The Value of Flexibility in New Power Plant Construction for Municipal Shanghai, China

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ESD.71 Engineering Systems Analysis for Design

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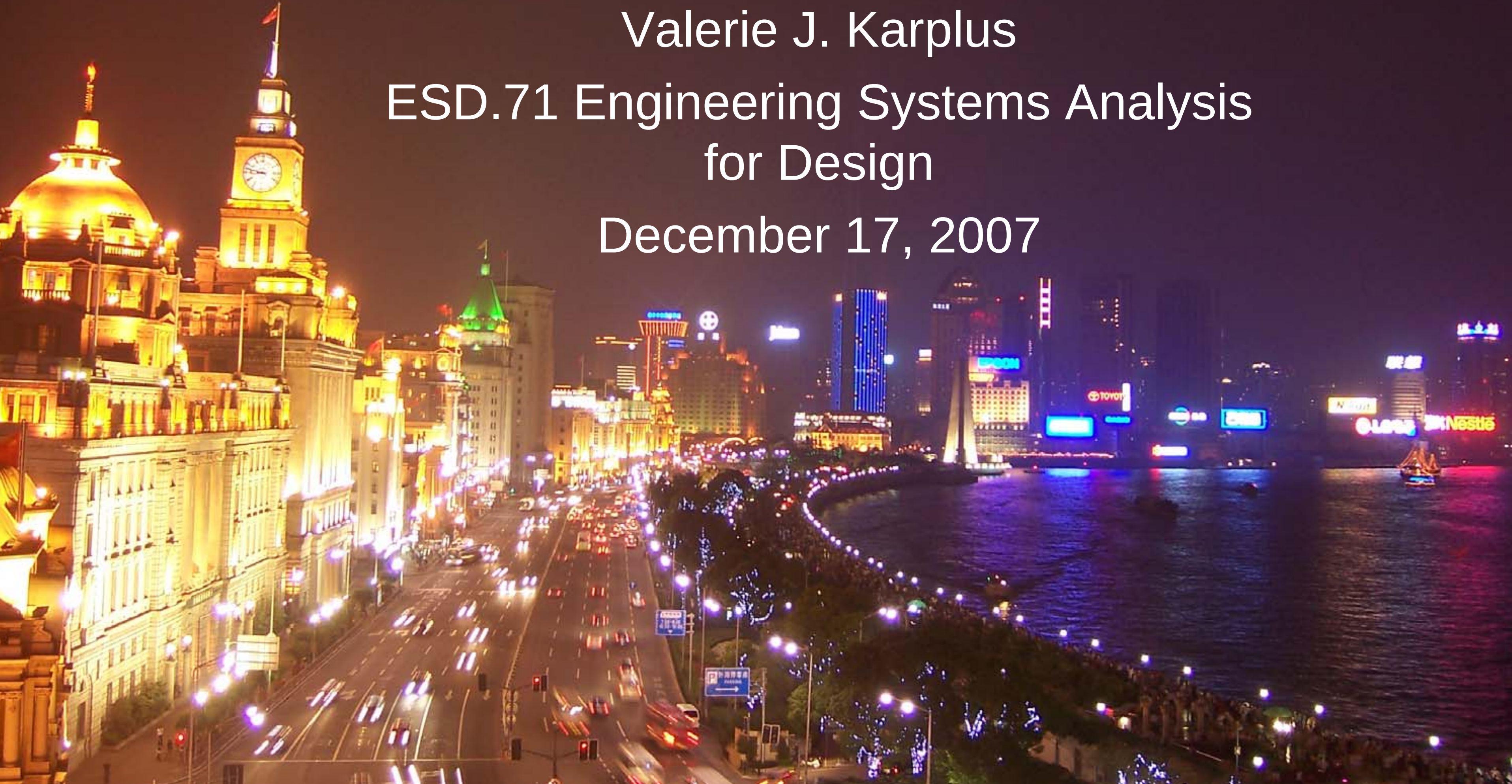
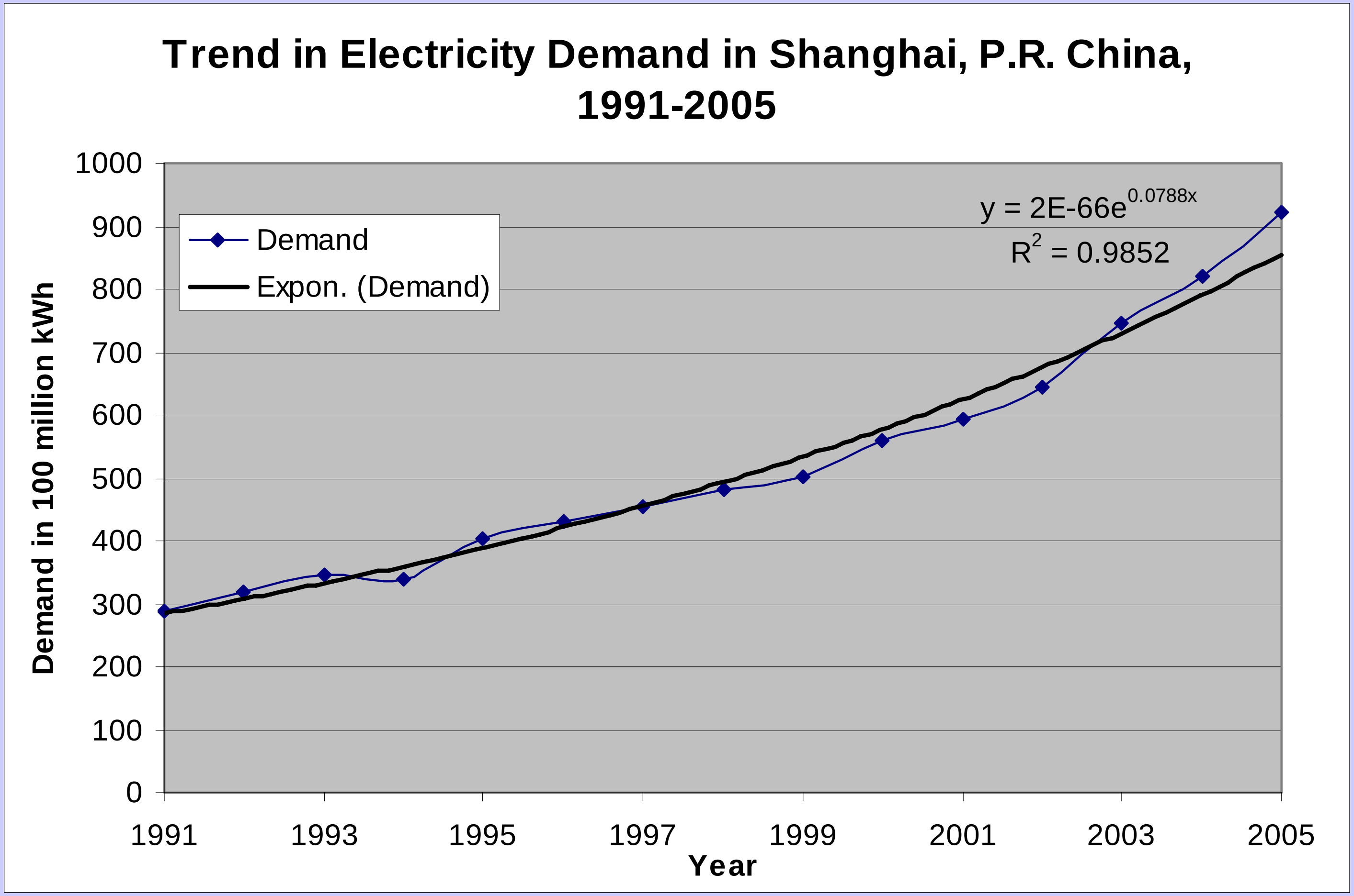


Objectives

- Background – Electricity demand in Shanghai
- Analysis of options for capacity expansion:
  1. Large coal plant
  2. Large natural gas plant
  3. Small natural gas plant + expansion option

  } **Compared directly**
- Tools used:
  - Decision analysis (NPV, cost-benefit)
  - Binomial lattice valuation of options
- Conclusion

Robust Demand Growth in Recent Decades



Total demand growth approximately 7.9% per year.

Requires rapid build-out of new capacity – how to meet demand?

How to encourage cleaner power production?

Options

Plan 1 – Large coal plant → "put-like" option to close

Plan 2 – Large natural gas plant

Plan 3 – Small natural gas plant → "call-like" option to expand

Analysis:

- Define assumptions (demand growth, feedstock price, regulation)
- Develop cost model
- Evaluate value of flexibility
  - Decision analysis
  - Binomial lattice valuation

Cost Model: Assumptions

	1 – Large Coal	2 – Large NG	3 – Flex NG
Capacity	500MW	500MW	300MW
Capital Cost	$500m	$400m	$300m
Expansion	N.A.	N.A.	$180m
Heat Rate	10,900 BTU/kWh	5687 BTU/kWh	5687 BTU/kWh
Feedstock Price	$1.05/MMBTU	$6.05/MMBTU ($7.05/MMBTU)	$6.05/MMBTU ($7.05/MMBTU)
O&M Cost	$10m	$10m	$6m (+ $6m)
Max Output	3,700m kWh	3,700m kWh	2,200m kWh (+ 2,200m kWh)
Period Length	2 x 5 years	2 x 5 years	2 x 5 years
Demand Growth	350m kWh/yr (450m kWh/yr)	350m kWh/yr (450m kWh/yr)	350m kWh/yr (450m kWh/yr)

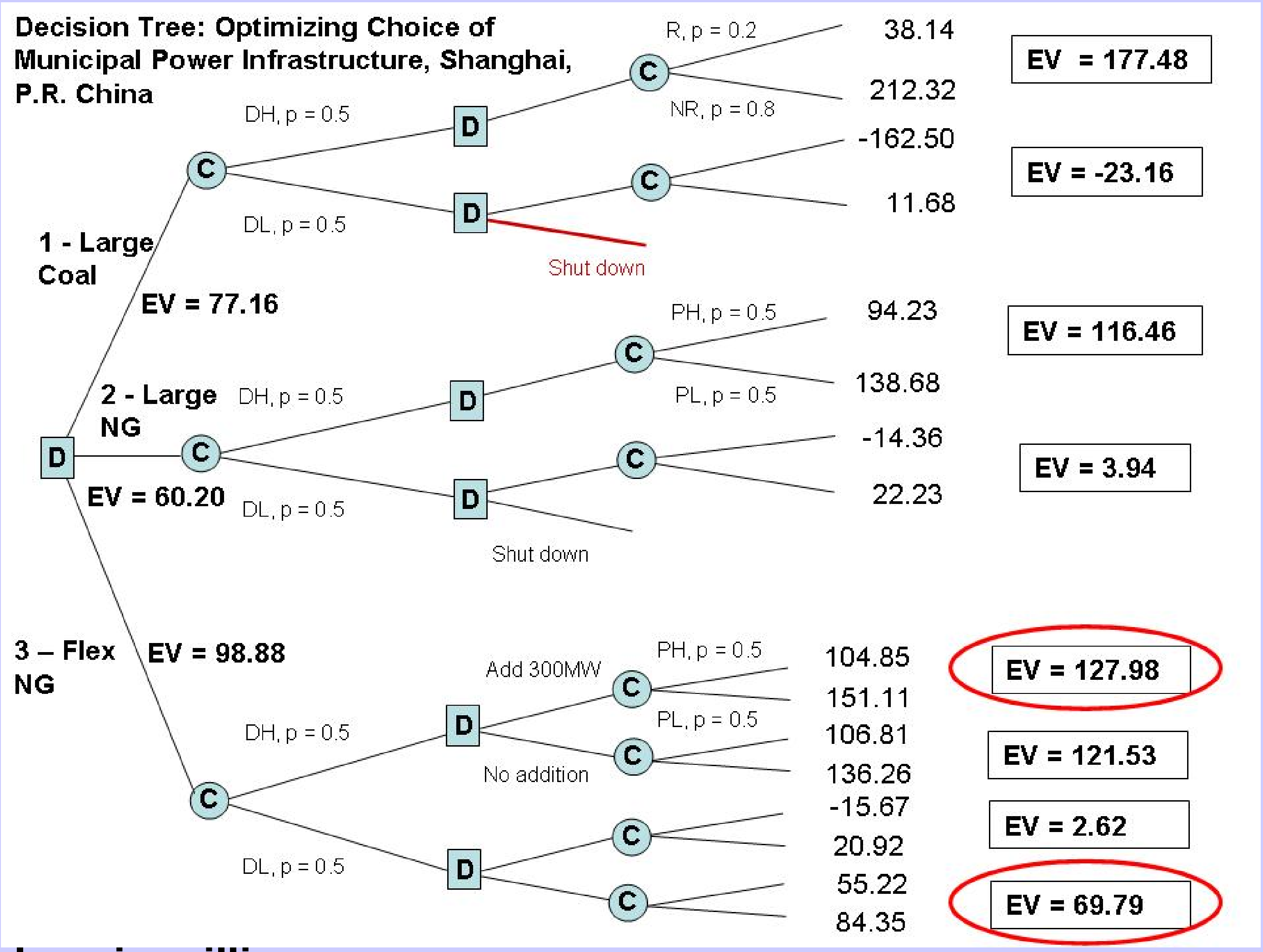
Sample Cost Model: Flex Plant

Used to determine net present value (NPV)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Capital Cost ($ millions)	300.00	0.00	0.00	0.00	0.00	180.00	0.00	0.00	0.00	0.00	0.00
Price of Gas ($/MMBTU)		6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.05	6.05
Fuel Cost ($ millions)		15.48	30.97	46.45	61.93	75.69	91.18	106.66	122.14	137.63	151.39
O&M Cost ($ millions)		6.00	6.00	6.00	6.00	6.00	12.00	12.00	12.00	12.00	12.00
Price of Electricity (cents/kWh)		8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20	8.20
Demand (100 million kWh)		4.50	9.00	13.50	18.00	22.00	26.50	31.00	35.50	40.00	44.00
Revenues ($ millions)		36.90	73.80	110.70	147.60	180.40	217.30	254.20	291.10	328.00	360.80
Net Income, NI = R - C(Cap) - C(Fuel) - C(O&M)	-300.00	15.42	36.83	58.25	79.67	-81.29	114.12	135.54	156.96	178.37	197.41
Discount Rate	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Discount Factor	1.00	1.10	1.21	1.33	1.46	1.61	1.77	1.95	2.14	2.36	2.59
Annual Discounted Cash Flow	-300.00	14.02	30.44	43.77	54.41	-50.48	64.42	69.55	73.22	75.65	76.11
NPV	-300.00	-285.98	-255.54	-211.78	-157.36	-207.84	-143.42	-73.87	-0.65	75.00	151.11

Assumptions: Start with 300MW capacity, demand high, price low, build new plant.

Decision Analysis



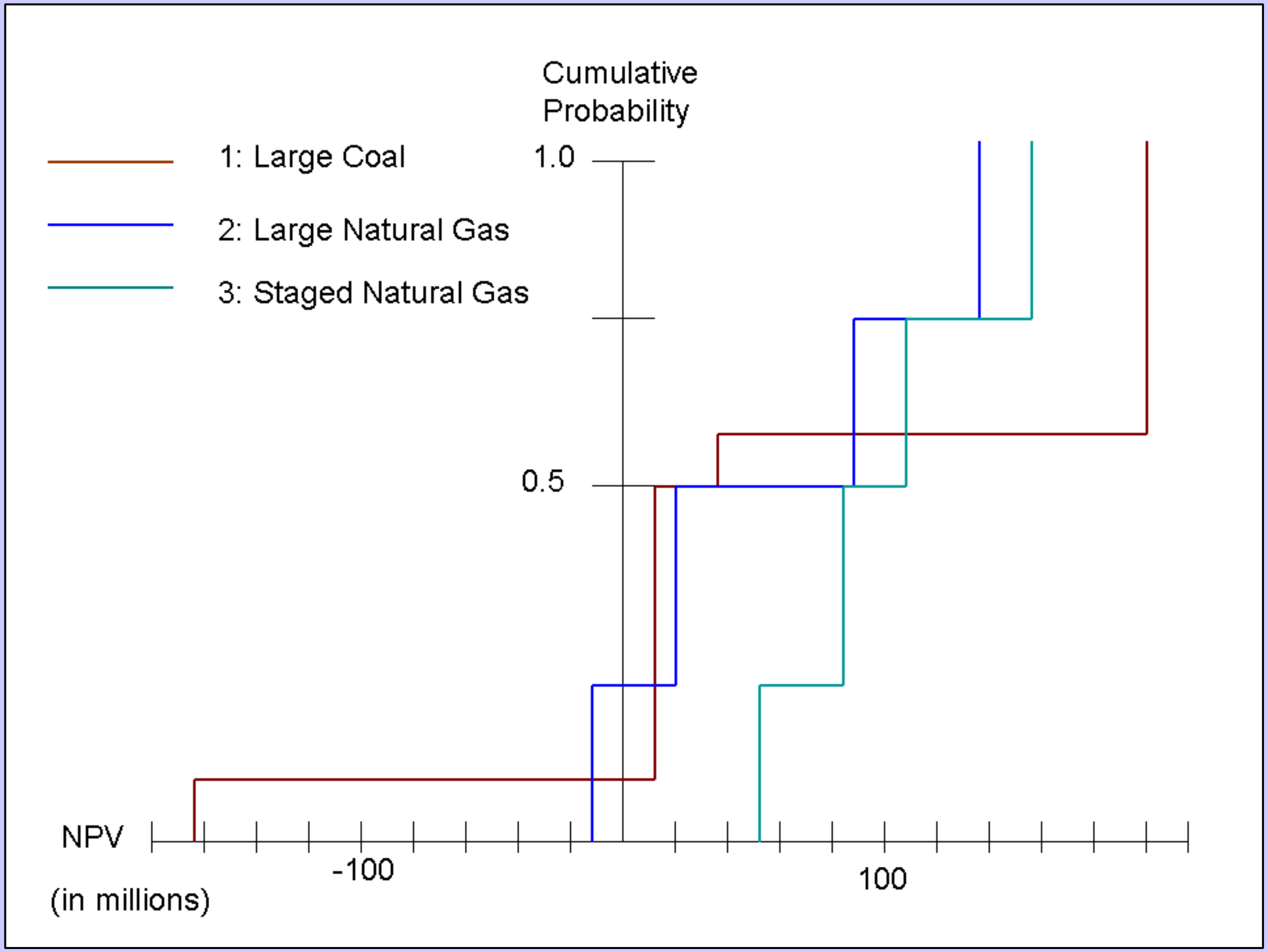
Values in millions of dollars

Probability of large losses if demand low, reg.

Ability to take advantage of upside limited.

Can exercise option to take greater advantage of upside if demand high.

Value at Risk and Gain



Based on probabilities in decision analysis:

Staged natural gas plant allows plant operators to take advantage of upside, minimize downside risks.

Coal plant has large potential upside but also large potential downside.

Choosing Best Design

Upside potential → Coal (Plan 1)

Downside minimized → Staged NG (Plan 3)

NPV → Staged NG (Plan 3)

Cost-Benefit Ratio → Staged NG (Plan 3)

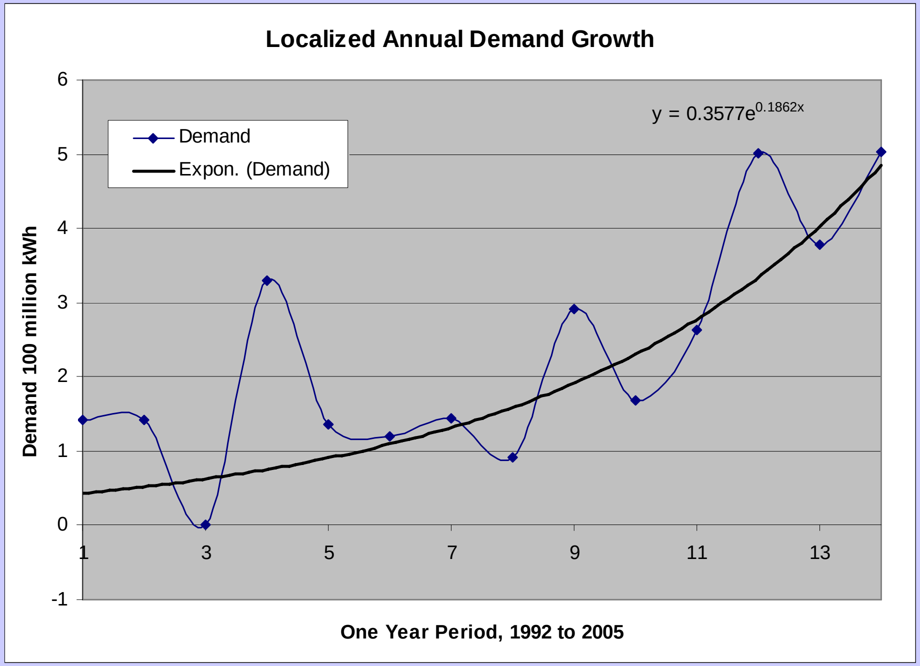
(C-B better than NPV for ranking)

Project	Expected NPV	NPV of Cap Ex	Benefit-Cost Ratio
Plan 1 – Large Coal (500 MW)	$ 77.16	$ 500	0.1543
Plan 2 – Large Gas (500 MW)	$ 60.20	$ 400	0.1505
Plan 3 – Phased Gas (300 MW or 600 MW)	$ 98.88	$ 300 (+$ 112*0.5) E = $ 356	0.2778

E = probability weighted capital expenditures for phased gas plant based on decision analysis.
All values in millions.

Annual Localized Demand Growth

- Goal: Meet localized demand
- Demand is growing year-on-year
- Used to estimate year-on-year demand growth in lattice model, summed to obtain cumulative growth in lattice
- Start value assumed is average of 3.0 100 million kWh
- Evolution described by lattice of probabilities

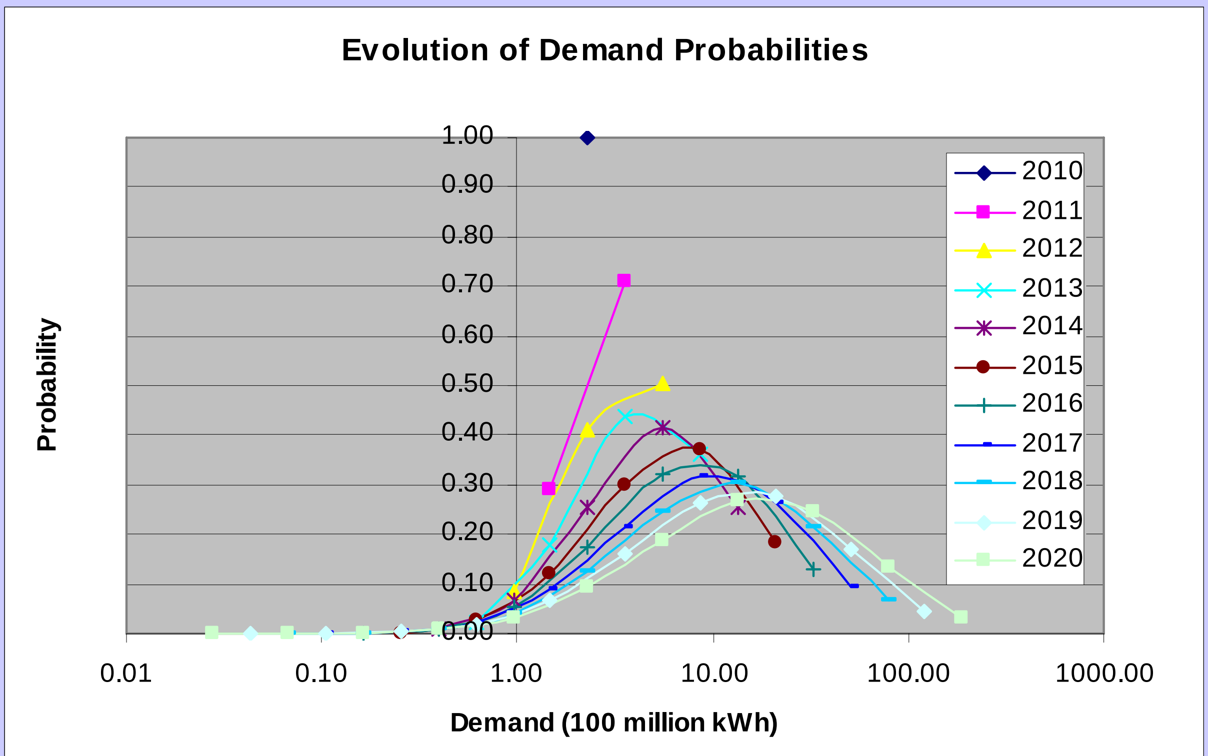


Binomial Lattice Analysis

Evolution of probabilities every year through 2020.

Used to model evolution of demand.

PROBABILITY LATTICE										
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
1.00	0.71	0.51	0.36	0.26	0.18	0.13	0.09	0.07	0.05	0.03
	0.29	0.41	0.44	0.42	0.37	0.32	0.26	0.21	0.17	0.13
		0.08	0.18	0.25	0.30	0.32	0.32	0.30	0.28	0.25
			0.02	0.07	0.12	0.17	0.22	0.25	0.26	0.27
				0.01	0.02	0.05	0.09	0.12	0.16	0.19
					0.00	0.01	0.02	0.04	0.06	0.09
						0.00	0.00	0.01	0.02	0.03
							0.00	0.00	0.00	0.01
								0.00	0.00	0.00
									0.00	0.00
										0.00



Upstate probability = 0.71

Downstate probability = 0.29

Assumed growth* = 18.62 %

Volatility = 44.12 %

Start value = 3.0 100 million kWh

* Based on annual localized incremental demand growth

“Call” Option *in* Natural Gas Plant

Value of Option:

- **Decision analysis** compared to single large plant:

  $98.88m - $60.20m = $38.68m

- **Binomial lattice valuation**

Base case (500 MW) – $ 144.49m

Flex case, not expand – $ 128.52m

Flex case, forced expand – $ 146.42m

Flex case, with option – $ 205.97m

Optimal Decision in Fifth Year

Probability	Demand	Strategy
0.18	70.94	EXPAND
0.37	31.11	EXPAND
0.30	15.76	EXPAND
0.12	10.14	NO CHANGE
0.02	8.28	NO CHANGE
0.00	7.81	NO CHANGE

“Put” Option *on* Coal Plant

Value of option to close – dynamic programming.

Cost of closing plant: $ 4.5 million

COAL PLANT - PROFITS WITH REGULATIONS - FLEXIBILITY										
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
523.86	715.32	898.34	1033.62	1051.08	916.39	737.77	617.36	484.34	338.01	177.05
	339.68	472.59	610.12	730.28	790.57	717.35	615.40	484.34	338.01	177.05
		175.61	249.48	331.75	414.54	472.39	542.47	476.87	338.01	177.05
			61.23	79.80	95.62	122.87	225.99	302.39	309.57	177.05
				18.44	11.47	-55.60	-17.58	41.44	88.26	89.86
					7.64	-61.91	-55.60	-45.43	-29.60	-0.91
						-64.62	-61.91	-57.70	-51.15	-36.88
							-63.50	-61.76	-59.05	-50.75
								-62.78	-61.66	-55.82
									-62.32	-57.50
										-57.93

$ 523.86m

$ 520.41m – Calculated from lattice without option to close.

Decision strategy

CONTINUE OPERATING PLANT?									
2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	NO	NO	NO	NO	NO	NO	NO	NO	NO
		NO	NO	NO	NO	NO	NO	NO	NO
			NO	NO	NO	NO	NO	NO	NO
				NO	NO	YES	YES	NO	NO
					NO	YES	YES	YES	YES
						YES	YES	YES	YES
							YES	YES	YES
								YES	YES
									YES

NPV with flexibility = $ 523.86m

NPV with no flexibility = $ 520.41m

Value of option to close = $ 3.45m

Conclusions

- Ability to adjust capacity as demand is valuable.

  $ 38.68m more value than single large plant (decision analysis)

  $ 77.45m more value than small plant, no expansion (lattice valuation)

- Ability to close coal plant in the event of low demand, regulations has value.

  $ 3.45m more value than without option to close

- Given high degree of uncertainty, flexibility can play an important role in construction of new infrastructure in Shanghai.

→ On many measures (cost-benefit, expected NPV, minimize downside), staged natural gas plant (Plan 3) is superior.

→ Option to close has small benefit for coal plant (Plan 1).