The Missing Money Problem

Quantitative Energy Economics

Anthony Papavasiliou

Contents

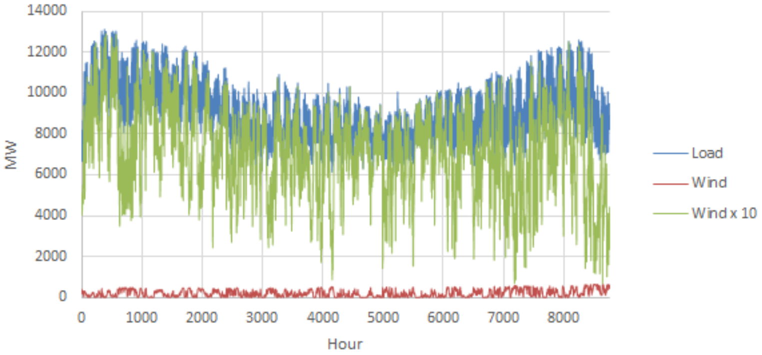
The Missing Money Problem

Missing money: money that is needed in order to keep the optimal mix of generators in the market, but is never recovered from the market

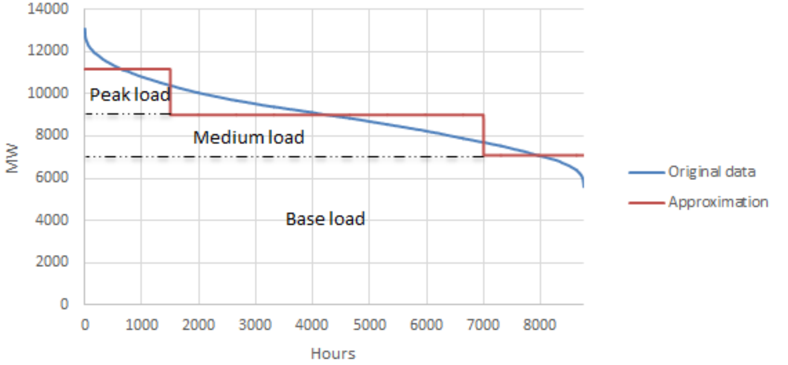
Outline

1. Screening Curves
2. Short-Run Versus Long-Run Equilibrium
3. Missing Money

Load and Wind in Belgium, 2013



Load Duration Curve



Load duration curve is obtained by sorting load time series in descending order

Horizontal Stratification of Load

Load duration curve describes number of hours in the year that load was greater than or equal to a given level (e.g. net load was $\geq$ 10000 MW for 2000 hours)

Step-wise approximation:

- Base load: 0-7086 MW, lasts for 8760 hours (whole year)
- Medium load: 7086-9004 MW, lasts for 7500 hours
- Peak load: 9004-11169 MW, lasts for 1500 hours

Technological Options

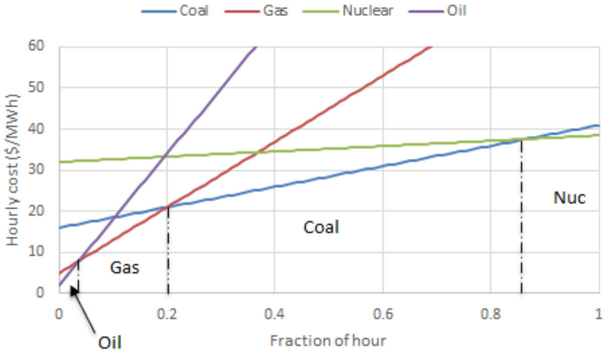
Technology	Fuel cost ($/MWh)	Inv cost ($/MWh)
Coal	25	16
Gas	80	5
Nuclear	6.5	32
Oil	160	2

- Fuel/variable cost: proportional to energy produced
- Investment/fixed cost: proportional to built capacity
- Discounted investment cost: *hourly* cash flow required for 1 MW of investment

Optimal Investment Problem

Optimal investment problem: find mix of technologies that can serve demand at minimum total (fixed + variable) cost

The optimal investment problem can be solved graphically with *screening curves*

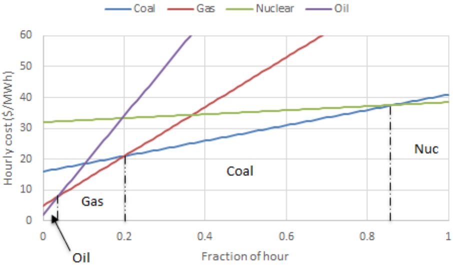


Screening curve: Total hourly cost as a function of the fraction of time that a technology is producing

Logic of Graphical Solution

- Total cost of using 1 MW of a technology depends on amount of time it produces
- Each *horizontal slice* of load can be allocated to an optimal technology, depending on its duration (which technology should serve base load? peak load?)

Optimal Solution



Fraction of time each technology should be functioning:

- For oil: $2 + 160 \cdot f \leq 5 + 80 \cdot f \Leftrightarrow f \leq 0.0375 \Rightarrow$ 0-328 hours
- For gas: $f > 0.0375$ and $5 + 80 \cdot f \leq 16 + 25 \cdot f \Leftrightarrow f \leq 0.2$ $\Rightarrow$ 328-1752
- For coal: $f > 0.2$ and $16 + 25 \cdot f \leq 32 + 6.5 \cdot f \Leftrightarrow f \leq 0.8649 \Rightarrow$ 1752-7576 hours
- For nuclear: $0.8649 \leq f \leq 1 \Rightarrow$ 7576-8760 hours

Optimal Solution

Recall,

- Base load: 0-7086 MW, lasts for 8760 hours (whole year)
- Medium load: 7086-9004 MW, lasts for 7500 hours
- Peak load: 9004-11169 MW, lasts for 1500 hours

From previous slide,

- Base-load is assigned to nuclear: 7086 MW
- Medium load is assigned to coal: 1918 MW
- No load is assigned to oil: 0 MW
- Peak load is assigned to gas: 2165 MW

Outline

Equilibrium Energy Price

Suppose suppliers are *price takers*, i.e. they do not account for impact of their decisions on prices

Competitive market equilibrium: combination of market prices and production quantities such that

- no producer can benefit from changing production quantity
- supply $\geq$ demand

A Short-Run Equilibrium

Marginal unit: most expensive unit producing energy

Suppose capacities fixed to optimal mix

- One possible competitive equilibrium: price = fuel cost of marginal unit
- In fact, any of the following prices result in an equilibrium
  - Base-load hours: price between 6.5 $/MWh and 25 $/MWh
  - Medium-load hours: price between 25 $/MWh and 80 $ MWh
  - Peak hours: price at or above 80 $/MWh

Average Hourly Profit

Consider the following competitive equilibrium price:

- Base load hours: 6.5 $/MWh
- Medium load hours: 25 $/MWh
- Peak load hours: 80 $/MWh

Average hourly profits

- Nuclear: $0.6849 \cdot 18.5 + 0.1712 \cdot 73.5 = 25.3$ $/MWh
  - Profit when nuclear is marginal: 0 $/MWh
  - Profit when coal is marginal (68.49% of the year): 18.5 $/MWh
  - Profit when gas is marginal (17.12% of the year): 73.5 $/MWh
- Coal: $0.1712 \cdot 55 = 9.4$ $/MWh
- Gas: 0 $/MWh

Missing Money

Technology	Hourly profit ($/MWh)	Inv cost ($/MWh)
Coal	9.4	16
Gas	0	5
Nuclear	25.3	32

Missing money problem: Least-cost configuration of capacity cannot survive if prices are set to marginal cost of the marginal unit (e.g. typical 1000 MW nuclear plant would be losing 6750 $ per hour...)

Results are not coincidental (observe that peak technology never earns profit if price equals marginal cost of marginal unit)

Short-Run Versus Long-Run Equilibrium

Apparent contradiction: definition of competitive equilibrium results in a situation where no technology can survive in the market!

To resolve the apparent contradiction, it is necessary to distinguish:

- **short-run equilibrium**: prices equalizing supply and demand, *given* choice of capacity
- **long-run equilibrium**: prices equalizing supply and demand, assuming capacity has yet to be decided

Reflections

Philosopher's corner:

- What is the formal definition of a competitive equilibrium?
- How do we model a competitive equilibrium?

Outline

1. Screening Curves
2. Short-Run Versus Long-Run Equilibrium
3. Missing Money

Price Caps

Market power: withholding production in order to *profitably* increase market prices above competitive levels

Impossible to distinguish rise of prices as a result of (i) strategic behavior, or (ii) true scarcity in generating capacity

Price caps imposed by regulators to limit offer price of generators (what is a plausible price cap in this example?)

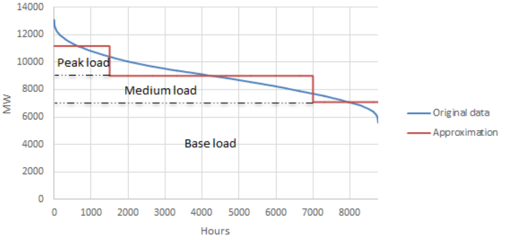
Capping at the Marginal Cost of the Peaker

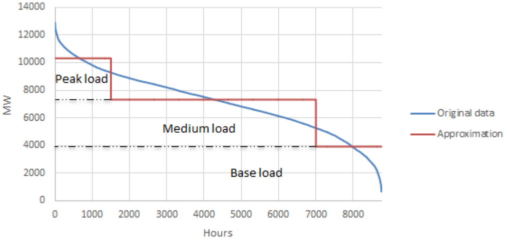
Consider the following (flawed rationale): let us cap prices at 80 $/MWh, because we know that in the optimal mix the most 'expensive' generator is gas, and gas 'costs' should never exceed 80 $/MWh

Fatal market design move: gas generators would never be built, but *should* be part of the optimal long-run fuel mix

Increasing Wind Penetration

Which load duration curve corresponds to 10x wind power?





Effects of Wind Power

- Load duration curve is less flat
- Hours when net load is near-zero
- Required amount of peaking gas units increases

But if the 80 $/MWh price cap is preserved, gas units (which are needed more with more wind power) will not be built!

Solving the Missing Money Problem

Why is there missing money? Price cap is keeping prices too low

- In theory, removing the cap will enable generators to recover their investment costs *exactly* under the optimal mix
- In practice, regulators intervene $\Rightarrow$ missing money problem

Demand Response

Missing money problem does not go away when cost of demand response (load reduction) is factored in

- Fully satisfying demand can be suboptimal
- Cost of load interruption can be included in the screening curves
- There will be hours when demand response sets prices $\Rightarrow$ huge (10-100x ‘normal’) price spikes
- If price cap is less than consumer valuation, the resulting investment may deviate from long-run optimum

Screening Curve with Demand Response