Scientific solutions for complex decision problems challenging senior management
Outline

1. Introduction and perspective
2. Critical dimensions of the energy system
3. Agent based modeling and public policy analysis
4. Building a model of Lithuania and surrounds
This Is The Number 1 Lesson I Learned In EES (PreCambrian Name)

- You have to build it yourself!!!!
- EES gives you the
  - Tools
  - Methodology
  - Breath of training
  - Confidence
to do it creatively and correctly and create value.
1. Introduction and Perspective
Dale M. Nesbitt


- Employment History
  - Employee #70 at legendary Xerox PARC (1972-4).
  - Stanford Research Institute, Decision Analysis Group (1974-7).
  - Co-founded and built Decision Focus Inc (DFI) into $25 million (sales) company (1977-95).
    - Their energy practice has become Altos
  - Co-founded four new companies (1996-05)
    - Altos Management Partners Inc. (management consulting)
    - MarketPoint Inc. (enterprise software)
    - Reticle Inc. (high surface area carbon, water deionization/desalination)
    - Ferritech Inc. (biotechnology/ferric oxidation)
Q: How many economists does it take to change a light bulb?

A: Eight. One to screw it in and seven to hold everything else constant.
What is the difference between an introverted economist and an extroverted economist?

An extroverted economist looks at YOUR shoes when he is talking to you.
Economics Is a Pragmatic Science

Why do economists carry their diplomas on their dashboards?
So they can park in the handicapped parking.
Q: How did the French revolution affect world economic growth?
A: Too early to say.
Economics Is the Science of Markets and Valuation

Source: Rice University Economics Department
2. Critical Dimensions of the Energy System
Consider Several Energy Conversion Factors

✓ Methane: ~1 MMBtu/Mcf
✓ Electricity: 3413 Btu/KW-hr
✓ Gasoline: ~5.2 MMBtu/bbl, 42 gal/bbl
✓ Price of Methane: $4.50/Mcf
✓ Price of Electricity: $60/MW-hr
✓ Price of Gasoline: $1.30/gal (wholesale, pre-tax)

■ Remember when you took physics and they said you could use whatever units you want?
■ I want to use a common unit, namely the British Thermal Unit or Btu (forget this metric $#%$^#@. That isn’t the way energy people think.)
Let’s Express Energy Prices on a Common Basis ($/MMBtu)

- **Electricity (6 cents/KWh)**
  \[
  \frac{60}{MW \cdot hr} \left( \frac{1 \text{KW} \cdot \text{hr}}{3413 \text{ Btu}} \right) \left( \frac{1 \text{MW}}{1000 \text{ KW}} \right) \left( \frac{1000000 \text{ Btu}}{1 \text{ MMBtu}} \right) = 17.58 / \text{MMBtu}
  \]

- **Gasoline (wholesale, pre-tax, $1.30/gal)**
  \[
  \frac{1.30}{\text{gal}} \left( \frac{42 \text{ gal}}{1 \text{ bbl}} \right) \left( \frac{1 \text{ bbl}}{5.2 \text{ MMBtu}} \right) = 10.50 / \text{MMBtu}
  \]

- **Natural Gas ($4/Mcf)**
  \[
  \frac{4.50}{\text{Mcf}} \left( \frac{1 \text{ Mcf}}{1 \text{ MMBtu}} \right) = 4.50 / \text{MMBtu}
  \]
What Are the Relationships Among These Markets?

- Electricity has extremely high “form” value
  - However, you cannot store electricity onboard a mobile platform or on a stationary platform.
  - Therefore, its value as a transportation fuel is low.
  - Not since Faraday has ANYONE figured out the electricity storage problem

- Gasoline has extremely high “form” value because you can store zillions of Btus on board a mobile platform like a car, truck, or plane.
  - Gasoline will always command premium prices.
  - Gasoline is heavily, heavily, heavily taxed, particularly in states like California and throughout Europe and Japan.
  - Gasoline and other refined products are unlikely to be used as stationary sources; they are too valuable in transportation uses.
  - Transportation is a major driver of all energy prices, even stationary sources.
What Are the Relationships Among These Markets?

- Transportation demand continues to grow.
- North America is short of refinery capacity, and refinery feedstock crude oils are getting heavier worldwide.
- Heavy liquids sell at the price of natural gas; light liquids sell at the price of gasoline.
  - The “cracking margin” and the “light-heavy differentials” are set by the market, not any particular refinery, and we model that.
  - Virtually every refinery in North America has cokers, catalytic crackers, hydrotreaters, vacuum distillation, and other components designed to produce light products and eliminate low value heavy products.
  - The oil yield will continue to be concentrated on the transportation sector and away from stationary use.
Heavy Refined Products Are Sold at Deep Discount to Light Refined Products

- HFO Demand
- Light Demand

This is the $4.50/MMBtu market
This is a light-heavy differential
This is the $10.50/MMBtu market

This is a cracking margin

Refinery (distill and crack)

Gas
Crude
Refiners Don’t Want to Sell at Discount, Particularly in a Capacity Limited Market

- Cracking margins are strong.
- Refiners are going to crack and crack and crack in order to avoid selling part of their feedstock (crude) at discount.
- The price and quality of crude oil MATTERS.
- Refinery modeling MATTERS.
- The price and availability of natural gas MATTERS.
We Require an Interregional Understanding of Flows of Crudes and Products

Region A Product Demands

Region A Crude Import

Crude

Supply

Region A Refinery

Interregional Crude Transshipment

Region B Product Demands

Region B Crude Import

Crude

Supply

Region B Refinery

Interregional Product Transshipment
Refining Data Are Available for North America and the World

- Every refinery in the United States is on the EIA website; you can download all that data.
- Every crude and product pipe is available.
- World refineries are easy to get too.
- You can model general equilibrium around the products-refining-crude markets.
- If you cannot do so, you have missed the largest (by volume) portion of the energy system—liquid fuels.
- If you cannot do so, you cannot model interfuel substitution in natural gas markets.
If You Are Going to Model Refining, You Have to Model Crude Oil Worldwide
The Altos World Oil Model Has Been Doing This Since 1982
You Need a Microeconomic Understanding of Oil

- We have the USGS World Energy Program world oil data base.
- We need world demand projections by region.
- We need world oil transportation costs by region.
- We need to calculate world oil markets on a fundamental basis worldwide.
Crude Oil and Natural Gas Futures Prices 2/25/2005
Natural Gas Is Systematically Coupled with Oil, and You Need a Model of Gas with Oil Substitution
The North American Gas Model (NARG)
You Need to Understand World Gas If You Are To Understand North American Gas

- You have to understand the marginal cost of LNG at the border.
- It is not sufficient to just “consider what happens to North American price and basis when LNG lands.”
- You have to understand the marginal cost of Mexican and Canadian gas at the border.
- We executed a World Gas Project that resulted in a World Gas Trade Model.
Scope of Altos World Gas Trade Model

Program Sponsors: Amoco, Arco, BP, Chevron, CEC, Enron, Exxon, Fina, Mobil, Phillips, Texaco, Shell
World Gas

- USGS has a detailed resource assessment for every basin in the world, existing and prospective.
- We have quantified every existing and prospective pipeline and LNG shipping route in the world.
- We have quantified demand for every country in the world by segment (core, noncore oil substitutable, noncore coal substitutable).
- We have tremendous detail in various regions of the world (e.g., Europe)
Electric generation has to be in your picture
Electricity Is Connected with Gas and Oil, and Electricity Models Must Represent That Connection

- Power generation induces a demand for heavy oil and for natural gas
- Power competes in end use against gas
- Power represents fewer Btus than oil or gas, but the value added is very high and the complexity is very high
Power Plants Are EXPENSIVE to Build and Operate (Otay Mesa)

- $250-350 million for a 500 MW, 2-on-1 gas combined cycle power plant.

- If the plant runs for 20 years…
  - It burns $92 million worth of gas in every year (at $3/Mcf), whose present value over 20 years is approximately $900 million!
  - It incurs $3/MWh variable O&M costs, meaning $15 million worth of variable O&M costs, whose present value over 20 years is approximately $150 million!

- The life cycle cost of the plant excluding site costs, property taxes, and insurance is $1.35 billion.
  - This is a very significant capital exposure for most municipalities, particularly those that have to sell a lot of the plant’s power output in the open market
  - A $250 million plant is actually a $1.35 billion plant!
Power Generation Consumes as Well as Competes with Oil and Gas

- This is the $4.50 stuff
- $4.50 and $18.00 stuff compete here
- This is the $18.00 stuff
- This is the $4.50 stuff
- Power Generation

- Res. Demand
- Pwr.
- Gas
- FO
North American Regional Electric (NARE) Model
Here Is the Way The Energy System Is Configured

- Res
- Comm
- Indust.
- Trans.
- Refining
- Primary Oil/NGL
- Primary Gas/NGL
- Primary Coal
- Generation
A New Complication—Environment and Public Safety

- Local and not-so-local environmental concerns have risen to the fore.
- There are no more regionally balkanized problems any more.
- There are now tradable and traded entitlements for SO\textsubscript{x}, NO\textsubscript{x}, Hg, and perhaps CO\textsubscript{2}.
- Clear Skies will really cement it if it passes.
- Current system is unlikely to leave.
Schematic Multiregional Electric Generation/Transmission Illustration
Accumulate Entitlements into Entitlement Supply Function

Accumulate entitlements into “aggregate demand” function

All the various generators

“Aggregate supply” function is a **policy variable**

Accumulated Entitlement Demand

Entitlement Supply

Entitlement scarcity is endogenously priced

\( p \)

\( \lambda^* \)

\( q^* \)
We Calculate Every Energy and Entitlement Price at Every Hub SIMULTANEOUSLY

The two power hubs

The four entitlement hubs

Region 2 Demand
Region 2 Busbar

Region 1 Demand
Region 1 Busbar

Electric Transmission
Tradable entitlements are not a “parlor game” played with “Monopoly Money.”

They are serious business designed to force multibillion dollar decisions to get made in order for compliance to occur and to force people to do things they would not otherwise do.

If you don’t endogenize entitlements with energy, you get the wrong answer.

This has been a problem with CO₂ analysis—I don’t believe people have closed the loop.
3. **Agent based** modeling and public policy analysis
Models Enumerate Chains of Processes from Primary Resources to End Use (All Companies)

<table>
<thead>
<tr>
<th>RESOURCES</th>
<th>RESOURCE EXTRACTION</th>
<th>PRIMARY TRANS.</th>
<th>PRIMARY CONVERSION</th>
<th>PRODUCT TRANS.</th>
<th>SECONDARY CONVERSION</th>
<th>DISTRIBUTION</th>
<th>END USE CONVERSION</th>
<th>FINAL ENERGY SERVICE</th>
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<tbody>
<tr>
<td>Foreign oil</td>
<td>Import</td>
<td>Tankers</td>
<td>Sour crude refining</td>
<td>Tankers</td>
<td>Combined cycle</td>
<td>Truck</td>
<td>Auto</td>
<td>Auto veh-mi.</td>
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<td>Domestic oil</td>
<td>Exploration and production</td>
<td>Crude pipeline</td>
<td>Sweet crude refining</td>
<td>Products pipeline</td>
<td>Combustion turbine</td>
<td>Tank cars</td>
<td>Truck/bus</td>
<td>Truck/bus veh-mi.</td>
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<td>Gas pipeline</td>
<td>Shale refining</td>
<td>Low Btu gas pipeline</td>
<td>Steam turbine</td>
<td>Gas lines</td>
<td>Aviation</td>
<td>Jet pass-mi.</td>
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<td>Retorting</td>
<td>Unit trains</td>
<td>H-Coal</td>
<td>Power transmission</td>
<td>Internal combustion</td>
<td>Service station</td>
<td>Marine</td>
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<td>High sulfur coal</td>
<td>Surface mining</td>
<td>Nuclear fuel shipping</td>
<td>High Btu gas pipeline</td>
<td>IGCC</td>
<td>Large fuel cell</td>
<td>Local delivery</td>
<td>Resistance heating</td>
<td>Resistance heating</td>
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<tr>
<td>Low sulfur coal</td>
<td>Underground mining</td>
<td>Yellow cake</td>
<td>Solvent refining</td>
<td>Power transmission</td>
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<td>Heat pump</td>
<td>Catalytic burner</td>
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<td>Natural gas</td>
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<td>Beneficiation</td>
<td></td>
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<td>Electromech. Drive</td>
<td>Ind. process steam</td>
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<td>Imported gas</td>
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<td></td>
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<td></td>
<td>Steam generation</td>
<td>Ind. direct heat</td>
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<tr>
<td>LPG</td>
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<td>Low Btu gasification</td>
<td>Power transmission</td>
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<td>Small fuel cell</td>
<td>Ind. electromech</td>
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<tr>
<td>Imported products</td>
<td></td>
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<td>Methanol refining</td>
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<td>Micro-turbine</td>
<td>Naphtha feed</td>
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<tr>
<td>Uranium ore</td>
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<td></td>
<td></td>
<td>Chemical manufacturing</td>
<td>Gas feed</td>
</tr>
</tbody>
</table>

Models Enumerate Regionality of Supply, Transport, and Demand
Agent-Based Microeconomic Models

Formalize the Process and Geographic Dimensions Using “Networks”

- **R/C Resistance**
  - Heater
- **R/C Electricity**
  - Distribution
- **Region Gate**
  - Electricity
- **Electricity Loading**
  - Intermediate
  - Peak
- **Nuclear Generation**
  - Fuel
- **Uranium Mining**
  - Coal Liquefaction
- **Industrial Steam**
  - Demand
- **High Btu Gas**
  - Pipeline
  - Coal Gasification
- **High Sulfur Coal**
  - Minemouth
- **Natural Gas**
  - Production
  - (Gas Region)
Elements of an Energy Network

- **Nodes** contain detailed economic fundamentals—logic and data.
- **Links** transmit commodities and prices from node to node.
- **Model** as a whole predicts:
  - Prices
  - Basis differentials
  - Flowing quantities
  - New capacity/reserve additions
  - Reaction of each part of the system to every other part of the system
Our Modeling System (MarketBuilder™)
Is “Economic TinkerToys”

Wooden Things:
Technologies/Economic Agents

Sticks: Prices and flowing quantities
MarketBuilder Is a “Tinkertoy Set” for Building and Running Models

- “Wooden things” are the nodes, the points where economic activities occur.
- “Sticks” are the commodities traveling from node to node.
- “Tinkertoy structure” is the network that comprises the problem.
  - “Tinkertoy structure” can be very large and intricate or fairly small and simple.
  - You will never lack the ability to immediately expand or contract your model or run myriad “What If?” cases.
  - Everybody from senior management to junior analysts can run and interpret your model; there is no “shuck and jive” black box.
Nodes Are Pre-programmed and Linked Using the Network

- Demand
- Market
- Generation
- Hydro
- Refinery
- Multiproduct Refinery
- Transportation
- Depletable Resource
- Conversion
- Storage
- Multiproduct Transportation
It Took 30 Years and Several Hundred Person-Years to Build Our “Economic TinkerToy,” Agent Based Modeling System

1971: Mexico CFE Model (Cazalet, EES, 1971)
1973: SRI-Gulf Model
1977: EIA LEAP Model
1979: TVA SAM Model
1981: EPRI IFM and LMSTM
1982: DOE World Oil Model
1983: North American Regional Gas (NARG) Model
1988: California Refining/Transportation Model
1989: World Gas Trade Model (WGTM)
1991: Crude Quality Model
1991: Western European Gas Model
1992: Southern Cone (South America) Model
1993: OG&E, Duke, Minnesota Power, SCE, CIPSCO, PP&L competitive electric models
1995: Southeastern Australia Model
1995: PanEnergy North American Regional Electricity Model
1995: Altos North American Electricity Model
1998: Altos Short Term NARG Model
2002: Completely Modernized Technology
2003: Modernized World Oil and Gas Models
2003: USGS and NPC partnerships
2004: Henwood partnership
This Is a Photo of the Working Team Building the Economic TinkerToy Modeling System
## DIMENSIONS OF ECONOMIC SYSTEM

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Altos</th>
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<tbody>
<tr>
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<td>2</td>
<td>Geographic diversity</td>
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Requirement No. 1

**PROBLEM**

1. Facility/asset enumeration

**SOLUTION**

1. Graphical process “Tinkertoy Set” with unlimited expansion capability
   - You must be able to drag and drop facility nodes into your model.
   - You must be able to drag facility nodes on top of a GIS
   - You must be able to aggregate or disaggregate
   - Altos has node based drag and drop in our modeling system today
   - Different fuels use different facilities
Fully Graphical, Drag and Drop, Completely Visual, Network Oriented Models

- No programming except at the “node” level.
- Construct regionalized network representations of vertically and horizontally integrated markets using nothing but graphical “drag and drop” methods.
  - Graphical “Tinkertoy set” for building network models.
- Your model documentation is the “picture” of your model.
  - Your model is quintessentially transparent.
- “Double click” on nodes to enter data.
- Select activities from a palette; no programming.
- Deliver model outputs to Excel or Access where the power of their embedded presentation capability can be invoked.
Algerian Gas Supply—World Gas Trade

Model

Supply: Tunisia
Hub: Tunisia Pipeline Quality Gas

Demand: Spain
Demand-Hub: Spain

Liquefaction: Algeria LNG
Hub: Algeria Gas into LNG Liquefaction

Pipelines:
Pipe: Algeria to Tunisia
Pipe: Algeria Trans Maghreb to Iberia
Pipe: Algeria to Algeria Demand
Pipe: Algeria to Algeria LNG Liquefaction

Hubs:
Hub: Algeria Pipeline Quality Gas
Hub: Algeria Methane
Hub: Algeria Field Processing

Supply:
- Algeria Ghardames Onshore Oil/Gas Conventional
- Algeria Illizi Onshore Oil/Gas Conventional
- Algeria Ghardames Proved Reserves
- Algeria Illizi Onshore Oil/Gas RG
- Algeria Illizi Proved Reserves
- Algeria Western Proved Reserves
- Algeria Offshore Oil/Gas
- Algeria Western Onshore Oil/Gas Conventional
- Algeria Western Onshore Oil/Gas RG
File manager representation of hierarchically regional model

“Palette” of things you can do

“Tinkertoy” process diagram of selected region
A Liquid Fuels Model
Central Power and Light Electricity Region (CPS) in ERCOT
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Requirement No. 2

PROBLEM

2. Geographic diversity

SOLUTION

2. GIS coupled with graphical “Tinkertoy Set” for building models

- You must be able to “drag and drop” regions hierarchically into your model.
- You must be able to use a GIS to characterize each region at whatever level of the hierarchy.
- Altos has that in our modeling system today.
- Spatial economic/physical approach
- Different fuels have different regional characteristics
Altos Has Complete Hierarchical Regionality Today Suitable for GIS Insertion

Diagram and map of selected region

Palette of actions or models you drag in
Altos Has Process Networks Overlaying Maps at Whatever Level You Want

Source: MarketBuilder screen from Altos NARG
Roll Down the Regional Hierarchy (into Alberta)
Roll Down Further into Alberta Supply
Our World Oil Model is GIS Enabled
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Requirement No. 3

**PROBLEM**

3. Everything is connected to everything else (which means you cannot ignore fuels, demand elasticities, etc.)

**SOLUTION**

3. Models need to be housed within a common software platform so they can be interconnected

- Altos has comprehensive power, gas, oil, products, and coal interconnected commercial today
- This doesn’t mean Altos’ models are the best; it means we can link models given common temporal assumptions.
- The models are under one computational and methodological roof.
When You Do This, You Can Build a Suite of Interconnected Models

THE ALTOS SUITE OF ENERGY MODELS

- Natural Gas
  - World Gas Trade Model
  - NARG Long Term

- Electricity
  - Annual North American Electricity Model

- Oil and Products
  - World Oil Model
  - NARR

- Coal
  - Henwood-Altos CoalView

Global
Regional

When You Do This, You Can Build a Suite of Interconnected Models

THE ALTOS SUITE OF ENERGY MODELS

- Natural Gas
  - World Gas Trade Model
  - NARG Long Term

- Electricity
  - Annual North American Electricity Model

- Oil and Products
  - World Oil Model
  - NARR

- Coal
  - Henwood-Altos CoalView

Global
Regional
<table>
<thead>
<tr>
<th>DIMENSIONS OF ECONOMIC SYSTEM</th>
<th>Altos</th>
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Requirement No. 4

PROBLEM

4. There is no “off the rack suit;” you have to add (or delete) detail in real time

SOLUTION

4. Real time graphical “Tinkertoy Set” that can implement any network configuration you want

- Drag and drop nodes and links onto drag and drop maps
- Double click node data access
- “In/out” data slice editing using pivot tables
- Full, modern ODBC/SQL data base interface
- No programming, modules preprogrammed

✓ Focus on what is important
A “Custom Tailored Suit” for Lithuania and Surrounds

- There is no decision or forecast anyone (including Lithuania) has ever done that did not require customization.

- There is no “out of the box” model or data base for Stanford or anyone else.

- Retainer services, vox populi model runs, etc. have low value because they are just not customized.
A Note on Lithuania

- The picture of the model **IS** the model.
- A very good exercise is to draw an oil, gas, coal, orimulsion, wood/agricultural, coal supply chain model of Lithuania and surrounds.
- If you miss the surrounds, you miss the problem.
- We will provide the technology to allow you to draw the pictures and thereby built the model(s).
- We are going to start (real time) in a minute.
Lithuania and Surrounding Environs
Consider natural gas.
The largest deposit of natural gas in the world is in Russia and the Middle East, both closer to Lithuania than the rest of the world.

Load file
c:/dalework/EurasiaGasPipelineMapInogate.pdf
The “Big Dog” Is Europe
Towns connected to the natural gas grid
1620 km of transmission pipelines
57 M/R stations
1 gas compressor station
1 border metering station
5980 km of distribution pipelines currently in operation
Let’s Look at a Pre-Existing Model

- Altos World Gas Trade Model

```
c:/models/worldgastrademodel_new.mkp
```
Here’s How We Did It in the United States (and How You Do It in Lithuania)
Within Every Box Lies the “Big Six” Power Issues

Indigenous Consumption

Competitive Hub

Indigenous Generation

Fuels

Outbound Transmission

Inbound Transmission

Native Load

LDC

Gas

Coal

Coal

Lignite

IGCC

GT/IC

GT/IC

Coal

Gas

Fuel

FO6

FO2

FO1
Load: You Need to Measure Demand Variation by Time of Day, Week, Season and Year

FERC Form 714 Downloading (USA)

In Lithuania, you gather or extrapolate from analogous countries

We can use either chronological or load histogram (load duration)
We Can Create Monthly Load Duration Curve by Sorting

We can create a monthly load duration curve by sorting observed chronological demand from largest to smallest hourly demand.
Example: TVA Load Duration Curves
We Disaggregate Each Month into Many Tranches So That We Consider the Critical Times of Extreme Peak and Extreme Off Peak

Each month is divided into 10 tranches of load and therefore 10 tranches of MW
What Do We Do to Make a Model?

- Sort regional hourly data to create
  - Load duration curves for the given time frame
    - Annual
    - Monthly
    - Daily
    - Chronological load periods.
  
- Discretize the load duration curves into demand and time blocks.
  - Discrete load factors and energy fractions.
Generation Data

“Supply stacks”
Example: Florida (FRCC) Supply Stack (from Winning Duke New Smyrna Beach testimony)

From Duke public testimony, December 3-4, 1998

Duke New Smyrna Beach Plant

Production Cost ($/MWH) vs. Cumulative MW Capacity
ERCOT 2002 Supply Stack (Incl. Demand Range)

Cumulative GW $/MWH

NU
HY
ST
CC
GT
IC
CG
Ur
Wat
Coal
NG
FO1
FO2
FO6
Wd
Wst

Demand Range

Magic Valley
Insights from Supply Stack

- Given sufficient transmission access, new plants are inframarginal in virtually every hour of the year.
  - Price will be above production cost virtually every hour of the year.
  - Transmission access to market during peak hours is the key to project profitability
- Profitability will not be sensitive to gas price or demand.
- New plants (e.g., Magic Valley) will be a profitable
- The thing that shuts new plants off is not enough operating hours
Example: California Supply Stack (CANV)

From TXU and Duke California plant bid analysis

These are the plants that were auctioned
Example: ECAR Supply Stack

Some of these plants failed in summer 1998
Capacity Investment Types

- Pulverized Coal
- Super-Critical Pulverized Coal
- Combined Cycle (Coal Gasification)
- Combined Cycle (Gas)
- Combined Cycle (Resid and Distillate)
- Simple Cycle (Gas)
- Nuclear
- Wind
### Capacity Investment Parameters

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Capital Cost ($/KW)</th>
<th>Economic Life (Yrs)</th>
<th>Operating Life (Yrs)</th>
<th>2002 Heat Rate (BTU/KWh)</th>
<th>Debt %</th>
<th>Interest Rate</th>
<th>Equivalent Availability (%)</th>
<th>Spending Lead (Yrs)</th>
<th>ROE</th>
<th>VOM ($/MWh)</th>
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</thead>
<tbody>
<tr>
<td>Pulverized Coal</td>
<td>$1,200</td>
<td>25</td>
<td>35</td>
<td>9,500</td>
<td>55.0%</td>
<td>8.0%</td>
<td>85.0%</td>
<td>4.0</td>
<td>16.0%</td>
<td>$2.00</td>
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<tr>
<td>Combined Cycle (Coal Gasification)</td>
<td>$1,400</td>
<td>20</td>
<td>30</td>
<td>9,500</td>
<td>55.0%</td>
<td>8.0%</td>
<td>90.0%</td>
<td>3.0</td>
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<td>Super Critical Pulverized Coal</td>
<td>$1,250</td>
<td>25</td>
<td>35</td>
<td>9,500</td>
<td>55.0%</td>
<td>8.0%</td>
<td>85.0%</td>
<td>4.0</td>
<td>16.0%</td>
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<tr>
<td>Combined Cycle (Gas)</td>
<td>$600</td>
<td>20</td>
<td>30</td>
<td>7,200</td>
<td>55.0%</td>
<td>8.0%</td>
<td>92.0%</td>
<td>2.0</td>
<td>14.0%</td>
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<td>Combined Cycle (Dist)</td>
<td>$670</td>
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<td>30</td>
<td>7,800</td>
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<td>30</td>
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<td>Combined Cycle (Resid)</td>
<td>$800</td>
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<td>30</td>
<td>8,200</td>
<td>55.0%</td>
<td>8.0%</td>
<td>70.0%</td>
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<td>14.0%</td>
<td>$3.10</td>
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<td>Combustion Turbine (Gas)</td>
<td>$350</td>
<td>20</td>
<td>30</td>
<td>11,000</td>
<td>45.0%</td>
<td>8.0%</td>
<td>92.0%</td>
<td>1.5</td>
<td>14.0%</td>
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<td>Nuclear</td>
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<td>Wind</td>
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<td>30.0%</td>
<td>3.0</td>
<td>14.0%</td>
<td>$0.00</td>
</tr>
</tbody>
</table>

- Gas and Coal IGCC units capable of build starting in 2006
- Pulverized Coal units capable of build starting in 2010
- Assumes a 40% income tax rate and a 2.5% insurance/property tax rate
Coal capacity additions allowed

Capacity Investment Restrictions (Coal)
Capacity Investment Restrictions (Oil)
# Plant Retirements Matter

## Total of 21,139 MWs forced to retire by the year 2010

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<tr>
<th>Region</th>
<th>MWs Retired</th>
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<tbody>
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<td>ECE</td>
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<tr>
<td>ECW</td>
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<td>MECS</td>
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<td>PJW</td>
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<td>PJE</td>
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<td>PJS</td>
<td>1,367</td>
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<tr>
<td>WUM</td>
<td>926</td>
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<tr>
<td>NIL</td>
<td>740</td>
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<tr>
<td>SOM</td>
<td>383</td>
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<tr>
<td>MAPPU</td>
<td>1,840</td>
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<tr>
<td>NE</td>
<td>915</td>
</tr>
<tr>
<td>NY</td>
<td>1,225</td>
</tr>
<tr>
<td>ENT</td>
<td>178</td>
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<tr>
<td>STHRN</td>
<td>504</td>
</tr>
<tr>
<td>TVA</td>
<td>25</td>
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<td>VCR</td>
<td>3,516</td>
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<td>FRCC</td>
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<td>SPN</td>
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<td>SPW</td>
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<td>AZ</td>
<td>43</td>
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<tr>
<td>CO</td>
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<td>SD</td>
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<td>UT</td>
<td>240</td>
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<td>TX</td>
<td>363</td>
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</table>

**Total**: 21,139
Results: Fuel Mix for Power Generation (Reference Case)

Excludes Hydro and Pumped Storage

- #6 Oil
- Coal
- Uranium
- Gas
- FO2
Results: Fuel Mix in Power Generation (Lower Gas Prices)

- #6 Oil
- Coal
- Uranium
- FO2
- Gas

Excludes Hydro and Pumped Storage
Results: Gas Consumption in Power by Region (Reference Case)
Results: Gas Consumption in Power by Region (Lower Gas Prices)
Results: New Capacity Build (Reference Case)
Results: New Capacity Build (Lower Gas Prices)

Graph showing new capacity build in MWs from 2002 to 2030 for various energy sources:
- Gas CC
- Gas SCCT
- Coal IGCC
- Gas/Oil CC
### DIMENSIONS OF ECONOMIC SYSTEM

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Requirement No. 5

PROBLEM
5. The real world is “agent based,” a myriad of independent agents all seeking maximum profits or minimum costs.

SOLUTION
5. Goal seeking fundamental microeconomic approach (impossible with LP, NLP, dispatch, production simulation, system dynamics)

- They give Ph. D.’s in economics and game theory
- There is no dictator that coordinates decisions or sets prices (and never will be!)
- There is no creativity allowed on this point
Agent-Based Approach

- The right methodology--most market modeling approaches are not “agent based models,” and no one doubts that the real world is agent based

  - Profit seeking entities who pursue self interest independently of but in competition with other agents (e.g., profit maximizing individual firms rather than aggregate cost minimization, the latter of which is preposterous on its face).
  - Fully intertemporal (fully dynamic) and endogenous, investment, operation, and retirement decisions. If capacity addition is not endogenous, the model is wrong.
  - “Putty-clay,” fully vintaged models of capital stocks. Models that are not vintaged are wrong.
  - Rational expectations, in which today’s investment decisions depend on tomorrow’s price and tomorrow’s price depends on today’s investment decisions.
  - Zero arbitrage over space and time. It cannot be possible to change any agent’s decisions over time or over space and beat the market solution.
  - “Clearing” of all markets, meaning that price is the variable that rations and eliminates shortages and excesses everywhere (“Walrasian equilibrium”)
  - Market imperfections (e.g., monopoly, oligopoly, market power) that can be represented using constraints, restraints, and alternative market structure assumptions.
If Your Model Has 1300 Agents or Entities in It, How Many Optimization Problems…

✓ …do LP and production simulation posit? ONE—every agent marches in lockstep to the drumbeat of an economic dictator to minimize aggregate cost. Huh?

✓ …do the real world and MarketBuilder posit? 1300 individual, independent profit maximization problems, one for each agent.
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Requirement No. 6

**PROBLEM**

6. You’d better not have a naïve model of demand

**SOLUTION**

6. Demand needs to be sensitive to lagged adjustment, own price, cross price, GDP, population and weather.

✓ Rice University has the best energy modeling shops right now

- Overall demand (Medlock and Medlock & Soligo)
- Market sharing (Jill Nesbitt, Ph. D. thesis in progress)
The Right Demand Models

Country/Sector

- GDP, Pop, Weather

Aggregate Demand Model
(Medlock, Medlock and Soligo)

Price Index

Market Share Model
(Jill Nesbitt)

- Wood/Ag.
- Gas
- Oil
- Coal

Own price, cross price
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Requirement No. 7

**PROBLEM**

7. You had better not have a naïve model of depletable resource supply

**SOLUTION**

7. Altos has the most sophisticated resource model in the industry

- It is a vintage, dynamic extension of the Hotelling model
Depletable Resource

- Depletable resource node allows sophisticated representation of long term commodity models such as NARG or World Oil Model
- Depletable resource process is fully dynamic over time
- It is derived from generic conversion process but has the Hotelling/CAPM/rational expectations dynamic specialization
- Includes capacity expansion logic, scarcity rent calculations, full inter-temporal arbitrage
- Complex, more than 30 related topics in User’s Guide
- Price taking, profit maximizing behavior of the owner of a depletable resource; national oil companies do this too!
The Depletable Resource Model
Drills Wells Like a Real Producer

- Resource is developed to optimize each producer’s NPV on resource.
- Drilling depends on forward curve and forward curve depends on drilling.

**Expended Resource (historical production)**

**Total supply from all vintages of well delivered to market over time, q(t)**

“New” Reserves added at time \( t \)

Proved reserves is green area—total inventory to be produced at time \( t \) and into the future.
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</table>
Requirement No. 8

**PROBLEM**
8. Completely general temporal structure

**SOLUTION**
8. Continuous forward timeline with arbitrary and different time increments

- You must be able to skip intervals, but you must be simultaneous over time
- Different time frames for different decisions
- Integrals and derivatives across time intervals must be pre-programmed
- Altos has this

Each Time Point Has a Continuous Load Shape

Arbitrary Number of Discrete Chronological or Nonchronological Subintervals

Demand (MW)
<table>
<thead>
<tr>
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**Requirement No. 9**

**PROBLEM**

9. Capacity additions and retirements must be endogenous

- The idea that you can “put in alternative capacity entry schedules” and thereafter “run sensitivities” or “look for basis blowouts” is preposterous at its heart—you are guessing at the most fundamental number.

**SOLUTION**

9. Fully endogenous, rational expectations, intertemporal model of capacity entry (and retirement)

- Altos represents new builds endogenously and consistently with economic theory.
- Capacity entry and fixed costs are the most important calculations in economics, and they MUST be endogenous.
Altos Features

**Fully endogenous, rational expectations, intertemporal model of capacity entry (and retirement)**

- MarketBuilder represents new builds endogenously and consistently with economic theory—no other model does.
- Other models require you put in alternative capacity entry schedules and run sensitivity cases. This time consuming task can be overwhelming to do well for a large model. MarketBuilder does this for you with an accuracy you can’t approach by trial and error.
- Capacity entry and fixed costs are the most important calculations in economics because:

  **Today’s capacity addition decision affects the full schedule of forward price and**

  **The full schedule of forward price affects today’s capacity addition decision.**
Zero Arbitrage Over Time in MarketPoint

- **Capacity** is added until present value of all future margin capture just compensates capital cost at the margin.
  - “Dynamic rational expectations equilibrium.”
    - Depletable resource nodes governed by Hotelling, zero temporal arbitrage models
    - Other nodes governed by zero temporal arbitrage NPV maximization models.
  - “You cannot deposit or withdraw money from the bank and beat the MarketBuilder model solution.”

- **Capital investments** must be paid by present and future margin capture; otherwise they will not be made.

- **Capital investments** are cold, hard, rational, properly located investments. Those investments “create” / “form” market prices

- Prices reflect capital cost of entry as well as operating cost of ongoing production
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Requirement No. 11

**PROBLEM**
11. Compute time

**SOLUTION**
11. Parallelism

- Impossible with LP, NLP, dispatch, production simulation
- It is only possible with price iteration
  - If we use 4 processors, we get it in ¼ the time
  - Parallelization algorithms don’t work in practice because algorithms are serial
- Altos has a fully parallel system, meaning compute time is not a limitation
Altos Features

**Fully parallelized calculation method so that execution time can be minimized.**

- People invariably want extremely detailed models, but they want short compute time.
- Computers increase performance beyond the fastest single processor machine by using parallel processors. However most software cannot utilize the extra processors.
- Because of its unique algorithm, MarketBuilder is able to utilize multiple processors simultaneously.

**No limit on model detail.**

- This is a direct corollary of parallelization.
- People need the flexibility to add detail at the level of individual plants or subsets of plants throughout the entire world all the way up to rather aggregated representations.
- Graphical representations need to be as large as anyone might want.
Basic System--MarketBuilder™

User → Market Builder → Single Machine/Single Processor
Analysis Accelerator™ (Many Processors/Single RAM)

User

Scenario Queue

Single Machine/Multiple Processors

Completed Scenarios
Analysis Grid™ (Many Processors Each with Independent RAM)

- User
- Scenario Queue
- Dispatcher “Scheduler”
- Completed Scenarios
- Multiprocessor-RAM Machine No. 1
- Multiprocessor-RAM Machine No. 2
- Multiprocessor-RAM Machine No. n

LAN “Workers”
At Our Offices in Los Altos

- We have six interlinked computers we have named
  - “Euler” (single 3.4 GHz)
  - “Riemann” (single 3.4 GHz)
  - “Gauss” (single 3.4 GHz)
  - “Bernoulli” (single 3.4 GHz)
  - “Rumsfeld” (dual 3.4 GHz)
  - “Friedman” (dual 3.4 GHz)

- (Guess which one is the “controller!”)

- Has been run on 16 interconnected computers (all Windows PCs).
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Définition de la nécessité 12

**PROBLEME**

12. Le monde est non-linéaire, et très fortement.
- La programmation linéaire est une approche pour le modélisation du marché *terrible*.

**SOLUTION**

12. Equations et technique de solution non-linéaire uniquement.
- Les équations différentielles linéaires sont appelées "linéaires" pour une raison.
- La programmation linéaire est appelée "linéaires" pour une raison.
- Les approximations linéaires discrètes des modèles non-linéaires sont coûteuses, subjectives à des problèmes de représentation de machine, et généralement intractables.
- Altos est intrinsèquement non-linéaire.
With LP, the Output Surface Is “Faceted” (Only Discrete Combinations Solutions)

Solution surface consists of hyperplanar (linear) facets or “flat areas”
With LP, the Vertexes Are the Only Allowed Solutions

There are a finite number of such discrete solutions

You always end up at a vertex

Lines of constant relative price

Quantity 1

Quantity 2
With LP, the Output Surface Therefore Has Nonunique Prices (actually Shadow Prices), and They Occur in Discrete Ranges

Every “slope” corresponds to a different mix of prices

The slope can vary through a finite range before the solution “bangs” to a contiguous vertex!
The answer suddenly changes instantaneously and drastically for an infinitesimal change in costs!
This Means LP Supply Curves at Each of the Demand Hubs Are Stepped
There May Be No Solution Using a Continuous, Price-Elastic Demand Curve
LP Sensitivities Differ from Real World Sensitivities

As you know from Decision Analysis, this is an **absolutely terrible property** of any deterministic model.

Cost element $c_i$
Why: Because You Cannot Make a “Tornado Diagram” with an LP Model

- Profit (NPV)
  - Gas Price
  - Coal Price
  - Capital Cost of Gas CC
  - Oil Price
  - Capital Cost of Gas CT
  - Peak Load Growth
  - Energy Demand Growth
  - Heat Rate of New Gas CC
  - Hydro Availability
  - Transmission and Congestion

- $62.8MM
- $124.7MM

Why: Because You Cannot Make a “Tornado Diagram” with an LP Model
Altos’ Continuous Nonlinear Methods Like Ours Have Accurate, Continuous Sensitivity Results

Small changes in input (supply curve shape) lead to SMALL, NONZERO changes in the Walrasian answer.
## DIMENSIONS OF ECONOMIC SYSTEM

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**Prerequisite No. 13**

**PROBLEM**

13. **Uncertainty**

**SOLUTION**

13. **Sampling**

- Monte Carlo
- Latin Hypercube
- Stratified
- Importance sampling

- Discrete trees or influence diagrams blow up
- Scenarios don’t cut it
“Hey, we’ll just stick in some Monte Carlo samples and go!!”

Myriad “What If?” cases or samples from distributions

This can be quite problematic

Uncertain Model Inputs

Histograms over model results
The Model Is a Nonlinear Relationship from the Data to a Result

\[ r = M(\alpha) \]

- \( \alpha \) = data (usually a gigantic vector)
- \( r \) = results (usually a vector)
- \( M(.) \) = complex system of nonlinear equations
- Uncertainty in the result derives from uncertainty in the data.
- Your model is a gigantic “change of variables” problem.
It is Uncertainty in the Data that Induces Uncertainty in the Result

\[ r = M(\alpha) \]

- \( \{\alpha\} = \) multivariate, correlated, joint probability density function over the data
- Example = probability density function over resources in Palo Verde, load in Seattle, precipitation in the Cascades, transmission from Colorado to Arizona, and outages at San Onofre.
- The model induces a probability density function over the result \( \{r\} \)

\[ M(\{\alpha\}) \rightarrow \{r\} \]
People want to put the expected value of the data \(<a>\) into the model and "hope" that they get the expected value of the result \(<r>\).

This is NOT right.

\[ <r> \neq M(<\alpha>) \]

There are no shortcuts in probability

- Who here got A’s in advanced probability in college?
- Did you find any shortcuts in the course?
Second Order Taylor Expansion of the Model About the Mean

\[ r = M(<\alpha>) + (\alpha - <\alpha>)^T \nabla M(<\alpha>) \]
\[ + \frac{1}{2} (\alpha - <\alpha>)^T \nabla^2 M(<\alpha>)(\alpha - <\alpha>) + O[(\alpha - <\alpha>)^3] \]

If we integrate over \( \alpha \), we obtain the following expression for the expected value of the model result.

\[ <r> = M(<\alpha>) + 0 + \frac{1}{2} \int d\alpha (\alpha - <\alpha>)^T \nabla^2 M(<\alpha>)(\alpha - <\alpha>) \]
\[ + O[(\alpha - <\alpha>)^3] \]

The first order effect of uncertainty in your model.
The Uncertainty Term Combines the Variance/Covariance Over Sample Uncertainties and the Nonlinearity of the Model

\[ \frac{1}{2} \int d\alpha (\alpha - <\alpha>)^T \nabla^2 M(<\alpha>)(\alpha - <\alpha>) \]

Curvature (Second derivative matrix that quantifies nonlinearity) of your model

Variance/covariance matrix of the uncertain input variables

Probabilistic dependence really matters

Model nonlinearity really matters
This Term is Prescient

- You MUST consider the full probability distribution over all inputs, and you must NOT make approximations that compromise correlation, jointness, and probabilistic dependence.
  - You CANNOT just pick one variable and move blithely ahead.
  - You need a tornado diagram.

- You MUST consider nonlinearities and curvature in your model.
  - You must not engage in “model inflation” that compromises the structure of your model
  - Nonlinearity and structure matter.
What Is Best Practice for Sufficiently Sophisticated Models

- Use exhaustive (but judgmental) single variable sensitivity analysis to quantify “local” model curvature.
- Flex the model across roughly equal confidence interval bounds in the marginal distributions over the input variables.
- These confidence intervals give some notion of a “common” range for each uncertain input variable.
The Two Most Important Elements of Modeling Uncertainty

You must have a **JOINT, CORRELATED** probability density over all model inputs

**Uncertain Model Inputs**

You must have a fully **accurate, NONLINEAR** model

\[ r = M(\alpha) \]

Histograms over model results
Two of the Three Biggest Mistakes People Make (We’ll Come to the Third in a Minute)

- **Too much probabilistic independence among inputs**
  - **Examples**
    - Independent samples of individual plant outage
    - Independent samples of price volatility (random walk)
    - Independent samples of gas supply and cost across basins

- **Linear or linear programming models.** With such models, you are wasting your time incorporating uncertainty—just calculate the mean value and move on. If the model is linear, key probabilistic terms are additive, and therefore you are wasting your time simulating. You can do the math directly.
You Cannot Run At Risk! Or Crystal Ball…They Aren’t Robust Enough

It is too easy to have independent inputs

Uncertain Model Inputs

You can’t use a full size model, only an Excel “toy”

“Toy” Model

Histograms over model results
Partial Fix--Run Tens or Hundreds of Single Variable Sensitivity Cases Across a Presumably Common Confidence Interval

Myriad “What If?” cases or samples from distributions

Toronado diagrams over model results

Variable 1

Variable 2

Variable n

\[ r = M(\alpha) \]

<table>
<thead>
<tr>
<th>Variable</th>
<th>Effect on Profit</th>
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<tbody>
<tr>
<td>Oil Price</td>
<td>-$124.7MM to +$62.8MM</td>
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<tr>
<td>Interest Rate</td>
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<td>Tax Rate</td>
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<td>Alberta Conventional Volumes</td>
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<td>Gulf R/P Ratio</td>
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<td>GNP Growth</td>
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<td>Noncore Demand</td>
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<td>Rockies Volume</td>
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<td>Gulf to Northeast Trans. Tariff</td>
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<td>Coalbed Methane Cost</td>
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The Most Important Variables to Most Decisions are Invariably Economic (Typical “Tornado” diagram)

Profit (NPV)

Gas Price

Coal Price

Capital Cost of Gas CC

Oil Price

Capital Cost of Gas CT

Peak Load Growth

Energy Demand Growth

Heat Rate of New Gas CC

Hydro Availability

Transmission and Congestion

-62.8MM

0

124.7MM
Treat Only the Variables at the Top of the Tornado Probabilistically

- Pick the top several variables and treat them probabilistically.
- Leave all the rest of the variables at their mean value.
- Have faith that the biggest precursors to uncertainty are treated probabilistically.
- What is wrong with this? The “linear” term integrates out! It is the nonlinear terms that matter.
Then Create a Tree from Ascending to Descending Single Variable Sensitivity

3^6 combinations (=3^6 calculations)
3^6 probabilities

Monte Carlo is precisely the same.
Then Make DARN SURE You Have the Probabilistic Correlations/Dependencies in the Tree

Electricity Price → Plant Cost → Income Tax Rate → ROE → O&M Cost → Gas Price

The branch you are on here

This probability is conditional on…
The Tree Systematically Enumerates the Requisite Model Scenarios

Exhaustively run every scenario at the terminal branches of the tree.
This Gives a Joint Probability Density Function Over Results

Each model scenario is probability weighted by the probability of that path through the tree

Result

Probability

0
And Yet This Isn’t the Worst Part!
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Prerequisite No. 14

**PROBLEM**

14. Agents have expectations, and they act on them

**SOLUTION**

14. Three alternatives

- Rational expectations
- Perfect expectations/lagged decision making (information diffusion)
- Imperfect expectations/perfect decision making (Arrow Debreu)

- We have the first two, and the third is on the way
Agents Have DIFFERENT Probabilities Over the Same Event

- Monte Carlo models have a **single probability distribution that is common and identical across every agent in their model**.
- This is **wrong on its face**
  - There are dramatic asymmetries of information in the real world (e.g., patents, basinal knowledge, IP, conservatism, access to data, classification, intentional deception, propaganda, individual plant knowledge, scope and scale of business, experience, business climate)
  - In general, every agent has different information about everything
  - There is no “Monte Carlo” distribution to sample from; every agent has his or her own distribution!!!
Examples Abound That the Agent View Is Paramount

- Companies build power plants, drill wells, build LNG regasification plants, etc.; government agencies do not.
- Companies pursue profits, not greater social goals such as WECC-wide cost minimization or congestion alleviation.
- Every company has its own private perception, probability, and information set.
- Once facilities are in place, each and every asset throughout the WECC is affected.
- The agent view is fundamental to success.