Financial Transmission Rights Markets: An Overview

Golbon Zakeri

A. Downward
Department of Engineering Science, University of Auckland

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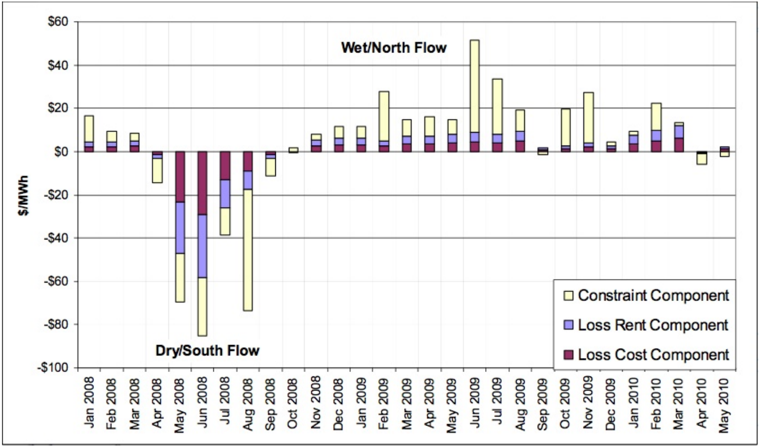
Outline

- Introduce financial transmission rights (FTRs).
- FTRs and exercise of market power in energy markets.
- FTR simultaneous feasibility auction formulations and implications.
- A word on the efficiency of FTR auctions.

LMP $\implies$ nodal price differences

- In every wholesale electricity pool market, generators offer supply functions that indicate the cost (to the system) of production of electricity. Generators provide power at grid injection points (GIPs) and electricity is drawn from grid exit points (GXPs).
- In wholesale electricity pool markets around the world, periodically a market clearing problem is solved to determine the dispatch quantities and clearing prices of electricity.
- In NZ in particular the Scheduling Pricing and Dispatch optimization problem is solved every 30 mins and determines the level of production for each generator as well as electricity prices at various GIP and GXPs. This is termed locational marginal pricing (LMP).
- LMP can cause prices to be different at different nodes of the network.

Nodal price differences are volatile



Why the volatility in nodal price differences matters

- Generator profits including a standard contract for difference (CFD) at a single node:

$$qP(q) - C(q) - \overline{Q}(P(q) - \overline{P}) = (q - \overline{Q})P(q) + \overline{QP} - C(q).$$

- If on the other hand, the generator had a CFD at a node different from their GIP their profits are:

$$qP_N(q) - C(q) - \overline{Q}(P_S(q) - \overline{P})$$

  This expression is equivalent to

$$(q - \overline{Q})P_N(q) + \overline{Q}(P_N(q) - P_S(q)) + \overline{QP} - C(q).$$

- Observe now that $\overline{Q}(P_N(q) - P_S(q))$ forms a part of the generator revenue so the generator would be sensitive to the nodal price difference.
- This is one reason that is stated for the lack of competition in retail markets in NZ and asset swaps were suggested as one possible remedy.

What is an FTR?

- A financial transmission right (FTR), otherwise known as a transmission congestion contract (TCC), is a financial instrument designed to manage risk associated with locational marginal price volatility.
- FTRs were first introduced by Hogan and are used in several jurisdictions in the US including the Pennsylvania-New Jersey-Maryland (PJM) and New York markets.
- Suppose that for a given period that the price at Otahuhu is \$40.00 more than that at Benmore. Then a firm equipped with an FTR of 100 MW from Benmore to Otahuhu, for that period, would be paid a coupon payment of $100 \times \$40.00 = \$4000.00$.
- There are various forms of FTRs, but in this talk we will only concentrate on balanced, point to point obligation FTRs. The essence of this talk is valid if we generalize to other forms of FTRs.

Entry in FTR auctions

- Who will enter an FTR auction and what is the value of an FTR to different participants?
- FTRs are worth more to those who can influence nodal prices of electricity for the nodes involved in the FTR in question.
- Joskow and Tirole, Philpott and Pritchard and Zakeri and Downward have all observed that *if the value of an FTR is more to a generator at the downstream node of the FTR who can drive the nodal price up by withholding*.
- Another possibility is that a generator equipped with and FTR will reduce prices, perhaps even below their cost of generation, at the upstream node. This again has the effect of causing a large difference in the nodal prices and would result in a large coupon payment for the FTR.

Mechanics of the FTR auction: revenue adequacy

- Once an auction is settled and FTRs are allocated, the system operator is bound by an agreement to pay the FTR holder the corresponding coupon payment on the FTR for every period for which the FTR is valid.
- In each period, the ISO collects any congestion rent and redistributes these rents through FTRs.
- Therefore to maintain its credit standing, the ISO must ensure that the revenue collected with locational prices in the dispatch should at least be equal to the payments to the holders of FTRs in the same period.
- This property is referred to by the term *revenue adequacy*.

Simultaneous feasibility (SF)

- A set of conditions imposed on the issued FTRs, termed *simultaneous feasibility* have been proved to guarantee revenue adequacy (under reasonably mild assumptions).
- Simultaneous feasibility states that treated as injections and withdrawals, the set of all FTRs that are extant for a single period, must comply with the transmission network constraints simultaneously. (2 node network example)

Mathematical formulation for SF

Let the vector $h(\alpha)$ denote an extant obligation FTR contract for $\alpha = 1, 2, \cdots, A$ (this set is the index set for the FTRs, each or a number of which may belong to a player in the FTR market). For example a balanced point-to-point FTR of magnitude τ with upstream node i and downstream node j will be represented by the vector h where

$$h_k = \begin{cases} \tau & \text{if } k = j \\ -\tau & \text{if } k = i \\ 0, & \text{otherwise.} \end{cases}$$

The set of FTRs $h(\alpha)$ for $\alpha = 1, 2, \cdots, A$ are simultaneously feasible if and only if there exists a vector y where

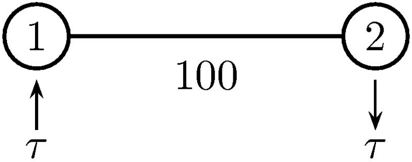
$$\begin{array}{ll} SFT & g_i(y) = \sum_\alpha h_i(\alpha), \quad i = 1, 2, \cdots, n \\ & y \in U. \end{array}$$

The mathematical definition of the FTR auction problem

$$
\begin{array}{lll}
\text{TRA-ND: maximize} & \sum_l \sum_{i,j} \beta_{ij}^l \tau_{ij}^l & \\
\text{subject to} & g_i(f_c) = \sum_l (\sum_{j \neq i} \tau_{ij}^l - \sum_{k \neq i} \tau_{ki}^l) & \forall c \in C \quad \forall i \\
 & f_c \in U_c & \forall c \in C \\
 & 0 \leq \tau_{ij}^l \leq T_{ij}^l. &
\end{array}
$$

A simple example

Example, two nodes. We start with a simple two node example. Consider a network consisting of two nodes (nodes 1 and 2 as depicted in the figure below and a 100MW line that links these nodes. Suppose that there is a bid for 99MW of FTR from node 1 to node 2, at price $10.00. The FTR simultaneous feasibility auction will solve the optimization problem Ex-2-node.



The auction's formulation for the example

$$
\begin{array}{lll}
\text{Ex-2-node:} & \text{maximize} & 10\tau \\
& \text{subject to} & \tau - f_{12} = 0 \quad [\pi_1] \\
& & f_{12} - \tau = 0 \quad [\pi_2] \\
& & f_{12} \leq 100 \quad [\eta^+] \\
& & -f_{12} \leq 100 \quad [\eta^-] \\
& & \tau \leq 99 \quad [\lambda] \\
& & \tau \geq 0.
\end{array}
$$

- The optimal solution to this problem is given by $\tau = f_{12} = 99, \lambda = 10, \eta = 0$, and $\pi_1 = \pi_2$. This means that the clearing price of the FTR from node 1 to node 2 is zero (which is also the clearing price of the counterflow FTR going from node 2 to node 1).
- On the other hand if the there was a bid for 101MW of FTR from node 1 to node 2, at the same price of $10.00, problem Ex-2-node would change slightly and the fourth constraint would be replaced by $\tau \leq 101$. This change would in turn change the solution to $\tau = f_{12} = 100, \lambda = 0, \eta = 10$, and $\pi_1 - \pi_2 = 10$. This would of course mean that the clearing price of the FTRs from node 1 to node 2 is now $10.00.

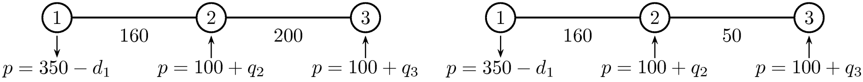
Notion of efficiency: quiz for the audience!

- Are simultaneously feasible FTR auctions efficient?
- What this means is that if all participants know what the expected price difference between 2 nodes is and they bid in for FTRs at that price, would the clearing price of the FTR auction be this expected difference?

Answers

- Clearly the answer is no as evident from the simple example. The clearing price is a function of the bid in volume.
- Deng et. al. argue that "expected flows" are "reasonable" FTR bid volumes and demonstrate that when these expected flow volumes are bid in at expected prices, the FTRs can interact so that the clearing price would differ from the expected price differences.

Simple 3 node example



(a) (b)

Here we have laid out 2 contingencies, one in which line 23 has a capacity of 200MW and the other where 23 has a capacity of 50 MW. We assume equal probabilities here.

Simple 3 node example II

The 2 tables below provide the cleared prices and the quantities, in the economics dispatch problem, under each contingency.

	(a)	(b)	$E[\pi]$
π_1	190.0	200.0	195.0
π_2	180.0	200.0	190.0
π_3	180.0	150.0	165.0

Table: Prices

	(a)	(b)	Ave
d_1	160.0	150.0	155.0
q_2	80.0	100.0	90.0
q_3	80.0	50.0	65.0

Table: Injections / Offtakes

Note that $E(\pi_1 - \pi_2) = \$5.00$ and $E(\pi_2 - \pi_3) = \$25.00$ from the previous slide. The flows in the different contingencies are provided below.

	(a)	(b)	Ave
f_{21}	160.0	150.0	155.0
f_{32}	80.0	50.0	65.0

Table: Flows

Bidding of the average quantities above at the expected prices will result in the clearing prices of \$25.00 for the FTRs from node 3 to node 2 and \$0.00 for FTRs from node 2 to node 1.

Chewing the fat

Any comments or questions?

Generator's revenue optimization problem

- There are 2 different types of generators, those whose actions impact the price of electricity and those whose actions don't impact the price.

$$
\begin{aligned}
\max_{\{p_g, q_g\}} \quad & R(\pi_g, x_g) \\
\text{s/t} \quad & Mx + Af + Bf^2 = d \\
& Lf = 0 \\
& p^T + \pi^T M = 0 \\
& \pi^T A + 2\pi^T BD_f + \lambda^T L = 0 \\
& 0 \leq x \leq q \\
& \text{conditions on the stack, e.g. 5 tranches, etc}
\end{aligned}
$$

Modelling of the revenue optimization problem

- The problem in the previous slide is the very first cut in generator revenue optimization.
- Thermal generators need to consider load obligations, the cost of their fuel, any fuel contract mechanisms and unit commitment.
- They also need to consider environmental constraints.

Modelling of the revenue optimization problem

- A hydro generator may need to run a river chain to keep the river balanced and keep within allowed minimum flow requirements. Reservoir levels also have minimum and maximum allowed levels.
- The unit commitment and running the river constraints make the optimization problems in different periods tied and this adds a whole new dimension of complexity.

Uncertainty

- So far we have assumed that each generator knows the demand and the actions of other generators. However this is definitely not true! So a better approximation is to cater for uncertainty.
- The concept of a residual demand curve and why we have offer stacks in the market.
- MLE estimation of the market distribution function. BOOMER software.

Demand side optimization

- Major users of electricity see the spot price and can respond to it by reducing demand.
- These market participants not only have to pay the spot price of electricity but they also have to pay for line charges.
- Line charges are incurred through periods of peak usage.

$$
\begin{array}{llll}
\min & PM & + \sum_{t \in T} (c_t - p_t) s_t & \\
\text{s.t.} & \sum_{t \in T} s_t & \leq S & \\
 & s_t & \leq a_t & \\
 & \sum_{t \in \tau} (d_t - s_t) & \leq M & \text{for all } |\tau| \leq k
\end{array}
$$

Distribution company's optimization problem

- Related to the consumer's problem is the revenue optimization for the distribution company.
- Here the distribution company will want to decide on optimal tariffs taking into account the response that the consumer will make to those tariffs.
- The optimal tariffs will maximize profits that come from earned revenue minus the cost of network expansion.
- Network expansion is determined from the peak usage of consumers.

Steady state behaviuor of the market

- The Wolak report commissioned by the NZCC.
- What Wolak concluded and some debate.
- This is allocative efficiency.
- How does one measure (approximately) productive efficiency.

Stochastic program to cater for optimal central planning

Some of what remains to be done

- Full blown market participant optimization problems.
- Models that capture the stochastic process of electricity prices.
- Consumer participation: smart meters, designing a system on how to pass the prices down.
- Tools that assess the impact os regulatory change on the market.
- Models that explore the optimal investment for electricity infrastructure including the transmission grid and generation assets.