Electricity Markets: Summer Semester 2016, Lecture 11

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Managing Interlocational Risk

Intertemporal versus interlocational risk

In Lecture 9 we exampled intertemporal risk, i.e. risks associated with market prices that change over time.

In this section we example interlocational risk, i.e. risks associated with market prices that differ between different nodes or regions.

Different market prices arise in different places if there is congestion in the network, so this topic is intimately tied to the study of congestion and investment in new capacity.

Network security affects the feasibility of contracts; bilateral contracts can protect against nodal prices.

Example of a contract between two regions

Suppose some electricity supplier "Borduria Power" in Borduria enters into a Contract for Difference (i.e. a Swap) with some consumer "Syldavia Steel" in Syldavia to provide 400 MW of power at \$30/MWh. If the market price is below this level, Syldavia Steel must pay Borduria Power the difference; if the market price is above this level, Borduria Power must pay Syldavia the difference.

If there is no congestion between Borduria and Syldavia, the price is equal in both regions, say at \$24/MWh.

The Contract for Difference (CfD) is settled as follows:

1. Borduria Power sells 400 MWh into the market at \$24/MWh, receiving \$9600.
2. Syldavia Steel buys 400 MWh at \$24/MWh, paying \$9600.
3. Syldavia Steel pays 400 MWh $\times$ \$$(30 - 24)$/MWh = \$2400 to Borduria Power to settle the difference.

CfD with congestion

Now suppose the transfer capacity between Borduria and Syldavia is limited to 400 MW and becomes congested. The price in Syldavia rises to \$33 and the price in Borduria sinks to \$23. As a result:

1. Borduria Power sells 400 MWh into the market at \$23/MWh, receiving \$9200.
2. Syldavia Steel buys 400 MWh at \$33/MWh, paying \$13200.
3. Borduria Power expects 400 MWh $\times$ \$$(30-23)$/MWh $=$ \$2800 from the CfD.
4. Syldavia expects 400 MWh $\times$ \$$(33-30)$/MWh $=$ \$1200 from the CfD.

These expectations are clearly incompatible: the CfD has failed with congestion.

The parties need to find a third party with whom to make a contract that pays out in the event of congestion.

CfD with congestion

Notice that the total value of the missing money is

$400 \text{ MWh} \times \$(33-30)/\text{MWh} + 400 \text{ MWh} \times \$(30-23)/\text{MWh}$

$= 400 \text{ MWh} \times \$(33-23)/\text{MWh} = \$4000$

This is none other than the congestion revenue/surplus that the network operator receives.

Therefore the network operator could sell its right to the congestion revenue to offset this risk for the network users.

This is a called a Financial Transmission Right (FTR).

Financial Transmission Rights (FTRs)

A Financial Transmission Right (FTR) is defined between any two nodes in the network and entitles their holders to a revenue equal to the product of the amount of transmission rights bought and the price differential between the two nodes. Formally, the holder of FTRs for F MWh between locations B and S is entitled to the following amount taken from the congestion surplus:

$$R_{FTR} = F(\pi_S - \pi_B)$$

The price of the FTR can be set by an auction by the network operator for the amount of power that can be transmitted over the interconnection.

Bidders base their bids on their expection of the price difference.

Transmission rights treat capacity as property, which right owners can rent or use.

Flow-Gate Rights (FGRs)

Another contractual tool used to manage interlocational risk is the Flow-Gate Right (FGR).

FGRs operate like FTRs except that the value of these rights is not tied to the difference in nodal prices, but to the value of the Lagrange multiplier or shadow cost associated with the maximum capacity of the flowgate.

When a flowgate is not operating at its maximum capacity, the corresponding inequality constraint is not binding, and the corresponding Lagrange multiplier μ has a value of zero. The only FGRs that produce revenues are thus those that are associated with congested branches.

FTRs versus FGRs

There is some debate about which tool is better.

In a perfect market, both produce the same results.

FGRs require detailed knowledge of the grid and its congestion status; only a small number of branches may be congested and it may be difficult to predict which become congested.

FTRs allow you to forget about the branches and focus on the nodal prices.

Transmission Investment

Context

So far we have discussed:

1. Efficient operation of the market in the short-run
2. Efficient operation of the market in the short-run with transmission constraints
3. Efficient investment in generation assets in the long-run

Now we will consider the final piece: efficient investment in the network in the long-run, and how that interacts with efficient investment in generation.

Features of Transmission Investment 1/2

1. Rationale for transmission: Load and generation do not coincide in location at all times, so electricity must be transported for some of the time.

2. Transmission is a natural monopoly: Like railways or water provision, it is unlikely that a parallel electricity network would be built, given cost and limits on installing infrastructure due to space and public acceptance. Natural monopolies require regulation.

3. Transmission is a capital-intensive business: Transmitting electric power securely and efficiently over long distances requires large amounts of equipment (lines, transformers, etc.) which dominate costs compared to the operating costs of the grid. Making good investment decisions is thus the most important aspect of running a transmission company.

Features of Transmission Investment 2/2

1. Transmission assets have a long life: Most transmission equipment is designed for an expected life ranging from 20 to 40 years or even longer (up to 60-80 years). A lot can change over this time, such as load behaviour and generation costs and composition.
2. Transmission investments are irreversible: Once a transmission line has been built, it cannot be redeployed in another location where it could be used more profitably.
3. Transmission investments are lumpy: Manufacturers sell transmission equipment in only a small number of standardized voltage and MVA ratings. It is therefore often not possible to build a transmission facility whose rating exactly matches the need.
4. Economies of scale: Transmission investment more proportional to length (costs of rights of way, terrain, towers, which dominate costs) than to power rating (which depends only on conductoring, which is cheap).

The value of transmission

As before, our approach to the question of "What is the optimal amount of transmission" is determined by the most efficient long-term solution, i.e. the infrastructure investement that maximising social welfare over the long-run.

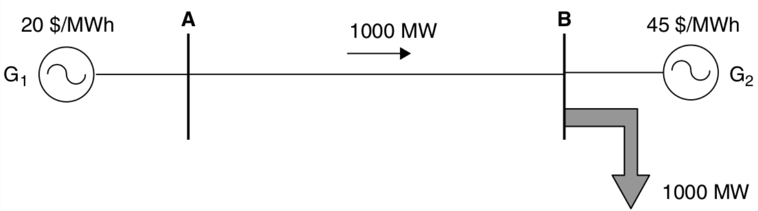
In brief:

Exactly as with generation dispatch and investment, we continue to invest in transmission until the marginal benefit of extra transmission is equal to the marginal cost of extra transmission. This determines the optimal investment level.

As before, it can be written in terms of a social welfare maximisation problem if we include the costs of transmission investment.

Two-node example

Consider this example of a two-node system:



If the generators are unconstrained, then for this given hour, it will be cheaper for node B to import all its power from node A.

The incremental value of the transmission is \$25/MW/h up until a capacity of 1000 MW.

This transmission line should be built only if its amortized cost amounts to less than \$25/MW/h.

Two-node example

If the maximum output of the local generators at B is less than 1000 MW, the transmission line must be used to supply the load. The value of transmission is then no longer determined by the price of local generation but by the consumers' willingness to pay for electrical energy, which could be very high. This puts it in a monopoly position, where it can abuse its market power.

Social-welfare maximising outcome: objective

As before with the efficient operation of the market with transmission constraints, construct a benefit function for each node, with the consumer utility minus the generator costs as a function of the nodal power imbalance Z_{is} at time s. Only this time include the generator fixed costs K_{it} for node i and technology type t, i.e. $C_{its}(Q^S_{its}, K_{it})$, to make the benefit function $B_{is}(Z_{is}, K_{it})$.

Now consider network configurations labelled by θ for links L^θ and PTDFs H^θ; the cost of link $\ell \in L^\theta$ is then $C(\theta, K^\theta_\ell)$.

The overall problem of finding the optimal dispatch and the optimal mix and level of investment in both generation and network capacity is as follows:

$$\max_{Z_{is}, K_{it}, \theta, K_\ell} \left[p_s B_{is}(Z_{is}, K_{it}) - C(\theta, K^\theta_\ell) \right]$$

Social-welfare maximising outcome: constraints

Subject to:

$$\sum_i Z_{is} = 0 \leftrightarrow p_s \lambda_s \qquad \forall s$$

$$\sum_i H^\theta_{\ell i} Z_{is} \leq K^\theta_\ell \leftrightarrow p_s \bar{\mu}_s \qquad \forall s, \ell$$

$$\sum_i -H^\theta_{\ell i} Z_{is} \leq K^\theta_\ell \leftrightarrow p_s \underline{\mu}_s \qquad \forall s, \ell$$

KKT on the line capacity K^θ_ℓ gives

$$\sum_s p_s(\bar{\mu}_s + \underline{\mu}_s) = \frac{\partial C}{\partial K^\theta_\ell}$$

Social-welfare maximising outcome: interpretation

How can we interpret $\sum_s p_s(\bar{\mu}_s + \underline{\mu}_s) = \frac{\partial C}{\partial K_\ell^\theta}$?

For any given network configuration the optimal level of network capacity is where the expected value of the constraint-marginal-value on the network flow limit constraint is equal to the marginal cost of adding capacity (taking into account the optimal mix of generation at each location).

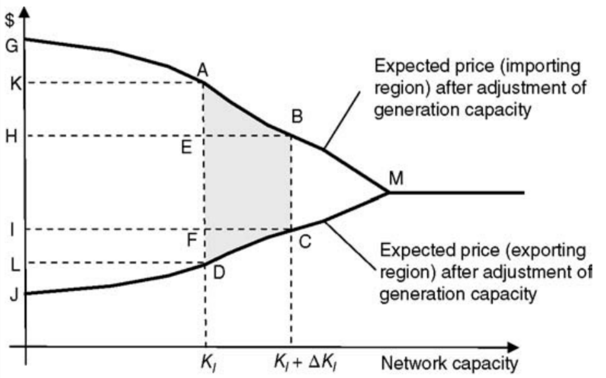
Note that since $\frac{\partial C}{\partial K_\ell^\theta} > 0$ at least some of the $\bar{\mu}_s, \underline{\mu}_s$ must be positive. As long as network capacity can be added in arbitrarily small increments, in the optimally configured network there is always some positive probability that any given network link will be congested. It is not optimal to build the network to the point where any given network link is never congested.

[This is just like with generation investment: there should always be some unmet load in the optimal generation configuration, so that the generator with highest marginal cost can make back its capital cost.]

Two Node Example

For two nodes, remember that the line shadow price was equal to the price difference.

We can visualise the welfare increase as a line capacity is increased from K_ℓ to $K_\ell + \Delta K_\ell$ as the area ABCD:



The ideal capacity is when $\mathbb{E}[\lambda_2 - \lambda_1] = \mathbb{E}[\bar{\mu} + \underline{\mu}] = \frac{\partial C}{\partial K}$.

Incentivising and Regulating Transmission Investment

Two models

There are two main models for investment in transmission:

1. A regulated cost-based transmission expansion: The regulator organizes incentives that encourage an efficient transmission expansion. These incentives should financially reward decisions that increase economic efficiency. They should also penalize inefficient expenditures. Setting the targets that measure efficient operation is particularly difficult with this approach. Allocating the costs and benefits of transmission expansion to all the network users is another major challenge.
2. A merchant transmission scheme: Independent grid operators build grids where they can make a profit from congestion and earn their money this way.

Merchant Transmission

While the overwhelming majority of transmission investments are still remunerated on a regulated basis, over the last several years a few transmission links have been built on a merchant basis. The regional regulated transmission company did not build these links. Instead, an unregulated company provided the capital needed for their construction. Rather than getting a modest but safe rate of return, these unregulated companies hope to obtain much larger revenues through the operation of these links. On the other hand, they carry the risk that these revenues may be insufficient to recover the cost of their investment.

Situation in Germany

The Network Regulator (Bundesnetzagentur (BNetzA)) allows the network operators to cover their costs plus a guaranteed rate of return on its investments. The network operators obtain this revenue via network charges (Netzentgelte).

Network operators (both TSOs and DSOs) received in 2015 a guaranteed rate of return of 9.05% for new infrastructure and 7.41% for investment in old infrastructure.

At TSO level, the TSOs submit a "Network Development Plan" to the BNetzA which then checks whether the projects are necessary and cost-effective.

The costs are distributed geographically for each TSO and DSO according to a combination of energy usage and peak power consumption, depending on the voltage level.

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