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Transmission Investment Incentives

Economic Analysis by Example

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PRODUCT DESCRIPTION

This report documents the use of agent-based simulation as a tool for studying incentives for transmission investment. It is meant to illuminate the sources of difficulties in aligning the incentives for enhancing electrical transmission systems. The report suggests that a new method of calculation for bid optimization be applied to the economic analysis of long-term incentives for transmission investment. This technology can be broadly applied to help negotiators in transmission planning quantify benefits and costs both for their counterparties and themselves. By investigating different schemes for transmission ownership, planners can better optimize outcomes.

This capability is important because U.S. regulators recognized in their Transmission Investment Ruling from July 2006 that transmission investment is a critical issue. New transmission investments are needed in order for efficient electricity transactions and non-discriminatory access to transmission, as well as system reliability, to be sustainable. Electric companies in the United States are also expected to enhance transmission investments because of sections of the Energy Policy Act of 2005 that grant penalty powers to the regulator to ensure system reliability standards are set and met. This Act grants authority to the regulator to use National Transmission Corridors for siting new projects that will reduce congested portions of the national transmission network.

Results & Findings

The results of the eighteen experiments clearly exhibit the incentives for transmission investments from eighteen different perspectives, based on the portfolio of generation, transmission, and load obligations of the stakeholder.

Challenges & Objectives

The technology, concepts, and results of this report should interest transmission system executives, strategists, planners, and analysts. The technology for maximizing the value of transmission to various stakeholders is new and can be utilized by analysts familiar with traditional transmission planning exercises. Planners and strategists will appreciate the enumeration of cases and the explanations of the dominant strategies of the different stakeholders. Executives will benefit from having the capability to demonstrate and better understand the decentralized nature of transmission investment decision making.

Optimizing transmission portfolios in the context of other holdings is computationally complex, but the examples presented in this report make it simple to understand. However, to put this technology into practice, the modeling would have to represent the actual power system more realistically and the analytical process would have to be enhanced so that it could be incorporated into a negotiation process. The most practical next step would be a demonstration modeling of a relatively simple, but real-life example.

Applications, Values & Use

The technology demonstrated in this report can be applied directly to two analyses related to the Transmission Investment Ruling (TIR) and the new regulatory power granted under the Energy Policy Act. The first is an analysis of the value of the independence of transmission as promoted by TIR. The second is an analysis of the costs and benefits of the new transmission projects under collaborative planning processes.

Each experiment in this report takes a single perspective, which is the prerequisite for later using this capability for investigating integrated perspectives that take into account how counterparties may change their decision modes when determining one's own key decision factors. This form of integrated decision-making is an integral part of markets and decentralized decision-making, where individuals interact under their own independent incentives. Accordingly, EPRI's market simulator will be used as a vehicle to commercialize this capability.

EPRI Perspective

EPRI is pioneering the development and application of agent-based simulation for the study of decision-making associated with electricity markets. While the use of computers for these simulations is relatively new, others have used people in related experiments for some time. In fact, the 2002 Nobel Prize in Economics was awarded to pioneers in this approach, which is called Experimental Economics. EPRI's agent-based efforts build on this experience directly, replacing people as participants with computer programs that make the same decisions. The aim is to continue to follow developments in Experimental Economics and to create agents that can mimic human decision-making processes, with the eventual goal of predicting actual market behavior.

Approach

The goal of this report was to document the use of agent-based simulation as a tool for studying transmission investment incentives. The project team devised a simple two-node network example and procedures to form optimal bids in a long-term planning environment. They ran the simulations over eighteen scenarios of transmission ownership for a simple power system. The scenarios were designed to elicit unique and interesting stakeholder perspectives to better understand what makes it difficult to align investments for enhancing the transmission system.

Keywords

Transmission investment
Transmission planning
Market simulation
Bid optimization
National transmission corridor

ABSTRACT

This report documents the use of agent-based simulation as a tool for studying transmission investment incentives, and it is meant to illuminate what accounts for the difficulties in aligning incentives for enhancing the transmission system. The report suggests that a new method of calculation for bid optimization be applied to the economic analysis of long-term incentives for transmission investment. This technology can be broadly applied to help negotiators in transmission planning quantify their counterparties' benefits and costs, as well as their own. By investigating different schemes for transmission ownership, planners can better optimize outcomes.

This capability is important because there is a renewed recognition by U.S. regulators, as stated in their Transmission Investment Ruling from July 2006, that transmission investment is a critical issue, not only in order to support system reliability but to sustain efficient electricity transactions and non-discriminatory access to transmission.

The goal of the report was to document the use of agent-based simulation as a tool for studying transmission investment incentives. A simple two-node network example was devised along with procedures to form optimal bids in this long-term planning environment. Simulations based on this example were run over eighteen scenarios of transmission ownership for a simple power system. The scenarios were designed to elicit unique and interesting stakeholder perspectives to better understand the difficulties in aligning incentives for enhancing the transmission system.

EXECUTIVE SUMMARY

This report documents the use of agent-based simulation as a tool for studying transmission investment incentives, and it is meant to illuminate the source and reasoning for the difficulties in aligning incentives for enhancing the transmission system. We devised a simple two-node network example and procedures to form optimal bids in this long-term planning environment. The simulations were run over eighteen scenarios of transmission ownership for a simple power system. The scenarios were designed to elicit unique and interesting stakeholder perspectives to better understand the source and reasoning for the difficulties in aligning investments for enhancing the transmission system.

This paper is third in a series on Transmission Investment. The first [1] contains case studies of the regimes for economic transmission investment in the England and Wales market, the PJM Interconnection, and the California ISO. The second [2] investigates the impact of the revision of Open Access Transmission regulation on investment and technology research and development. This paper focuses on the economic analysis of long-term incentives for transmission investment.

In a decentralized decision-making context, we consider the perspectives of different combinations of electricity sectors (generation, transmission, and demand) that could benefit (or not) from transmission expansion. The value of cataloging these simple examples is to identify both the differences and the common ground for organizing and developing large transmission systems.

This is important in because recent industry restructuring has focused on the creation of sustainable and competitive markets for generation, while leaving transmission issues behind as something that can be settled later. Now, there is a renewed recognition by United States regulators [3] in the Transmission Investment Ruling (TIR) that transmission investment is a critical issue that requires enhancements to the traditional rationale (supporting system reliability) in order for efficient electricity transactions and non-discriminatory access to transmission to be sustainable.

United States electric companies are also expected to enhanced transmission investments because of sections of the Energy Policy Act of 2005 (EPAct) [4] that grant penalty powers to the regulator to ensure system reliability standards are set and met and that grants authority to the regulator to utilize National Transmission Corridors [4, 5] for citing new projects that will reduce congested portions of the national transmission network.

The contribution this paper makes, relative to the established practice and the literature, is that it shows the beginning of taxonomy of positions and strategies for transmission investment. As will be seen, many researchers have studied the subject examining its pitfalls and suggesting new options for proceeding under collaborative decision models. By reviewing and understanding the content of this report one begins to get an idea variety of viewpoints and, hopefully, how they can be accommodated simultaneously in the future.

Application

The technology demonstrated in this report can be directly applied to the two analyses raised by the TIR and the new regulatory power granted under EPAct. The first is the analysis of the value of the independence of transmission as promoted by TIR. The second is the analysis of the costs and benefits of the new transmission projects under collaborative planning processes.

The theme of this report is the process of negotiating the investment and development of new transmission projects. This report chronicles the fundamentals of determining one's own position, and that of the potential partners in a project. By utilizing economic calculations and considering potential counterparty perspectives in addition to one's own perspective it is more likely that modeling and analysis, based on sound financial principles, take a prominent role in the negotiations among stakeholders for enhanced transmission systems.

Summary

The two-node network in the experiments is not meant to be representative of any specific situation. It is meant to demonstrate the use of market simulation technology as a tool for analyzing positions of various stakeholders who may be participating in a negotiation for transmission enhancements. The cases in the experiments, while extensive, are not exhaustive, because the characteristics of the simple network are static (aside from the ownership pattern) and additional situations will likely arise as the collection of stakeholders become more intricate. Ultimately, 18 different simulations were run, with most yielding unique results and strategies.

Seven of the experiments result in a Competitive Equilibrium, because the value to be derived of the transmission capacity congestion rents is non-existent or because the participant is unable to exploit the resource from its particular position. Ownership of transmission rights opposite to the direction of the prevailing flow is the typical example of vacuous value.

Another class of cases involves net suppliers utilizing their pivotal status to raise prices. There where two ways for the supplier to incorporate the transmission capacity into its strategy. When the inexpensive supplier controlled import capacity, it chose to have no transmission so as to dominate the local market. When the expensive supplier controlled import capacity, it chose to allow some transfer, but extracted all possible rents from the alternate supplier at the opposite end of the link. In other cases, the supplier controlled capacity opposite to the direction of flow and could not exploit it.

Finally, there are the cases when the net buyers can benefit from transmission. In every case, the benefit will be limited, because the more that transmission is utilized the more of an effect it has on market prices that tends to diminish its value. The lesson in these cases is that these types of stakeholders prefer to have a congested network. That is, they prefer to limit transfers to within the most beneficial range. A similar phenomenon is seen in other markets, for instance, when a large player affects prices with its own trades and must execute them in a disciplined fashion.

To put this technology into practice, one would need to enhance the power system model to have a more realistic representation of the actual power system and enhance the analytical process so that it can be incorporated into a negotiation process. These types of extensions are now in progress.

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1
INTRODUCTION

This paper is third in a series on Transmission Investment. The first [1] contains case studies of the regimes for economic transmission investment in the England and Wales market, the PJM Interconnection, and the California ISO. The second [2] investigates the impact of the revision of Open Access Transmission regulation on investment and technology research and development. This paper focuses on the economic analysis of long-term incentives for transmission investment.

In a decentralized decision-making context, we consider the perspectives of different combinations of electricity sectors (generation, transmission, and demand) that could benefit (or not) from transmission expansion. The value of cataloging these simple examples is to identify both the differences and the common ground for organizing and developing large transmission systems.

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The contribution this paper makes, relative to the established practice and the literature, is that it shows the beginning of a taxonomy of positions and strategies for transmission investment. As will be seen, many researchers have studied the subject examining its pitfalls and suggesting new options for proceeding under collaborative decision models. By reviewing and understanding the content of this report one begins to get an idea variety of viewpoints and, hopefully, how they can be accommodated simultaneously in the future.

Application

The technology demonstrated in this report can be directly applied to the two analyses raised by the TIR and the new regulatory power granted under EPAct. The first is the analysis of the value of the independence of transmission as promoted by TIR. The second is the analysis of the costs and benefits of the new transmission projects under collaborative planning processes [6, 7, 8].

The theme of this report is the process of negotiating [9] the investment and development of new transmission projects. This report chronicles the fundamentals of determining one's own position, and that of the potential partners in a project. By utilizing economic calculations and considering potential counterparty perspectives in addition to one's own perspective it is more likely that modeling and analysis, based on sound financial principles, take a prominent role in the negotiations among stakeholders for enhanced transmission systems.

Centralized Transmission Investment

Joskow [10, 11] describes centralized transmission investment under different regulatory regimes. The long and short of this story is told in terms of two example regimes. The first regime is to Cost-of-Service, wherein the regulated entity has little to no incentive to reduce costs on its own. This is referred to in the economic literature as a *moral hazard*. The second regime involves a form of price control or price cap. While it overcomes the moral hazard by offering benefits to the transmission investor to lower costs (by keeping the savings), it has its own risk that the regulated price exceeds actual cost of service. This is referred to in the economic literature as an *adverse selection*. Between these two regimes lay more complex regimes for avoiding these problems, but they place extra burdens on regulators to monitor and to analyze the information necessary to implement them.

The results in this paper are not necessarily dependent on any one regulatory regime or on merchant investment projects. The different scenarios do, however, imply certain regulatory restrictions, because of our underlying assumption that the investor gains rights to the congestion rents on the line. Thus, a supplier invests to sell into a distant market, and a consumer invests to buy from a distant market.

Decentralized Transmission Investment

Part of the challenge of analyzing decentralized transmission investment incentives, as occurs within regions having markets and across regions of even regulated utilities, is that the role of transmission is to integrate the incentives of the many and diverse stakeholders associated with electric power systems. For instance, Latorre, et al. [12] surveys transmission planning models, along with the major modeling and solution techniques, and as mentioned in [Joskow Merchant] none of the 100 or so references deals with the interacting incentives of generation and transmission planning. Sauma, et al. [13] chooses the perspective of giving transmission investors the lead to decide first the transmission system configuration, while leaving generation and demand to respond. The conclusions from these works are that aligning incentives for transmission investment is difficult under most circumstances.

Joskow and Tirole [14] take on the subject of merchant transmission. Their conclusions are that a purely merchant transmission investment model will not stimulate efficient levels of investment. In simple situations, merchant transmission projects can be viable, but over- or under-investment can occur when the situation is more complex. Economies of scale in the size of a transmission line can cause under investment in transmission, distort the timing of investments, and preempt generation investment. The exercise of market power distorts price signal and misallocates investments. The availability of a new transmission line, relative to existing installations, can distort investment incentives. Finally, the differences in risk perceptions between the investors and an independent operator can upset efficient investment levels and use of the line.

Their analysis is related to the following experiments, because they utilize a simple network model to demonstrate their results, and they show the investment distortions caused by deviations from the least-cost or competitive model. The following experiments supplement their analysis, showing for situations beyond purely merchant transmission how to set up, compute, analyze, and understand the interactions surrounding specific projects.

Agent-Based Simulation

The examples of economic analysis that follow are expressed in terms of EPRI's market simulation software, STEMS [14, 15, 16]. The computational setting is one in which there is a centralized market clearing mechanism, surrounded by satellite bidding agents as in Figure 1-1. Agents submit bids into the market, which clears and returns schedules and prices. This form of simulation is different from traditional production simulation, because of its use of profit-maximizing agents. It is different from Monte Carlo simulation, because it does not use sampling and observations to collect statistics.

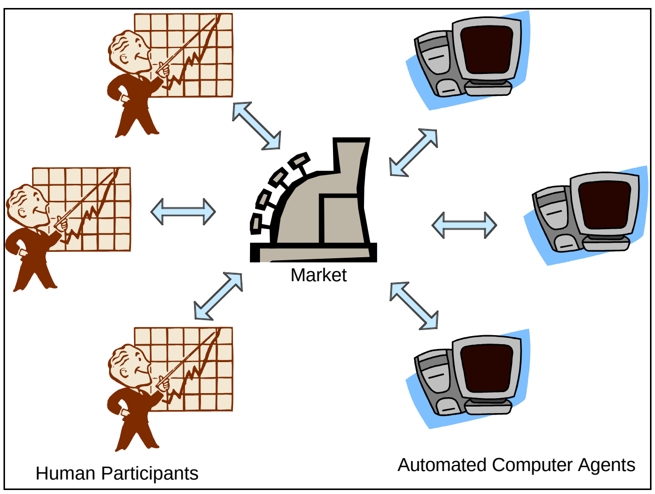

Figure 1-1
Agent-Based Simulation Structure

STEMS is an *agent-based simulation*, which is a new way of doing simulations. It is designed to have any collection of Human Participants and Automated Computer Agents bidding into the Market. Human Participants will typically attempt to maximize their profits. Automated Computer Agents can utilize a number of strategies to bid. Strategies range from competitive behavior to strategic bidding to optimal bidding.

It is a direct implementation of Experimental Economics and when used in automated mode, it is very closely related to computations of Economic Equilibria. Under some conditions it computes theoretic equilibria. As described shortly, the examples in this report are optimizations in the context of an economic equilibrium.

The latest techniques and strategies for bidding are incorporated into STEMS Automated Computer Agents. STEMS not only serves as a proving ground for the latest theoretical developments regarding market participation, but in Single-User mode individuals can quickly learn and test new strategies of their own. STEMS also incorporates realistic market rules, like Zonal or Locational Pricing, Automatic Price Mitigation, and Energy Options.

Report Contents

The report is organized in a progression of chapters that describe, through variations on a single example, the various perspectives on the introduction of transmission between two regions. Chapter 2, **Error! Reference source not found.**, introduces the types of bidding used by automated agents in the experiments, including the formulation and solution of the Optimal Bidding Problem. Chapter 3, Experimental Set-Up, contains the data inputs for the simulations. Roughly, the input is a description of a simple, two-node network with five energy capacity resources and demand for capacity at each node. The experimental scenarios involve different combinations of ownership of these resources. Chapter 4, Experimental Results, explains how the experiments are run and the strategies for profit maximization as seen from the various stakeholder perspectives.

2
BIDDING STRATEGIES

The following description of bidding strategies is generalized in terms of one or more traded *products*. Within EPRI's agent-based simulator [16, 17], STEMS, *products* represent elements of endowments that can be exchanged, consistently, among market participants. Products can be exchanged directly or indirectly, converted into other products. Indirect exchange is transparent to the participant.

STEMS utilizes a central market clearing mechanism in the form of a Linear Program [18] and a number of manual and/or automated bidding agents. The constraint relations of the market-clearing problem are expected to treat consistently any interrelations between products.

STEMS' convention is for market participants to begin a simulation with a product endowment (like energy capacity and transmission capacity), and a price-quantity pair ((p, q) pair characterizes each product element). Product elements have consistent measurement units in quantity, like megawatts (MW) for capacity, and price, like dollars per megawatt ($/MW). An endowment quantity represents the amount of a certain product with which the agent begins. The price in the endowment represents the marginal cost of the product. The participant can further divide product elements within the endowment during the bidding process and offered at different prices.

Without loss of generality, we will refer to product elements equally in both the sense of the original elements of endowment and the sense of potential sub-elements of the bidding.

STEMS bidding agents have available many different strategies for bidding. In the experiments for transmission investment incentives, only two strategies described in the next two sections are used: marginal cost bidding and optimal bidding.

Marginal Value or Marginal Cost Bidding

Marginal cost bidding is the simplest agent strategy. It consists of submitting a copy of the endowment as a bid. Recall that the endowment has resource quantities with marginal cost prices.

A marginal cost bidding strategy is typically used for participants (agents) who are not strategic. They can be referred to as price takers, as they will accept whatever market-clearing price (MCP) is determined, without trying to affect directly the result.

Optimal Bidding

To formulate an optimal bid [18] a STEMS agent utilizes the existing market clearing problem to form an Optimal Bidding Problem (OBP), which can be stated as, "Maximize the profits of the given agent, subject to the best estimate of the market response to its bid." The bid, as mentioned, is to choose a set of (p, q) pairs. Thus, these pairs are the decision variables of the problem. The best estimate of the market response is represented by the market equilibrium conditions, given the bids of the other market participants.

Formulation

Figure 2-1 depicts the Optimal Bidding Problem formulation as an arrangement of four boxes. The boxes represent two dimensions of an optimization model. The horizontal dimension represents decision variables, while the vertical dimension represents the objective function and constraints.

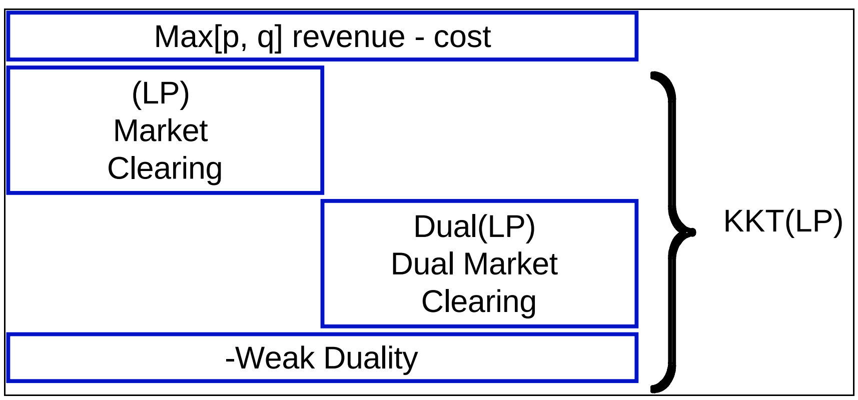

Figure 2-1
Optimal Bidding Problem Formulation Diagram

The objective function, to maximize profit, appears as the top box. The next box, middle left, represents the constraints of the market-clearing problem, which is a Linear Program (LP) [18]. The next box, middle right, represents the constraints of the dual of the market-clearing problem. Finally, the bottom box enforces equality between the objective functions of the market clearing problem and its dual. This for multiple reasons [19] this equality is actually represented as the first objective being less than or equal to the second. This is known in LP lore as the opposite of weak duality, which holds only at the market clearing problem solution (equilibrium). The collection of the constraints of the market clearing problem are the conditions for optimality of the market clearing problem, which are also known as the Karush-Kuhn-Tucker conditions (KKT(LP)). Because of the nature of the market-clearing problem, there is an equivalence between the optimality of the market clearing problem and the market equilibrium, based on the submitted bids.

Solution

The nature of the Optimal Bidding Problem and its solution is depicted in Figure 2-1, as a very simple example under the condition that only one product is being traded, like energy capacity, and that the agent is playing against a static opposition.

Since the opposition is static, the optimizing bidder can choose any (p, q) pair that satisfies the equilibrium conditions. In the figure, the horizontal axis is for the choice of market clearing quantity (q) and the vertical axis is for the choice of market clearing price (p).

The descending staircase is the *residual demand curve*, which is a composite of the demand bids minus the supply bids. If the demand is fixed (inelastic), then the last step represents the price and quantity of the lowest competitive supply offer. The residual demand curve is also the collection of (p, q) pairs determined by the equilibrium conditions. In OBP, it is the feasible region, and it is highly non-convex.

The parallel hyperbolas are curves of constant profit (isoprofit curves). Imagine for a moment that marginal costs are zero, then profit would be price times quantity, yielding such functional forms. Since the objective function of OBP is to maximize profit, the curves in the figure show that profit increases for higher prices and higher quantities. They also show that for a given level of profit, one must sell more at a lower price or sell less at a higher price.

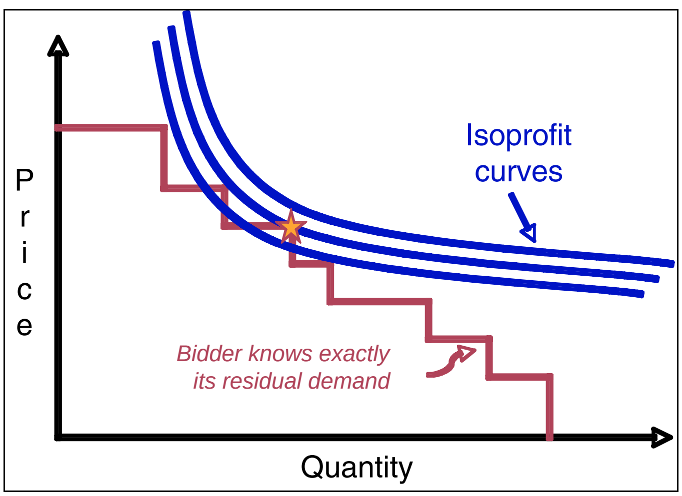

Figure 2-2
Nature of the Optimal Bidding Problem and it's Solution

The star on the center isoprofit curve represents the solution for the optimal bidding problem. It is the point on the residual demand curve that offers the highest profit.

Figure 2-3 depicts the addition of a bid curve that passes through the solution point of OBP. Note that the agent formulates and solves OBP obtaining a single (p, q) pair, but needs to submit a bid curve in the form of multiple (p, q) pairs. The agent we use in the following experiments converts the single-pair solution into multiple pairs that have prices close to p for quantities less than q, and the remaining endowment bid at a price much higher than p. This is called a *hockey stick bid*, because of the angled shape of the curve.

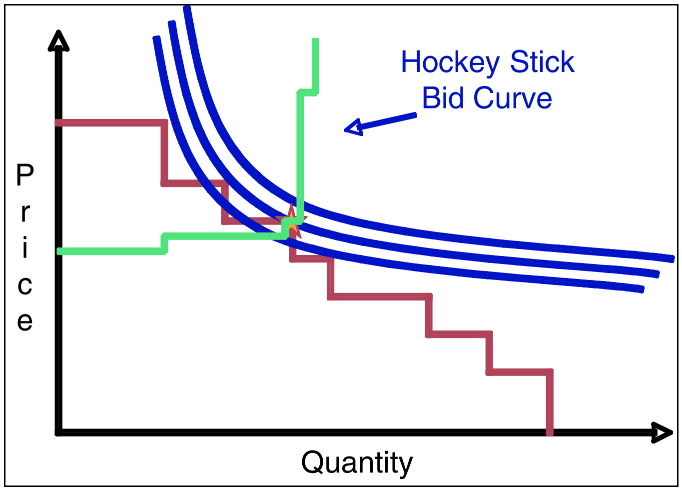

Figure 2-3
Determining the Profit Maximizing Bid

The hockey stick bid curve has the characteristic of maintaining the desired price, should the quantity accepted decrease from the solution value. Subject to the condition that the bid curve must be non-decreasing, this is the direction of least descent of the profit gradient. It also has the characteristic of increasing profits most rapidly if the quantity accepted is higher than the solution value.

Note that a horizontal bid curve corresponds to bidding a price only, as in a Bertrand Equilibrium [20] calculation, and that a vertical bid curve corresponds to bidding a quantity only, as in a Cournot Equilibrium [21] calculation.

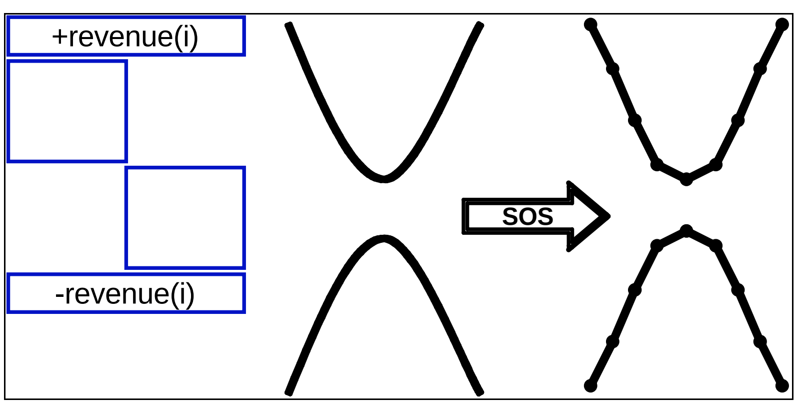

Figure 2-4
Optimal Bidding Solution Method

Figure 2-4 depicts a refinement on OBP that converts it from the form of an non-convex Non-Linear Program (NLP) to the form of a Mixed Integer Linear Program (MILP or MIP). Note that the objective function for OBP is quadratic, having the product of the price and quantity decision variables. Also, the Weak Duality condition contains the negative of the same term. This is the origin of the non-convexity of the problem, which is depicted as two smooth hyperbolic curves in the center of the figure.

The right-most curves transform from the smooth curves into piecewise linear curves via the use of Special Ordered Sets (SOS) [22]. This is a modeling trick that moves from smooth optimization methods to combinatorial methods, which are better capable of finding global solutions to non-convex problems. Note that the transform represents the smooth functions with approximations, and, as such, the resulting problem is not guaranteed to find the exact solution to the original NLP. In practice, however, the segments in the approximation can be refined to obtain an arbitrary accuracy in the price-quantity product at the expense of increasing the problem size.

Even though this example of how to solve the optimal bidding problem is simplified by the assumption of only one product being traded, the general formulation and solution methodology scales to trading multiple products within the context of a market clearing problem that is a Linear Program. For the purposes of the experiments on transmission investment in this report, the following chapter describes how the problem will be set up for the simultaneous trading of energy and transmission capacity.

3
EXPERIMENTAL SET-UP

This chapter describes the experimental setup, which utilizes a stylized example in order to facilitate the exposition. The first section describes the treatment of time, which for the purposes of investigating investment is necessarily long. The next few sections describe the resources in the power system, one section for each product type. The section titled *Competitive Equilibrium* describes the typical economic efficiency benchmark, and is followed by an example settlement. The final sections describe scenarios of resource ownership (the means for investigating incentives), settlement and bidding.

STEMS represents many electricity products, but for the purposes of this report, we will refer only to energy and transmission capacity, where energy capacity quantities can be positive (for supply) and negative (for demand). Transmission capacity quantities will always be positive. Consumption (demand) for transmission capacity is implicit in the representation of the relation between energy production, consumption, and transport, within a linearized electricity network flow model.

Time

In the following, time is treated as a single, long period. The length is on the order of decades, in order to encompass the aspects of investment incentives. The exact length is less important, since the purpose of the exposition is to demonstrate the first-order incentives, based on long run, average decision-making.

Subsequently, we characterize endowment capacity quantities as long-run averages, and their attached prices are long-run expected marginal costs, incorporating construction, operations, maintenance, etc. Treating the time horizon and the endowments, conveniently, simplifies the analysis into a one-shot equilibrium calculation.

Aspects that cannot be addressed appropriately in this context are those associated with dynamics and uncertainty: the fact that capacity can be differentiated by how quickly it can change over short periods, like fast-response generation, the diurnal and seasonal patterns of energy demand, and the random fluctuations in supply and demand. Here, we treat their associated nuance as less important than the determination of which entities generally want transmission capacity, which do not, and why.

Transmission

To show transparently the perspectives of a variety of market participants on transmission investment, we consider a very simple two-node network, with a single capacitated link. We name the two nodes as North and South, and while the endowed quantity of transmission capacity is nominally 2.5 GW, this value is less important than the fact that the quantity is in excess of what could be economically transferred. Thus, the transmission capacity endowment will always be in surplus for whichever entity is assigned. Later, in the *Bidding* section we discuss the interpretation of bidding a portion of the endowment above the long-run marginal cost.

Table 3-1
Transmission Capacity Supply Resources

Resource Name	Link	Quantity (MW)	Price ($/MW)
TNS	North–South	2500.0	0.0
TSN	South–North	2500.0	0.0

The value we use for the long-run marginal cost of the transmission endowment is zero, which removes any comparison of the relative merits of transmission and generation supply. Transmission will be treated as the preferred means of joining supply and demand—rather than relocating one or the other.

Energy Capacity Demand

The demand for energy capacity is divided equally between the two locations as in Table 3-2, with the total being 10,000 MW. Normally, such demand is treated in practice as stable and increasing from year to year, mainly because of the difficulty in relocating existing capacity and in producing new capacity over time frames of less than one or two years.

The long-run willingness to pay for energy capacity is 100 $/MWh. In our current context, this value represents a cap on prices.

Table 3-2
Energy Capacity Demand Resources

Resource Name	Node	Quantity (MW)	Price ($/MW)
DN	North	-5000.0	100.000
DS	South	-5000.0	100.000

Note: Our convention is to treat demand values as negative quantities.

Since these experiments treat the demand for energy capacity as being constant over decades, there is no ability to address the timing issues associated with new investment. Again, our focus will be on the incentives for different entities to invest in transmission.

Energy Capacity Supply

There are five energy capacity supply resources identified in Table 3-3. Each has the same quantity, 3000 MW. On the other hand, the long-run marginal costs (prices) have been chosen carefully to differ in such a way as to elicit a few surprising results.

Table 3-3
Energy Capacity Supply Resources

Resource Name	Node	Quantity (MW)	Price ($/MW)
R1	North	3000.0	25.000
R2	North	3000.0	36.000
R3	South	3000.0	25.000
R4	South	3000.0	25.000
R5	South	3000.0	35.000

The supply in each region is sufficient to provide for the local demand, but the South has a larger endowment of less expensive energy capacity. Neither region alone is capable of providing for all of the energy capacity demand.

Competitive Equilibrium

The Competitive Equilibrium corresponds to the case when all of the market participants bid marginal cost. Coincidentally, it also corresponds to the case when a central authority dispatches the system at least cost. For these reasons, it is an important performance benchmark.

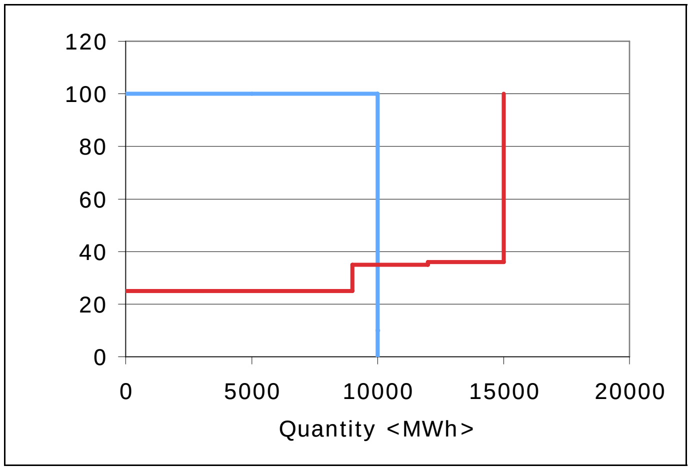

Figure 3-1
Diagram of the Competitive Equilibrium

Based on the data provided so far, it is easy to determine the Competitive equilibrium for this experimental setup. The chart in Figure 3-1 depicts, in the p-q plane, the supply and demand curves and the Competitive Equilibrium (10,000, 35.0)—where they meet.

Since the transmission capacity supply is in surplus, the two regions can be treated electrically as one, and all of the energy capacity supply and demand resources can be combined into a single chart. The supply resources are ordered by price, low to high, while the demand resources, typically, are ordered oppositely. (Note that since all of the demand resources have the same price, the latter is inconsequential.)

Settlement

To precisely understand the incentives being modeled in the experiments, it is important to know where the money is going. For instance, the focus of the Optimal Bidding agent is on maximizing profits to be gained from its endowment of resources.

Energy Capacity Demand receives customer payments (100 $/MW) and pays the market-clearing price for energy capacity.

Energy Capacity Supply receives the market-clearing price of energy capacity and pays the long-run marginal cost (which vary by resource as seen in Table 3-3).

Transmission Capacity Supply receives capacity congestion rents, the difference between the linked energy capacity prices, and it pays no costs (by convention in these experiments).

As an example of how the market is settled, consider the calculation in Table 3-4 for the Competitive Equilibrium. The Quantity row contains the level of activity of the resource. The Price row contains the market-clearing price for the resource, which can be different for the two energy capacity regions, and which will be the positive difference of regional prices for the transmission resources.

Table 3-4
Settlement at the Competitive Equilibrium

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	2000	-5000	-5000	3000	0	3000	3000	1000
Price ($/MW)	0	0	35	35	35	35	35	35	35
Revenue (k$)	0	0	-175	-175	105	0	105	105	35
Cost (k$)	0	0	-500	-500	75	0	75	75	35
Profit (k$)	0	0	325	325	30	0	30	30	0

The Revenue row contains the value of the Quantity times Price for each resource, and similarly the Cost row contains the value of the Quantity times the marginal cost of each resource. The Profit, finally, is Revenue minus Cost.

Note that at the Competitive Equilibrium the over-capacitated transmission system would provide its owner no economic value from congestion rents. There also seems to be no use for a flow from North to South.

Later, in the results chapter, the participant profits will be compared to the amount of profit at the Competitive Equilibrium. For instance, a participant owning R1, R2, and TSN has competitive profit 30 k$.

Also for comparison is the result having no transmission linking the North and South. In Table 3-5, the activity of the TNS and TSN resources are zero and the market clearing prices are 36 $/MW in the North and 25 $/MW in the South. Each region self-supplies its demand for energy capacity.

Table 3-5
Settlement with No Transmission

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	0	-5000	-5000	3000	2000	3000	2000	0
Price ($/MW)	0	0	36	25	36	36	25	25	25
Revenue (k$)	0	0	-80	-125	108	72	75	75	35
Cost (k$)	0	0	-500	-500	75	72	75	75	35
Profit (k$)	0	0	320	375	33	0	0	0	0

Compared to the Competitive Equilibrium, the consumer surplus (profits of DN and DS) increases by 40 k$ and the producer surplus (profits of R1, …, R5) decreases by 57 k$. This implies that the transmission line contributes $17 k to the social welfare (consumer plus producer surplus).

Scenarios

Beyond the Competitive Equilibrium (and centralized ownership and decision making) lay economic results that depend on decentralized ownership and decision-making. Our scenarios enumerate a eight variations of ownership, and in the next section we describe how decentralized decision-making is implemented.

We divide the electric system stakeholders into three categories: generation (G), transmission (T) and demand (D). Using these single-letter mnemonics, Table 3-6 describes the eight scenarios we will investigate in this paper. As transmission is grouped, or is independent of, different sectors, each scenario takes a different stakeholder perspective on investment incentives.

Table 3-6
Scenarios of Resource Ownership

Resource Grouping		Scenario Name
D + T	G	Demand Import Demand Export
D	G + T	Generation Import Generation Export
D G T		Three Independent
D + G	T	Demand + Generation
D + G + T		Vertical Utility Import Vertical Utility Export

The left column of the table shows the generalized grouping of stakeholders and the right side shows a refinement on transmission ownership (when not independent) by either the import or the export capacity.

In our experiments we classify stakeholders according to four names: Load Serving Entities (LSE), Transmission Owners (TO), Utilities (U), and Independent Power Producers (IPP). While, reasonable people could dispute the application of any one of these names to the ownership situations that follow, please realize that our intent is merely to differentiate the market participants in each scenario, using memorable and somewhat meaningful monikers.

Table 3-7 lists the unique names and descriptions of the market participants in each scenario. Participant names utilize the four classifications and are further differentiated by a regional suffix (N or S), as necessary.

Table 3-7
Participant Names and Descriptions

Participant Name	Description
LSE_N	Load Serving Entity in the North
LSE_S	Load Serving Entity in the South
TO	Transmission Owner
U_N	Utility in the North
U_S	Utility in the South
IPP_N	Independent Power Producer in the North
IPP_S	Independent Power Producer in the South

Table 3-8 utilizes the participant names in a two dimensional grid, by scenario and resource to indicate the detailed ownership of each resource by each participant for each scenario.

Table 3-8
Resource Ownership Details

Scenario Name	Resource Name								
	TNS	*TSN*	*DN*	*DS*	*R1*	*R2*	*R3*	*R4*	*R5*
Demand Import	LSE_S	LSE_N	LSE_S	LSE_N	IPP_N	IPP_N	IPP_S	IPP_S	IPP_S
Demand Export	LSE_N	LSE_S	LSE_S	LSE_N	IPP_N	IPP_N	IPP_S	IPP_S	IPP_S
Generation Import	IPP_S	IPP_N	LSE_N	LSE_S	IPP_N	IPP_N	IPP_S	IPP_S	IPP_S
Generation Export	IPP_N	IPP_S	LSE_N	LSE_S	IPP_N	IPP_N	IPP_S	IPP_S	IPP_S
Three Independent	TO	TO	LSE_N	LSE_S	IPP_N	IPP_N	IPP_S	IPP_S	IPP_S
Demand + Generation	TO	TO	U_N	U_S	U_N	U_N	U_S	U_S	U_S
Vertical Utility Import	U_N	U_S	U_N	U_S	U_N	U_N	U_S	U_S	U_S
Vertical Utility Export	U_S	U_N	U_N	U_S	U_N	U_N	U_S	U_S	U_S

Down the columns of the energy capacity resources, ownership is relatively constant. Down the columns of the two transmission resources (TNS and TSN), ownership varies by scenario. This is the main independent variable of the experiments.

Bidding

The bidding of the market participants is organized to focus on the ability of individual energy capacity owners to profit additionally from transmission capacity ownership. So, only one participant bids optimally in each experiment.

Segmenting the bidding, so that there is only one optimal bidder, emphasizes the profit-making incentive of the individual participant and its strategy. Because we orient transmission ownership by import or export direction, when one of two transmission owners is able to profit from transmission capacity, the competitor transmission owner is typically not able to do so, because power flows in the wrong direction to be profitable. There is only one case where something odd occurs in this respect, an IPP attempts to reverse the flow.

Table 3-9 lists the participant bidding strategies for each scenario. The scenarios are listed in the left-most column and under each strategy heading in the other columns are the names of participants that use the strategy.

Table 3-9
Participant Bidding Strategies

Scenario Name	Bidding Strategy	
	Marginal Cost	*Optimal*
Demand Import	IPP_N & IPP_S	LSE_N or LSE_S
Demand Export	IPP_N & IPP_S	LSE_N or LSE_S
Generation Import	LSE_N & LSE_S	IPP_N or IPP_S
Generation Export	LSE_N & LSE_S	IPP_N or IPP_S
Three Independent	–	LSE_N, LSE_S, or TO
Demand + Generation	TO	U_N or U_S
Vertical Utility Import	–	U_N or U_S
Vertical Utility Export	–	U_N or U_S

Having only one optimal bidder, with the rest behaving statically (bidding marginal cost) by always submitting marginal costs, reduces the use of STEMS to the special case of formulating and solving an MPEC model. For this reason, only one round of bidding is necessary, since the bid submitted by the optimal bidding agent will be based on the solution of its own MPEC and the market's clearing problem will result in the identical solution.

More information about the rationale for these bid settings is provided in the sections of the next chapter, which describes the experimental results.

4
EXPERIMENTAL RESULTS

The five sections of this chapter divide the scenarios according to stakeholder perspectives on the ownership of transmission. The demand and generation perspectives are taken in the first two sections, respectively. The next two sections take the perspective of stakeholders in the presence of independent transmission ownership, and the final section looks at how two vertically integrated utilities view the construction of a tie line between their two regions.

While the description of the experimental setup is technically complete (in the previous chapter), each section offers further nuance on the rational of the assigned endowments and bidding behaviors.

Demand Ownership

This section describes the results of four variations on the ownership of transmission coupled with energy capacity demand resources. The Load Serving Entities, LSE_N and LSE_S, in the North and South, respectively, alternate in ownership of either the import or export transmission capacity.

The results from solving these four MPEC problems, via STEMS, are given in Table 4-1. The independent parameters in the first two columns are the participant bidding optimally and whether it owns import or export transmission capacity. The next three columns contain the direction, active quantity, and congestion price for transmission. The regional energy capacity prices come next. In the last column, labeled *Bonus*, is the ratio of the profit for the given participant and its competitive profit. So, the value of 1.000 for (LSE_N, Export) means that this participant, who has the freedom to maximize its profit in the face of marginal-cost-bidding competitors, cannot raise its profit above the competitive level.

Table 4-1
Results for Demand Ownership

Strategic Participant	Owns	Transmission			Energy Price		Bonus
		Dir	Qty	Price	North	South	
LSE_N	Export	S → N	2000	0.00	35.00	35.00	1.000
LSE_S	Export	S → N	1000	11.00	36.00	25.00	1.188
LSE_N	Import	S → N	1000	11.00	36.00	25.00	1.018
LSE_S	Import	S → N	2000	0.00	35.00	35.00	1.000

The main conclusion from this set of results is that the demand-side participants prefer that the transmission line be congested in the S → N direction. Note that in the two cases, (LSE_N, Export) and (LSE_S, Import), the strategic participant owns the transmission capacity in the N → S direction, opposite to the direction of activity. In these cases, there is no strategy the participant can use to increase its profits above the competitive level. In the two remaining cases, (LSE_S, Export) and (LSE_N, Import), the strategic participant can gain from the creation of a price difference across the transmission link.

Table 4-2
Settlement of Demand Ownership (LSE_S, Export) and (LSE_N, Import)

Scenario Name	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	1000	-5000	-5000	3000	1000	3000	3000	0
Price ($/MW)	0	11	36	25	36	36	25	25	25
Revenue (k$)	0	0	-180	-125	108	36	75	75	0
Cost (k$)	0	0	-500	-500	75	36	75	75	0
Profit (k$)	0	11	320	375	33	0	0	0	0

In (LSE_S, Export), there is a 18.8% premium over the Competitive Equilibrium to be gained. By lowering the price of southern energy capacity from 35.00 $/MW to 25.00 $/MW, it gains 50 k$ from energy capacity sales to its customers, and by causing the link price to go from zero to 11.00 $/MW, it gains almost 11 k$ from the transmission capacity. LSE_N loses 5 k$ in profit due to the increase in the energy capacity price from 35 $/MW to 36 $/MW, relative to the Competitive Equilibrium.

The market clearing for case (LSE_N, Import) is identical to (LSE_S, Export), despite the change in transmission ownership. It has the same prices and the same transmission capacity. In this case, LSE_N receives the transmission benefits of 11 k$ and instead of losing profits over the northern price increase, it has a net gain 6 k$ over the Competitive Equilibrium.

For the configuration of supply and demand in these experiments, the Load Serving Entities, LSE_N and LSE_S, share an interest in having 1000 MW of transmission capacity between their regions. Of course, they would both like to have the 11 k$ in profit it nominally brings. If LSE_N and LSE_S were negotiating to build a transmission line, they could agree to a 1000 MW line, and LSE_N would be neutral at an ownership level of 455 MW, which allows the quantity of transmission benefits to cover losses from higher energy capacity prices in the north.

Generation Ownership

This section describes experiments that investigate the incentives of generation owners to invest in transmission. Like the previous experiments with demand-side transmission ownership, this section has four combinations of the northern or southern Independent Power Producer, IPP_N or IPP_S, respectively, drawing congestion rents from rights to the import or export transmission capacity.

The results from solving these four MPEC problems, via STEMS, are given in Table 4-1. The columns of this table are likewise oriented, with the independent variables (Strategic Participant and Transmission Ownership) in the left columns and the computational results to the right.

Table 4-3
Results for Generation Ownership

Strategic Participant	Owns	Transmission			Energy Price		Bonus
		Dir	Qty	Price	North	South	
IPP_N	Export	S → N	2500	65.00	100.00	35.00	6.25
IPP_S	Export	N → S	1000	0.00	100.00	100.00	10.0
IPP_N	Import	S → N	1000	75.00	100.00	25.00	12.1
IPP_S	Import	–	–	–	36.00	100.00	6.25

Since the market has been set up with substantial market power on the generation side, none of the four cases results in a Competitive Equilibrium. The dominant strategy is simply to raise the energy capacity price to the cap (100 $/MW), with little regard for the gains from the transmission.

Case (IPP_N, Export) is a simple example of owning the transmission in the wrong direction, with the resulting strategy of selling energy capacity at the highest price, 100 $/MW. IPP_N sells 2500 MW at 100 $/MW gaining 187.5 k$, 6.25 times more than at the Competitive Equilibrium.

In case (IPP_S, Export), the southern IPP can gain from the export transmission, but its strategy is to instead offer only 4000 MW of energy capacity, forcing the maximum import quantity from the North. This raises the North energy capacity supply at its maximum of 6000 MW, causing a shortage in the North and forcing the prices in both regions to the cap. Note that this strategy does not rely on transmission benefits in the export direction. IPP_S sells 4000 MW at 100 $/MW gaining 300 k$, 10.0 times more than at the Competitive Equilibrium.

Not shown is the result when the two IPPs owning export capacity bid against each other. As we have just shown, both IPPs want to sell at the highest price, and this example is limited by the setup having the two IPPs having market power. While the above IPP_S strategy is interesting, because it would reverse the flow, the result when both suppliers bid against each other cannot be sustained. IPP_N bids high on its own, removing the incentive for IPP_S to force a high North price by withholding quantity. Instead, both suppliers bid high, split the market, and no transmission is used.

In Case (IPP_N, Import), the northern IPP can gain by extracting rents from the inexpensive Southern supplier. The transmission capacity is held down to 1000 MW so that the southern energy capacity price is depressed to 25 $/MW, and then the northern energy capacity price is raised to 100 $/MW. In this way, IPP_N gains 75 k$ from its import transmission capacity and sells 4000 MW of energy capacity at 100 $/MW gaining 289 k$ for a total of 364 k$, 12.1 times more than at the Competitive Equilibrium.

In case (IPP_S, Import) the southern supplier can and does withhold import transmission capacity, in contrast to the (IPP_S, Export) strategy. In this way, it can force more of its own capacity to be used at the very high price of 100 $/MW. IPP_S sells 5000 MW of energy capacity at 100 $/MW gaining 375 k$, 6.25 time more than at the Competitive Equilibrium

These simple examples of the incentives for energy capacity suppliers to invest in transmission are dominated by their local market power. More realistic examples would incorporate a cost of new entry (CONE), above which, outside suppliers of energy capacity are likely to enter. By incorporating CONE and outside suppliers, the incumbents (IPP_N, IPP_S) would have their strategies disciplined. This extension is beyond the scope of this report, since the scenarios as modeled primarily illuminate basic incentives for energy suppliers to invest in transmission.

Independent Three

This section gives results for the three groups of stakeholders (generation, transmission, and demand) being independent of each other. Table 4-4, shows the five cases for each of the northern and southern energy capacity supply and demand, plus the independent transmission owner.

Table 4-4
Results for Independent Three

Strategic Participant	Owns	Transmission			Energy Price		Bonus
		Dir	Qty	Price	North	South	
IPP_N	None	S → N	2000	0.00	35.00	35.00	1.000
IPP_S	None	N → S	1000	0.00	100.00	100.00	5.000
LSE_N	None	S → N	2000	0.00	35.00	35.00	1.000
LSE_S	None	S → N	2000	0.00	35.00	35.00	1.000
TO	All	S → N	1000	11.00	36.00	25.00	Undefined

The Competitive Equilibrium is the result for cases (IPP_N, None), (LSE_N, None), and (LSE_S, None). In the former, IPP_N cannot make additional profit by raising the price above 35 $/MW. In the latter two, LSE_N and LSE_S are net buyers, so the Competitive Equilibrium provides for them the minimum cost of procurement.

In case (IPP_S, None), the southern supplier utilizes the same strategy as in (IPP_S, Export); it withholds so much of its energy capacity supply so as to cause a universal shortage. This results in energy capacity prices everywhere being at their maximum, 100 $/MW.

In case (TO, All), the business of the TO is to invest in order to derive benefits from price differences between the northern and southern regions. Its strategy is to limit transmission capacity to 1000 MW in order to drop the southern energy capacity price to 25 $/MW and increase the northern price to 36 $/MW, maximizing the price difference. The transmission capacity gets a price of 11 $/MW, and the TO reaps 11 k$ in profit. Since the TO would have made no profit under the Competitive Equilibrium, its gains are undefined.

Not shown in the table is the result when IPP_S and TO utilize optimal bidding simultaneously. The bidding was conducted for 6 rounds and resulted in IPP_S and TO attempting to dominate the market. The strategy of IPP_S to withhold supply becomes unnecessary as in the IPP Export ownership, because the prices rise to the price cap and no transmission is used.

Demand and Generation

This section describes experiments that investigate the incentives of utilities, while holding transmission independent. This situation corresponds to a vertical utility with transmission as an independent subsidiary, or an IPP and LSE having a large contract covering a time period of decades, like the time horizon in these experiments.

These are two cases of the northern or southern utilities, U_N and U_S, respectively, individually maximizing their profits, with the results from solving these two MPEC problems given in Table 4-5. The columns of this table have the independent variables (Strategic Participant and Transmission Ownership) in the left columns and the computational results to the right.

Table 4-5
Results for Generation and Demand Being Independent of Transmission

Strategic Participant	Owns	Transmission			Energy Price		Bonus
		Dir	Qty	Price	North	South	
U_N	None	S $\rightarrow$ N	2000	0.00	35.00	35.00	1.000
U_S	None	S $\rightarrow$ N	1988	0.00	36.00	36.00	1.005

In case (U_N, None), the northern utility prefers the Competitive Equilibrium, under which it can import 2000 MW of energy capacity over the transmission line. This keeps the local, northern price from rising to 36 $/MW.

In case (U_S, None), the southern utility prefers to raise the cost of its energy capacity supply to the north from 35 $/MW to 36 $/MW. Note that even though the Energy Capacity Price has risen, the accounting within U_S is net zero for its self-provided load of 5000 MW. It is attempting to raise the price of its export to just below the value at which the northern resource, R2, would enter.

Vertical Utilities

This final section has experiments with two vertically integrated utilities located in each of the two regions: North and South. The four cases involve ownership according the northern or southern utility, U_N and U_S, respectively, and according to the direction of the transmission capacity. Table 4-6 shows the independent variables (Strategic Participant, and Transmission Ownership) in the leftmost columns and the dependent simulation results in the others. The main observation is that both utilities prefer the S $\rightarrow$ N direction to be have a limited capacity of 1000 MW.

Table 4-6
Results for Vertical Utilities

Strategic Participant	Owns	Transmission			Energy Price		Bonus
		Dir	Qty	Price	North	South	
U_N	Export	S → N	2000	0.00	35.00	35.00	1.000
U_S	Export	S → N	1000	11.00	36.00	25.00	1.003
U_N	Import	S → N	1000	11.00	36.00	25.00	1.025
U_S	Import	S → N	2000	0.00	36.00	36.00	1.005

Cases (U_N, Export) and (U_S, Import) have transmission capacity in the direction opposite of the flow. They have the familiar strategies of the net buyer (U_N, Export) preferring low prices (Competitive Equilibrium) and the net seller (U_S, Import) preferring somewhat higher prices. We saw similar results in (U_N, None) and (U_S, None), respectively.

Case (U_S, Export) is like (LSE_S, Export), (LSE_N, Import), and (TO, All) where the dominant strategy is to maximize the price difference between regions. In (LSE_S, Export), this strategy coincides with additional profits from southern energy capacity demand, due to the reduction in its market-clearing price. In (U_S, Export), only exported energy capacity provides additional profit. The energy capacity used for self-supply does not change with the energy capacity price. Nevertheless, the fact that U_S is a net supplier provides it with the incentive to maximize the regional price difference, which means lowering the local energy capacity price from 35 $/MW to 25 $/MW.

Case (U_N, Import) the northern importer tries to maximize revenue from the transmission line by creating a large price difference. Once the southern price bottoms out at 25 $/MW, there is no further gain from raising the northern price higher than 36 $/MW. The fact that all northern prices between 36 and 100 $/MW offer the same profit to U_N actually makes this problem difficult to solve, because there are very many solutions having almost identical profit values. In all of these solutions, the net profit for U_N is 364 k$, 2.5% higher than at the Competitive Equilibrium.

5 SUMMARY

The two-node network in the experiments is not meant to be representative of any specific situation. It is meant to demonstrate the use of market simulation technology as a tool for analyzing positions of various stakeholders who may be participating in a negotiation for transmission enhancements. The cases in the experiments, while extensive, are not exhaustive, because the characteristics of the simple network are static (aside from the ownership pattern) and additional situations will likely arise as the collection of stakeholders become more intricate. Ultimately, 18 different simulations were run, with most yielding unique results and strategies.

Seven of the experiments result in a Competitive Equilibrium, because the value to be derived of the transmission capacity congestion rents is non-existent or because the participant is unable to exploit the resource from its particular position. Ownership of transmission rights opposite to the direction of the prevailing flow is the typical example of vacuous value.

Another class of cases involves net suppliers utilizing their pivotal status to raise prices. There where two ways for the supplier to incorporate the transmission capacity into its strategy. When the inexpensive supplier controlled import capacity, it chose to have no transmission so as to dominate the local market. When the expensive supplier controlled import capacity, it chose to allow some transfer, but extracted all possible rents from the alternate supplier at the opposite end of the link. In other cases, the supplier controlled capacity opposite to the direction of flow and could not exploit it.

Finally, there are the cases when the net buyers can benefit from transmission. In every case, the benefit will be limited, because the more that transmission is utilized the more of an effect it has on market prices that tends to diminish its value. The lesson in these cases is that these types of stakeholders prefer to have a congested network. That is, they prefer to limit transfers to within the most beneficial range. A similar phenomenon is seen in other markets, for instance, when a large player affects prices with its own trades and must execute them in a disciplined fashion.

To put this technology into practice, one would need to enhance the power system model to have a more realistic representation of the actual power system and enhance the analytical process so that it can be incorporated into a negotiation process. These types of extensions are now in progress.

6
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A

SCENARIO SETTLEMENTS

Table A-1
Settlement of Competitive Equilibrium

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	2000	-5000	-5000	3000	0	3000	3000	1000
Price ($/MW)	0	0	35	35	35	35	35	35	35
Revenue (k$)	0	0	-175	-175	105	0	105	105	35
Cost (k$)	0	0	-500	-500	75	0	75	75	35
Profit (k$)	0	0	325	325	30	0	30	30	0

By definition, LSE_N Bonus = 1.0, and LSE_S Bonus = 1.0.

Table A-2
Settlement of Demand Ownership (LSE_S, Export)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	1000	-5000	-5000	3000	0	3000	3000	1000
Price ($/MW)	0	11	35	35	35	35	35	35	35
Revenue (k$)	0	0	-175	-175	105	0	105	105	35
Cost (k$)	0	0	-500	-500	75	0	75	75	0
Profit (k$)	0	0	325	325	30	0	30	30	0

LSE_N Bonus = 325/325 = 1.000. LSE_S Bonus = (0 + 325)/325 = 1.000.

Table A-3
Settlement of Demand Ownership (IPP_N, Export)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	2500	-5000	-5000	2500	0	3000	3000	1500
Price ($/MW)	0	65	100	35	100	100	35	35	35
Revenue (k$)	0	162.5	-500	-175	250	0	105	105	52.5
Cost (k$)	0	0	-500	-500	62.5	0	75	75	52.5
Profit (k$)	0	162.5	0	325	187.5	0	30	30	0

IPP_N Bonus = 187.5 / 30 = 6.25. IPP_S Bonus = (162.5 + 30 + 30) / 60 = 3.708.

Table A-4
Settlement of Demand Ownership (IPP_S, Export)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	1000	0	-5000	-5000	3000	3000	1000	3000	0
Price ($/MW)	0	0	100	100	100	100	100	100	100
Revenue (k$)	0	0	-500	-500	300	300	75	75	0
Cost (k$)	0	0	-500	-500	75	108	25	75	0
Profit (k$)	0	0	0	0	225	192	50	0	0

IPP_N Bonus = (225 + 192) / 30 = 13.9. IPP_S Bonus = (75 + 225) / 30 = 10.0.

Table A-5
Settlement of Demand Ownership (IPP_N, Import)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	1000	-5000	-5000	3000	1000	3000	3000	0
Price ($/MW)	0	75	100	25	100	100	25	25	25
Revenue (k$)	0	0	-500	-500	300	100	75	75	0
Cost (k$)	0	0	-500	-125	75	36	75	75	0
Profit (k$)	0	75	0	375	225	64	0	0	0

IPP_N Bonus = (75 + 225 + 64) / 30 = 12.1. LSE_S Bonus = 0 / 60 = 0.

Table A-6
Settlement of Demand Ownership (IPP_S, Import)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	0	-5000	-5000	3000	2000	3000	2000	0
Price ($/MW)	64	0	36	100	36	36	100	100	100
Revenue (k$)	0	0	-180	-500	108	72	300	200	0
Cost (k$)	0	0	-500	-500	75	72	75	50	0
Profit (k$)	0	0	320	0	225	192	225	150	0

IPP_N Bonus = (225 + 192) / 30 = 13.9. LSE_S Bonus = (225 + 150)/60 = 6.25.

Table A-7
Settlement of Generation and Demand Independence (U_N, none)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	2000	-5000	-5000	3000	0	3000	3000	1000
Price ($/MW)	0	0	35	35	35	35	35	35	35
Revenue (k$)	0	0	-175	-175	105	0	105	105	35
Cost (k$)	0	0	-500	-500	75	0	75	75	35
Profit (k$)	0	0	325	325	30	0	30	30	0

IPP_N Bonus = (325 + 30) / (325 + 30) = 1.0. LSE_S Bonus = (325 + 30 + 30) / (325 + 60) = 1.0.

Table A-8
Settlement of Generation and Demand Independence (U_S, none)

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	2000	-5000	-5000	3000	10	3000	3000	990
Price ($/MW)	0	0	36	36	36	36	36	36	36
Revenue (k$)	0	0	-180	-180	108	0.4	108	108	35.6
Cost (k$)	0	0	-500	-500	75	0.4	75	75	34.6
Profit (k$)	0	0	320	320	33	0	33	33	0.9

IPP_N Bonus = (320 + 33) / (325 + 30) = 0.994. LSE_S Bonus = (320 + 33 + 33 + 0.9) / (325 + 60) = 1.005.

Table A-9
Settlement of Generation and Demand Independence (U_N, Import) with High North Price

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	1000	-5000	-5000	3000	1000	3000	3000	0
Price ($/MW)	0	75	100	25	100	100	25	25	25
Revenue (k$)	0	0	-500	-125	300	100	75	75	0
Cost (k$)	0	0	-500	-500	75	36	75	75	0
Profit (k$)	0	75	0	375	225	64	0	0	0

U_N Bonus = (75 + 0 + 225 + 64) / (325 + 30) = 1.025. U_S Bonus = (375 + 0 + 0) / (325 + 30 + 30) = 0.974.

Table A-10
Settlement of Generation and Demand Independence (U_N, Import) with Low North Price

Settlement Item	Resource Name								
	TNS	***TSN***	***DN***	***DS***	***R1***	***R2***	***R3***	***R4***	***R5***
Quantity (MW)	0	1000	-5000	-5000	3000	1000	3000	3000	0
Price ($/MW)	0	11	36	25	36	36	25	25	25
Revenue (k$)	0	0	-180	-125	108	36	75	75	0
Cost (k$)	0	0	-500	-500	75	36	75	75	0
Profit (k$)	0	11	320	375	33	0	0	0	0

U_N Bonus = (11 + 320 + 33 + 0) / (325 + 30) = 1.025. U_S Bonus = (375 + 0 + 0) / (325 + 30 + 30) = 0.974.

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