0.10)	NFV (2010) (r=0.10)
2001	3255.4	2959.4	7676.0
2002	4045.8	3343.6	8672.5
2003	4831.0	3629.6	9414.3
2004	4515.3	3084.0	7999.1
2005	3830.1	2378.2	6168.5
2006	1962.0	1107.5	2872.6
2007	1687.9	866.2	2246.6
2008	626.2	292.1	757.7
2009	450.1	190.9	495.1
2010	79.5	30.6	79.5
Totals	25283.4	17882.3	46382.0

Cost Discounting and Breakeven

				NPV (2000)	
Year	$M2000	Flights	Revenue	Costs	Revenue
2001	3255			2959.4	
2002	4046			3343.6	
2003	4831			3629.6	
2004	4515			3084.0	
2005	3830			2378.2	
2006	1962	3	5057	1107.5	2854.4
2007	1688	3	5057	866.2	2594.9
2008	626	3	5057	292.1	2359.0
2009	450	3	5057	190.9	2144.5
2010	79	3	5057	30.6	1949.6
Totals	25283	15	25283	17882.3	11902.3

$8428/lb

Breakeven with Discounting

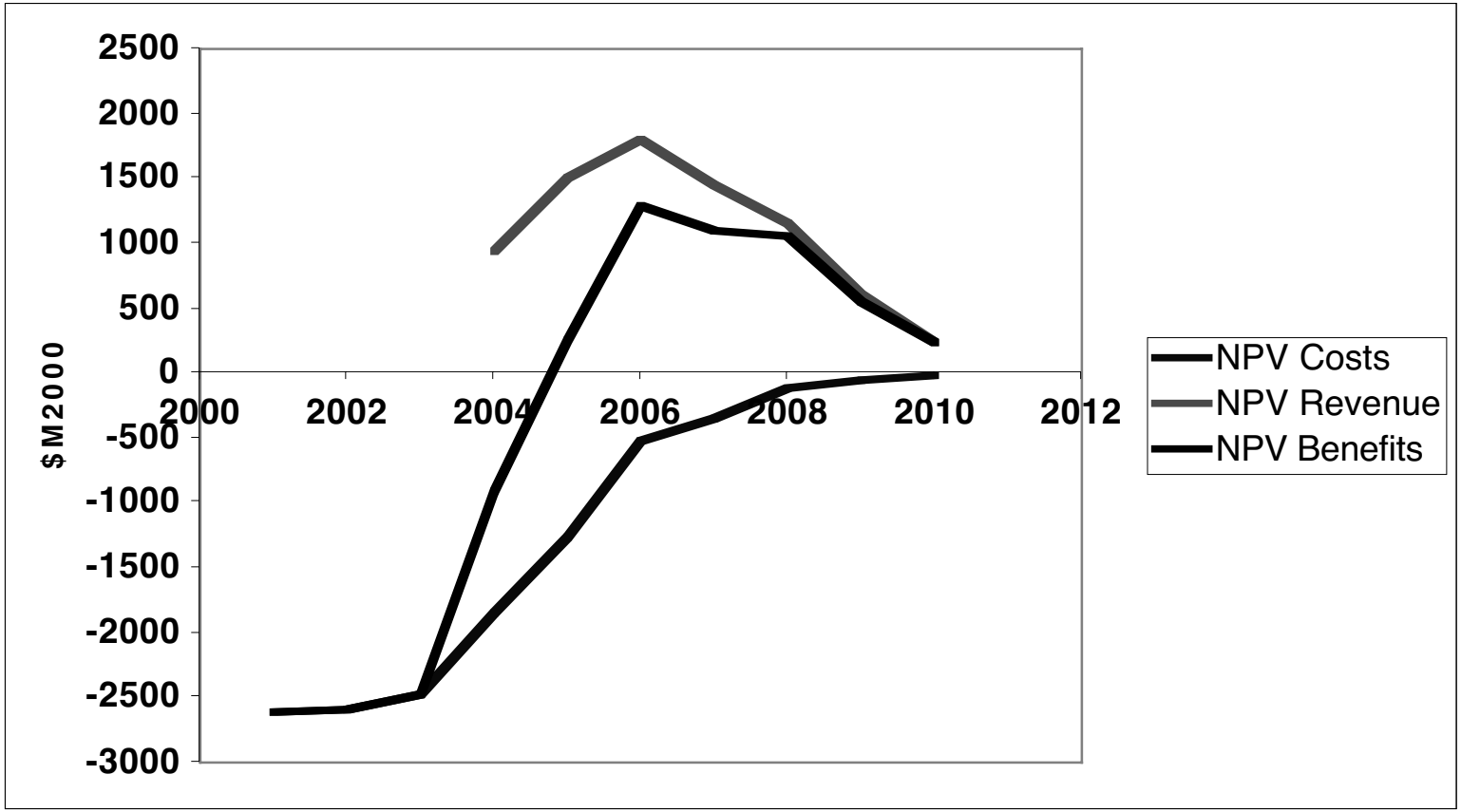
Year	$M2000	Flights	Revenue	Costs	Revenue
2001	3255			2959	
2002	4046			3344	
2003	4831		$12,660/lb	3630	
2004	4515			3084	
2005	3830			2378	
2006	1962	3	7597	1108	4288
2007	1688	3	7597	866	3899
2008	626	3	7597	292	3544
2009	450	3	7597	191	3222
2010	79	3	7597	31	2929
Totals	25283	15	37986	17882	17882

Effect of Moving Revenue Forward

				NPV (2000)	
Year	$M2000	Flights	Revenue	Costs	Revenue
2001	3255			2959.4	
2002	4046			3343.6	
2003	4831			3629.6	
2004	4515	1	2295.2	3084.0	1567.7
2005	3830	2	4590.5	2378.2	2850.3
2006	1962	3	6885.7	1107.5	3886.8
2007	1688	3	6885.7	866.2	3533.5
2008	626	3	6885.7	292.1	3212.2
2009	450	2	4590.5	190.9	1946.8
2010	79	1	2295.2	30.6	884.9
Totals	25283	15	34429	17882.3	17882.3

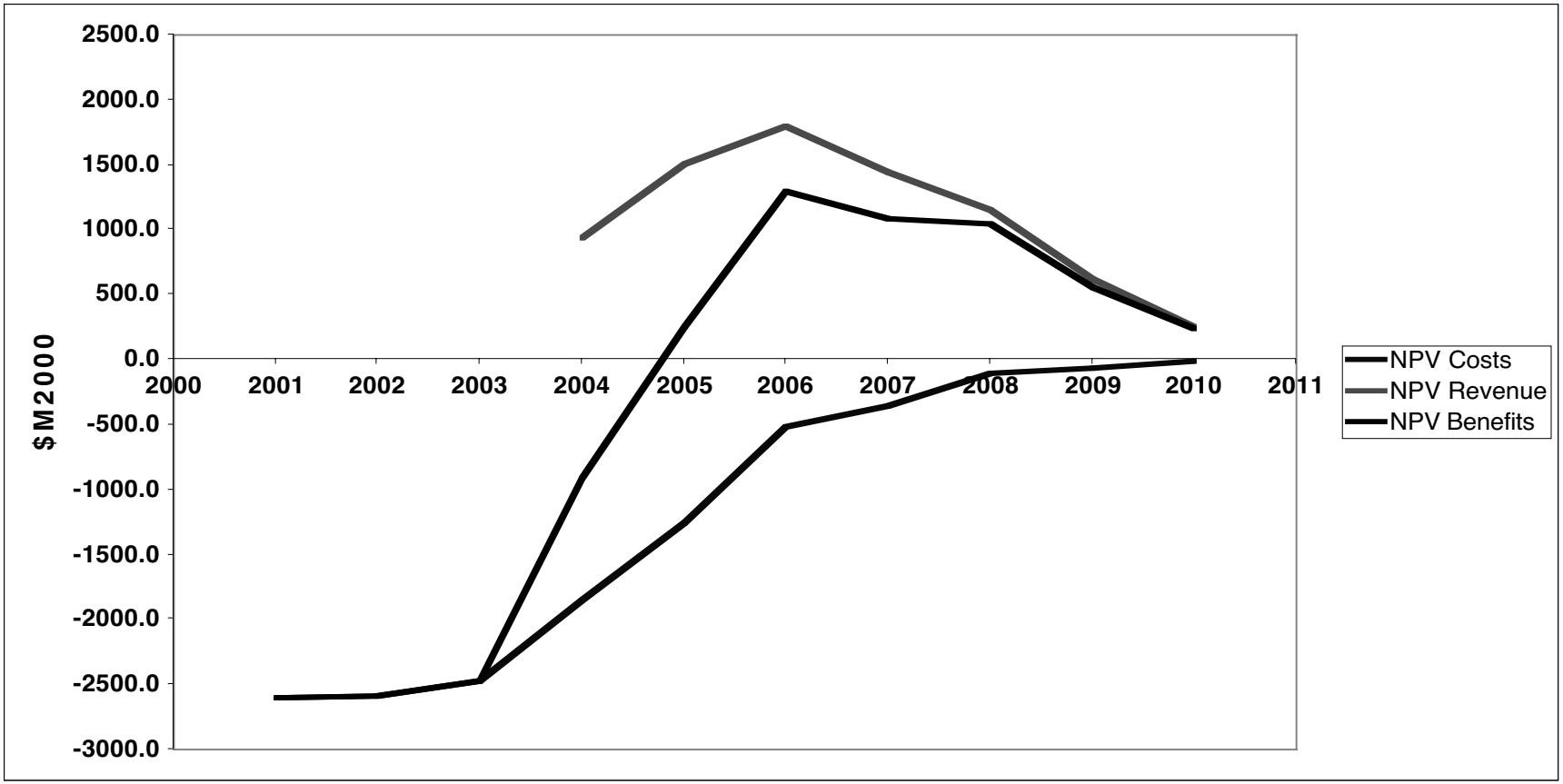
$11,480/lb

Rate of Return



Internal Rate of Return

- Discount rate that produces breakeven



Effect of IRR Targets

- Investors generally require specific minimum values of IRR
- Have to increase revenue stream to achieve IRR
- Saturn V launch case:
  - 10% IRR $11,480/lb
  - 25% IRR $17,580/lb
  - 50% IRR $32,700/lb
- Venture capitalists general look for 70-100% IRR with 18-month payback

Cost Estimating Relations

- Available at each level of detail
  - Vehicle
  - System
  - Component
- Typically established based on system inert mass
- Separate CERs for nonrecurring and first unit recurring costs
- Multiple models may be contradictory!

System-Level Cost Estimating Relations

	Nonrecurring		First Unit	
Item	A	B	A	B
Structure (complex)	587.5	0.623	77.1	0.789
Structure (simple)	493.7	0.454	80.89	0.536
Thermal Control System	341	0.572	129.1	0.584
Power System	104.6	0.893	52.36	0.894
Avionics System	1382	0.762	203.1	0.971
Attitude Control System	798.6	0.768	177.2	0.888
Reaction Control System	557.9	0.667	337.4	0.536

All costs are of the form Cost <$K2002> = $A[(M_{inert}\text{<kg>})^B]$

Component-Level Cost Estimating Relations

	Nonrecurring		Recurring	
Item	A	B	A	B
Module Structure	44.5	0.663	29.66	0.663
Solar array structure	14.23	1.000	14.23	1.000
Sail Structure	14.09	1.000	17.22	1.000
Wheel Assy	7.828	1.000	6.405	1.000
Pointing system	653.5	0.200	435.7	0.200
Support boom	27.22	0.900	33.27	0.900
Drive Mechanism	19.38	1.160	19.38	1.160
Other support structure	25.3	0.789	25.3	0.789
Active thermal control	28.96	0.960	9.653	0.960
Passive thermal control	48.87	0.482	39.98	0.482

All costs are of the form Cost <$K2002> = $A[(M_{inert}\langle kg\rangle)^B]$

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Component-Level Cost Estimating Relations

	Nonrecurring		Recurring	
Item	A	B	A	B
Solar array	27.69	0.946	51.42	0.946
Battery	8.779	1.145	7.183	1.145
Power supply electronics	609.5	0.500	328.2	0.500
Power supply components	148.8	0.638	99.22	0.638
Wiring harness	75.33	0.593	75.33	0.593
Fixed antenna	208.8	0.793	139.2	0.793
Deployable antenna	156.3	0.913	104.2	0.913
Transponder	253.7	0.898	169.1	0.898
Receiver	308.1	0.697	252.1	0.697
Transmitter	187.3	0.793	187.3	0.793

All costs are of the form Cost <$K2002> = $A[(M_{inert}\text{<kg>})^B]$

Component-Level Cost Estimating Relations

	Nonrecurring		Recurring	
Item	A	B	A	B
Tape recorder	12.45	1.610	15.21	1.610
Signal conditioning	105.8	0.938	86.6	0.938
Processor	193.6	0.690	158.4	0.690
Horizon sensor	179.3	1.000	179.3	1.000
Sun sensor	164.4	1.321	246.5	1.321
Star tracker	336.5	1.000	224.3	1.000
Gyro	115.3	1.000	115.3	1.000
Mom/reaction wheel	10.14	1.217	10.14	1.217
Magnetic torquer	28.18	1.000	23.06	1.000
Nutation damper	78.14	1.000	95.51	1.000

All costs are of the form Cost <$K2002> = $A[(M_{inert}\text{<kg>})^B]$

Component-Level Cost Estimating Relations

	Nonrecurring		Recurring	
Item	A	B	A	B
Att. cntl. electronics	339.2	0.888	226.2	0.888
Hydrazine thruster (small)	62.41	1.129	41.61	1.129
Hydrazine tank	8.967	1.000	10.96	1.000
Solid prop. motor	49.82	1.000	149.5	1.000

All costs are of the form Cost <$K2002> = $A[(M_{inert}\text{<kg>})^B]$

References

- Richard de Neufville and Joseph H. Stafford, *Systems Analysis for Engineers and Managers* McGraw-Hill, 1971