The Efficiency of Point-to-Point Financial Transmission Rights is Limited by the Network Topology

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Abstract: Many restructured electric power systems use the notion of locational marginal pricing (LMP) to optimally price network congestion. In order for market participants to hedge against volatile congestion costs, as well as to spur investments, market-makers in restructured power systems offer point-to-point financial transmission rights (FTRs), whose per-unit value is defined as the difference in LMP at any two points in the network. Since they can be defined between any two points regardless of geographic proximity or connectedness, FTRs represent a system decomposition that does not depend on the network topology. In addition to providing a hedge against congestion costs, Hogan (1992) and Bushnell and Stoft (1996) claim that FTRs have desirable properties in promoting investment in the transmission grid. In particular, if FTRs are allocated to investors in new transmission in a way which respects the physical limits of the system, then investors will have no incentive to alter the transmission grid in ways that cause, rather than relieve, congestion. An additional efficiency theorem is implicit in the "admittance rights" formulation of Gribik, et. al. (2005). Counterexamples to these FTR efficiency theorems are developed using the four-bus Wheatstone network. The counterexamples illustrate the importance of explicitly considering network topology when evaluating system upgrades.

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1. Introduction

Early visions of the restructured electric power industry envisioned replacing the transmission business of a regulated utility with a "Transco," or regulated transmission company. Such entities would be responsible for maintaining and investing in the electric power grid, subject to rate-of-return regulation in much the same way as the regulated vertically-integrated utility (Joskow and Schmalensee 1983). This, however, subjects transmission to the same regulatory challenges that were supposed to be removed with the deregulation of the generation portion of the business. A further problem is that managing a large power grid is difficult. Managing congestion and deciding what upgrades are needed are extremely difficult tasks.

A different vision of electric-sector restructuring would place transmission under a market regime similar to generation. Sometimes called the "merchant transmission"model (Joskow and Tirole 2004), this institutional arrangment would place the responsibility for transmission-grid investment and enhancement on independent transmission companies, much in the same way that the deregulated generation sector looks to merchant generation to maintain resource adequacy.[1] The merchant transmission model, like the merchant generation model, relies on nodal prices to send signals to investors in a competitive environment. Price signals would provide incentives for independent transmission companies to invest in the grid so as to alleviate congestion; these companies would then earn a return on their investment based on nodal price differences.

To operate a large grid efficiently, a transco needs to solve the same problems as the merchant model, absent the incentive problem. Managing a network above a small size requires calculating congestion costs and indicators of where investments are needed. Thus, the only major difference between managing a Transco and merchant transmission is the incentives that each face.

2. Point-to-point Financial Transmission Rights, Flowgate Rights, and Admittance Rights

The theory of optimal pricing for electric power systems was first developed by Fred Schweppe (Bohn, Caramanis, and Schweppe 1984), who derived equilibrium nodal prices (currently referred to as "locational marginal prices" or LMPs) from the static security-constrained steady-state economic dispatch problem. Hogan's (1992) "contract network" expanded upon Schweppe's nodal prices, envisioning a central authority that would control the network through nodal pricing and the assignment of financial rights to portions of the network. These rights, commonly called financial transmission rights (FTR) or transmission congestion contracts (TCC) would allow individual grid

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[1] The merchant transmission model has a number of variations other than the direct analogue to merchant generation. One such variation is "participant-funded transmission," in which a group of firms (possibly including merchant parties) makes a joint investment in new transmission infrastructure.

participatns to hedge congestion costs and would allow the grid operator to hedge revenue risk.[2]

Schweppe's spot prices and Hogan's contract network were originally oriented towards short-term efficient operation of the electric network and did not explicitly consider any long-run implications (although Hogan (1992) discusses long-term transmission rights co-existing with nodal spot prices). Although the spot prices were conceptually simple to compute, interpretation was not necessarily straightforward. Price differences between network nodes represent the marginal social cost of moving power from one node to another. As Wu et. al. (1996) discuss, this correct interpretation was often confused with an incorrect analogy to other transportation networks, in which nodal price differences signal market participants as to which paths are congested, and also indicate potential profit opportunities.[3]

Subsequent work has thus focused on the role of the contract market to provide incentives and recover costs, as opposed to relying purely on the spot market. Initially, two flavors of transmission rights emerged. The first, initially suggested by Hogan (1992) and further promoted by Bushnell and Stoft (1996) would allow for contracts based on the difference in nodal prices between any two points in the grid, regardless of the presence of congestion on the link(s) connecting the two points. Thus, the value of the contract is determined as a by-product of the energy spot market.[4] Such contracts were initially referred to as point-to-point transmission congestion contracts, but are now generally called financial transmission rights (FTRs).

The second type of transmission rights contract, suggested by Chao and Peck (1996) would involve trading transmission rights on a link-by-link basis separately from the energy market. As such, these have become known as "flowgate" rights. Assuming a competitive market for transmission, flowgate rights would have a nonzero price only in the case of congested links. Competition would naturally drive the price of flowgate rights down to the marginal cost of transmitting energy between two points. Thus, the outcome of the competitive market for flowgate rights could be determined through the shadow prices derived from Schweppe's constrained economic dispatch formulation.[5] The appeal of flowgate rights was that the contract value would reflect the value of an underlying physical good, i.e., transmission. In this way, the flowgate model would more closely mirror the pricing model in transportation networks, where nodal price differences signal both the presence of congestion and the cost of transportation between the two nodes.

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[2] Hogan (1992) proves a useful result known as the "revenue adequacy theorem," which provides conditions on the assignment of FTRs in order to balance revenue (net congestion payments made to the grid operator) and obligations (net FTR payments made by the grid operator).

[3] Wu, et. al. (1996) show that nodal price differences in power networks can arise even in the absence of congestion, and thus it is not unusual to see power moving from a high-priced node to a low-priced node. Absent the exercise of market power, in equilibrium these phenomena should not be observed in other transport networks.

[4] For this reason, Oren (1997) refers to these as "passive" transmission rights.

[5] In one sense, a competitive flowgate market would be just as "passive" as the FTR market, since the equilibrium prices could be determined as a by-product of the nodal price calculations.

Gribik, Shirmohammadi, Graves, and Kritikson (2005) have considered expanding the flowgate concept to include admittance payments in addition to capacity payments. The reasoning of Gribik et. al. is that while flow on networks is largely governed by the line admittances, FTR payments are made on the basis of the line's megawatt capacity limit.[6] RTOs auctioning off incremental transmission rights following network expansion would thus expand the number of contracts awarded to include these admittance rights. In the model of Gribik et. al., payments for admittance amount to transfers from holders of incremental capacity FTRs. Thus, admittance payments expand the number of contracts awarded, but also amount to a zero-sum game and thus will not violate Hogan's revenue adequacy rule. Of course, this also implies that the electrical properties of transmission lines are welfare-neutral; social wealth can neither be created nor destroyed through a change in admittance to a particular line or part of the system (wealth can only be transferred from one party to another). Intuitively, it is difficult to see how this can be the case, and the examples shown in Section 3 demonstrate that changes in the system admittance matrix can have both positive and deleterious effects on aggregate welfare.

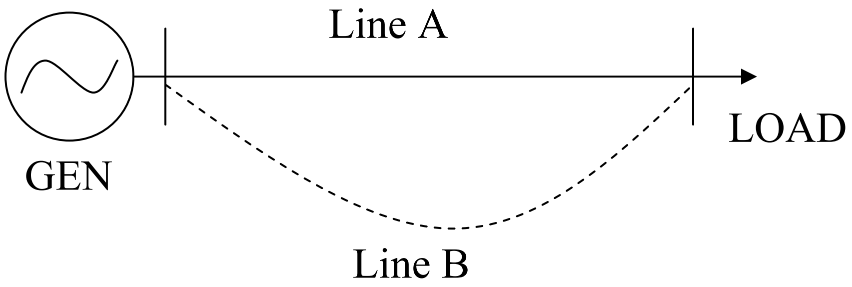

Figure 1: Even in simple networks, new lines can be added which constrain the system as a whole. If the admittance of line B is sufficiently large and the thermal limit (or stability limit) is sufficiently small, placing Line B in parallel with Line A will cause additional congestion in the system.

Despite its appeal, the flowgate-rights model can be criticized on at least two fronts with respect to promoting an efficient level of investment in transmission. The first problem, as described by Bushnell and Stoft (1996) and Joskow and Tirole (2000), is that under a flowgate rights mechanism, investors can be rewarded for building transmission lines which cause congestion in the grid. The simplest example is the case of a two-node system connecting one generator to one load, as shown in figure 1. Under a market-based transmission system with flowgate rights, a merchant transmission company could build a line with a large admittance but low thermal limit (Line B in figure 1). When placed in the system parallel to the existing line (Line A), the new line will cause

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[6] The capacity and admittance of a transmission line are first-order independent. However, in evaluating the value of a line to the system, they are not necessarily separable. Thus, the notion of separate payments for each has a great deal of appeal.

congestion where none existed before.[7] Although such an investment would be wholly unnecessary, it would still be profitable.

The second is that while the shadow prices can be good signals as to which lines are congested (and thus act as signals to avoid scheduling on these lines), they do not always signify constraints. An example is provided by the unbalanced Wheatstone network in figure 2.[8] In such a network, the existence of the Wheatstone bridge (link S_{23}) causes congestion on lines S_{12} and S_{34}. Running a DC optimal power flow on the network in figure 2 yields Lagrange multipliers of $45.87 on line S12 and $20.30 on line S_{34}.[9] In a competitive market for flowgate rights, the value of transmission contracts on these two links would be based on these Lagrange multipliers. The other, uncongested links, would have zero value attached to their associated transmission contracts.

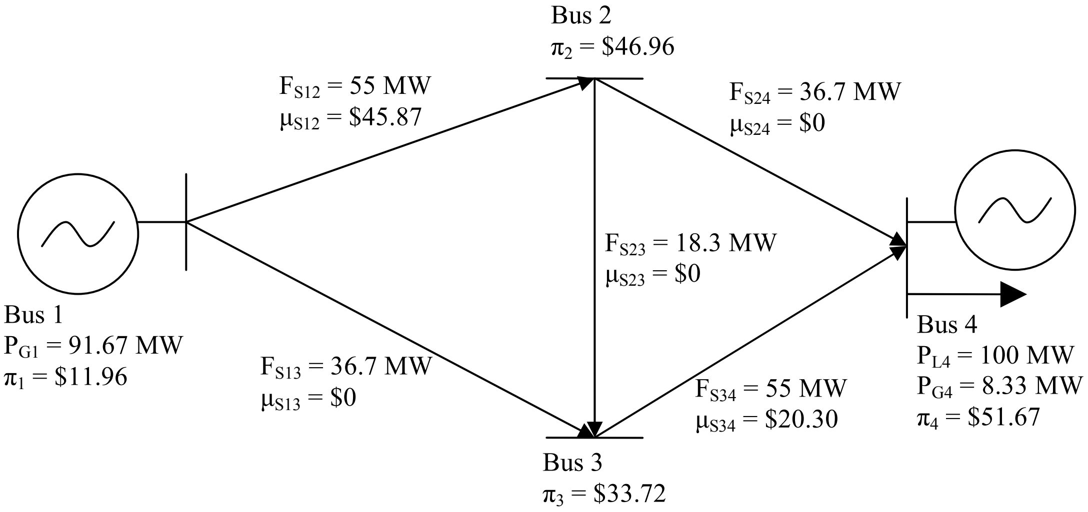

Figure 2: A Wheatstone transmission network. The nodal prices and shadow prices for transmission are obtained from a DC optimal power flow simulation each line has a thermal limit of 55 MW.

Under market-based transmission provision, the positive flowgate value assigned to links S_{12} and S_{34} should signal independent transmission companies to invest in either of those two lines. However, the parameters of the network in figure 2 yield misleading signals in two important respects, also discussed in Blumsack (2005). First, increasing the carrying capacity of either of lines S_{12} or S_{34} without increasing the capacity of the other will not

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[7] From Kirchoff's and Ohm's Laws, the exact condition under which the parallel line will cause congestion is $[Y_B/(Y_A + Y_B)]P_{GEN} > F_{B,max}$, where Y_A and Y_B are the line admittances, and $F_{B,max}$ is the thermal or stability limit on the new line.

[8] This test network is described in more detail in Blumsack (2005). These network structures are quite common in realistic systems; for example, the IEEE 14-bus test network has at least six embedded Wheatstone subnetworks.

[9] The load at bus 2 has a constant real power demand of 100 MW. The line resistances are all 0.03 per-unit, except for lines S_{13} and S_{24}, which have resistances of 0.06 per-unit. The cost curves for the generators are $C(P_{G1}) = 200 + 10.3P_{G1} + 0.009P_{G1}^2$ and $C(P_{G4}) = 300 + 50P_{G4} + 0.1P_{G4}^2$.

relieve congestion on the system. This phenomenon is a function of the network parameters – since the network in figure 2 is symmetric, in the sense that the admittances on lines S_{12} and S_{34} are identical; and the admittances on lines S_{13} and S_{24} are identical. Conservation of energy requires that the flow patters in the cut sets represented by buses {1,2,3} and buses {2,3,4} be identical. Second, the shadow prices obtained through the linearized optimal power flow are not unique. In the particular network configuration at hand, the dual objective function is parallel to the feasible region formed by the constraint set. Thus, the correct signal is actually the sum of the two positive shadow prices, indicating that both transmission constraints would need to be relieved before the system would see any benefit.[10]

That the price signals are misleading in the network of figure 2 may seem obvious. But in larger networks, it may be more difficult to identify which price signals are misleading, particularly if network participants cannot identify sub-topologies similar to that in figure 2. A merchant or other investor, given incentives solely through nodal and/or shadow prices, might make an investment (and earn a return on the investment, paid for by consumers on the grid) without resolving any congestion in the network.

Hogan (1992) and Bushnell and Stoft (1996) have advocated a system of point-to-point transmission rights, combined with a feasibility allocation rule, instead of the flowgate model. The feasibility allocation rule is based on the "revenue adequacy theorem" proven by Hogan (1992) and Wu, et. al. (1996), which shows that the merchandizing surplus earned by a centralized transmission authority (the "transco") defines the revenue possibility frontier for an independent transmission company operating under a system of FTRs.[11] If FTRs are allocated in such a way that the net position of all the players in the system is identical to the actual flow of power through the system, then the holders of FTRs will have maximized revenue. Further, Bushnell and Stoft (1996) show that when the feasibility condition is satsified, under a number of other assumptions (including constant returns to scale and marginal-cost pricing in spot and forward energy markets), then the set of profitable investments is identical to the set of economically efficient investments. Attempts to extort the system by making detrimental investments will yield negative returns for the merchant transmission company.

The merchant transmission model has come under attack on a number of fronts. Oren (1997) analyzes the behavior of competitive generators in congested systems and finds that the combination of congestion and FTRs encourages implicit Cournot collusion among the generators.[12] Yu, Leotard, and Ilic (1999) argue that network investments

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[10] An alternative would be to disconnect line S_{23} from the system entirely. In this case, the network would reduce to a purely parallel system, with 50 MW flowing along each path. Line S_{23} might, however, be justified on the basis of some system security or reliability criteria.

[11] The original motivation for the revenue adequacy theorem was a solvency condition for the transco. This would ensure that the transco collected enough congestion revenue to fulfill its FTR obligations. More recently, Lesieutre and Hiskens (2005) have shown that the revenue adequacy theorem fails to hold in AC power flows due to nonconvexity. Since most RTOs use the DC load flow approximation to determine the feasible set of FTRs, the issue may be moot.

[12] Naturally, Oren (1997) suggests that this problem will not occur in systems with tradeable flowgate rights.

should be viewed as risk-management activities and not through the lens of supporting competition in the generation market.[13] Joskow and Tirole (2005) examine the implications of relaxing the stringent economic assumptions underlying the Bushnell-Stoft FTR efficiency theorem. Unsurprisingly, they find that relaxing the competitive and static assumptions introduces inefficiencies, and suggest that in the real electric power industry, the merchant transmission model may be untenable.

History has largely supported the position of Joskow and Tirole. Enthusiasm for the purest form of the merchant transmission model has largely waned, amid the deteriorating financial position of the merchant sector in electricity (Joskow 2005, Blumsack, Apt, and Lave 2005) and the realization that siting costs (which are not reflected in the short-run locational price calculations) may be the dominant factor in determining which projects are built and which are not (Vajjhala and Fischbeck 2006). Joskow (2004) has gone so far as to pronounce the merchant transmission model "dead," and Roark (2006) has gone even further, suggesting that the model has never been taken seriously by industry players or policymakers.[14] RTOs in the northeastern U.S., however, still appear to support the merchant transmission model, and continue to dangle FTRs as carrots in exchange for investment. The contract network is not as "dead" as it might appear.

Even if all of the assumptions used by Hogan (1992) and Bushnell and Stoft (1996) in formulating the contract network hold, there still may be network-specific adverse incentive problems associated with merchant transmission, as we show below. Allocation of incremental FTRs to merchant transmission provides an incentive to increase the grid capacity in directions in which market participants expect to be using the grid and in which they have nominated and have been awarded FTRs. At the same time merchant transmission may decrease capacity in unexpected directions in which no or little FTRs were nominated. The merchant investment can be detrimental if actual flows on the grid move in these unexpected directions. Further, the set of nodal and transmission prices is not always unique (Blumsack 2006). Thus, under certain network specifications with point-to-point FTRs, independent transmission companies may still be able to profitably add links to a network in ways that cause congestion in other parts of the network.

3. FTR Efficiency Theorems and Counterexamples

An FTR is defined as a contract that entitles the holder to the nodal price difference between any two points in the network times the number of megawatts specified in the contract, for the duration specified in the contract. Following Bushnell and Stoft (1996), we will denote an FTR of size *f* between nodes *i* and *j* by an *n*-vector whose only nonzero entries are $-f$ in the *i*th row, and *f* in the *j*th row. The revenue stream accruing from an individual FTR in a given hour is therefore $\mathbf{p'f}$, where $\mathbf{p}$ is the *n*-vector of hourly nodal

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[13] Still, if competition among generators is to flourish, then the transmission grid must be robust enough to facilitate such competition (Lave, Apt, and Blumsack 2004). Thus, one important issue is who should bear the risk.

[14] Roark (2006) advocates an integration of merchant transmission investors into the centralized transmission planning process, similar to the strategy followed by Argentina when it first restructured its electric power industry in the early 1990s. See Littlechild and Skerk (2004a, 2004b).

prices. Since FTRs equal in magnitude and duration, but in opposing directions, cancel each other out, we can write the total (net) amount of FTRs in the entire system as $\mathbf{F} = \sum_k \mathbf{f}_k$, and the total revenue earned by all parties in the system is $\mathbf{p}'\mathbf{F}$. Further, define a dispatch as a vector of nodal (net) real power injections **q**, where q_i is the real power injection at node *i*. The system dispatch can similarly be defined as a vector $\mathbf{Q} = \sum_k \mathbf{q}_k$. Contracts are said to match dispatch at the individual level if **f** = -**q**, and at the systemwide level if $\mathbf{F} = -\mathbf{Q}$. The physical interpretation of contracts matching dispatch is that any physical transaction (say, on the spot market) is cancelled out by an equal (in MW magnitude) FTR. On a more general level, a set of FTRs is said to be feasible if an equivalent dispatch would not violate any of the system constraints.

In addition, Bushnell and Stoft define the social surplus arising from a system dispatch **Q**, denoted *W*(**Q**), as the difference between the total benefit enjoyed by all loads in the system and the (minimized) total cost of serving that load. Thus, $W(\mathbf{Q}) = \sum_k C_k(\mathbf{q}^*_k)$, where **q*** is the cost-minimizing dispatch vector and C(**q**) is the (convex) cost or benefit function at each node in the system. Benefits are assumed to have a positive sign and costs are assumed to have a negative sign.

Bushnell and Stoft offer two key results which imply the efficiency of FTRs. The first, which is Lemma 2 in their 1996 paper, says that any player in the system whose individual contracts match their individual dispatch will be at least as well off in the event of a change in (optimal) nodal prices in the system. The second result, which Bushnell and Stoft refer to as Theorem 2, says that when contracts match dispatch at the system level, then any player who causes congestion through their investments in the grid will be compensated by a set of FTRs that have a negative value. The unbalanced Wheatstone network shown in figure 2 can be used to construct counterexamples to both of these assertions.

Lemma 2 (Bushnell and Stoft): For any player in the system whose contracts match its dispatch (so **f** = -**q** for that player), the net benefit accruing to that player is greater than or equal to zero for any price change.

Counterexample to Lemma 2: Bushnell and Stoft define net benefits for the *k*th player as $NB = \mathbf{p}'\mathbf{q}_k - \mathbf{p}'\mathbf{f}_k - C_k(\mathbf{q}_k)$. They show that if contracts match dispatch, $\mathbf{f}_\mathbf{k} = -\mathbf{q}_\mathbf{k}$, then the change in net benefit accruing to the *k*th player after any price change is:

$$\Delta NB = \mathbf{p}^{*\prime}(\mathbf{q}^*_k - \mathbf{q}_k) - \left(C_k(\mathbf{q}^*_k) - C_k(\mathbf{q}_k)\right),$$

where variables with stars refer to the new set of prices and associated optimal quantities. Lemma 2 states that $\Delta NB \geq 0$; the proof uses the convexity of C_k as well as the assumption that nodal price differences in the network reflect differences in marginal costs (and congestion costs).

Consider the generator located at node 1 in the network of figure 2. The cost function of the generator is assumed to be $C(P_{G1}) = 200 + 10.3P_{G1} + 0.009P_{G1}^2$. Assume that the only spot market position taken by the generator is to inject power into the grid at node 1. In other words, the **q** vectors for generator 1 contains all zeros except for the real power production of the generator, which is in the first entry of the injection vector:

$$q_{G1} = \begin{pmatrix} P_{G1} \\ 0 \\ 0 \\ 0 \end{pmatrix}, \quad q_{G1}^* = \begin{pmatrix} P_{G1}^* \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

In addition to injecting P_{G1} MW of real power into the grid, suppose that the generator also has an FTR between node 1 and any other node in the network. The size of the FTR is equal to P_{G1} in magnitude.

Suppose that prior to the construction of the link between nodes 2 and 3 of the network in Figure 1, the generator at node 1 could supply the entire load at a lower cost than generator 2. Thus, P_{G1} = 100 MW and $\mathbf{q}_{G1}$ = (100, 0, 0, 0). After the construction of the link between nodes 2 and 3, the network becomes congested and generator 1 is only able to supply 91.67 MW (as in Figure 1). Thus, $\mathbf{q}^*_{G1}$ = (91.67, 0, 0, 0). The vector of nodal prices following the network expansion is **p*** = (11.96, 46.96, 33.72, 51.67). According to the formula derived by Bushnell and Stoft, the change in net benefit to generator 1 from the construction of Line S23 is:

$$\Delta NB = \begin{pmatrix} 11.96 \\ 46.96 \\ 33.72 \\ 51.67 \end{pmatrix}' \left(\begin{pmatrix} 91.67 \\ 0 \\ 0 \\ 0 \end{pmatrix} - \begin{pmatrix} 100 \\ 0 \\ 0 \\ 0 \end{pmatrix} \right) - \left[C_{G1}(91.67) - C_{G1}(100) \right] = -1.05 .$$

Thus, generator 1 sees her net benefit decline with the addition of the Wheatstone bridge to the network. This is contrary to the assertion in Lemma 2 of Bushnell and Stoft that fully-hedged market participants cannot be harmed by network additions that cause nodal prices to change.

Theorem 2 (Bushnell and Stoft): Suppose that the total set of FTRs in the system matches the systemwide dispatch (so that **F** = **-Q**), and suppose that an investment is made in the grid which lowers the social surplus of the system, so that $\Delta W < 0$. If the new set of FTRs **f*** allocated to the builder of the detrimental investment is feasible, then the revenue stream arising from these new FTRs will be negative and larger in magnitude than the loss in social surplus. Mathematically, $\mathbf{p}^{*\prime}\mathbf{f}^* < 0$ and $\mathbf{p}^{*\prime}\mathbf{f}^* < \Delta W$, where **p*** represents the vector of (optimal) nodal prices after the new investment is made.

Theorem 2 is meant to illustrate that no player or group of players (whether they be merchant transmission owners or not) would ever have an incentive to modify the grid in such a way as to cause additional congestion in the network. (Bushnell and Stoft state this explicitly in their two corollaries to Theorem 2.) The proof of Theorem 2 offered by Bushnell and Stoft makes use of Lemma 2. However, since the result in Lemma 2 does not necessarily hold in the Wheatstone network of figure 2, it follows that Theorem 2 does not necessarily hold.

Counterexample to Theorem 2: Again, we will use the Wheatstone network of figure 2 as an example. Suppose that a merchant transmission company decided to build a link between nodes 2 and 3 in the network of figure 2. The thermal limit of line S_{23} is 55 MW. According to the feasibility allocation rule, the merchant transmission owner would be free to take up to 55 MW worth of FTRs in either direction (from node 2 to node 3 or from node 3 to node 2). In this case, line S_{23} causes congestion along line S_{12}, so the nodal price at node 2 is greater than the nodal price at node 3. The total cost of serving the load without line S_{23} is \$1,622.20, while the total cost of serving the load with line S_{23} is \$1,945.50. The difference in social surplus is therefore (\$1,945.50 - \$1,622.20) = \$323.30. The profit-maximizing merchant transmisson owner would clearly take the FTRs from node 2 to node 3, earning a net benefit of $\pi_2 - \pi_3$ = \$46.96 - \$33.72 = \$13.24 per MW.[15]

Another counterexample to Theorem 2: The first counterexample to theorem 2 is somewhat weak in the sense that the positive net benefit earned by the merchant transmission company could be made negative by forcing the merchant transmission owner to accept an allocation of FTRs that matches the dispatch along the new line.[16] In this case, when the merchant transmission company builds a line connecting nodes 2 and 3, they will be forced to take 18.3 MW of FTRs from node 3 to node 2. The net benefit of these FTRs is 18.3 MW × (\$33.72 - \$46.96) = -\$242.29, which is in fact negative, although smaller in magnitude than the -\$323.30 loss in social surplus from the construction of line S_{23}.

Note that after construction of the new line, the load carried on lines S_{12} and S_{34} increases to 55 MW. For the feasibility rule to be maintained, the merchant transmission company would then be given FTRs so as to match the dispatch on line S_{12} and S_{34}. This would involve acquiring 5 MW of FTRs from node 2 to node 1 and 5 MW of FTRs from node 4 to node 3. The net benefit to the merchant transmission company from this transaction would be equal to:

$$5 \times (\pi_2 - \pi_1) + 5 \times (\pi_4 - \pi_3)$$

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[15] In private communication, Dmitri Perekhodtsev has suggested that in reality, RTOs would insist that the investor has not added capacity between buses 2 and 3, but rather has reduced capacity between buses 1 and 4. In both the flowgate model and in the admittance-payment formulation of Gribik et. al., this point is moot, since payments are only made in the case of congested lines. Both the feasibility allocation rule discussed by Bushnell and Stoft (1996) and actual RTO protocols are vague on this issue.

[16] This is technically a stronger condition than that suggested by Bushnell and Stoft, but similar rules are used by exisiting RTOs; for examples, see PJM (2003), New York ISO (2003), and ISO New England (2003).

$= 5 \times [(\$46.96 - \$11.96) + (\$51.67 - \$33.72) = \$264.75$.

Combining the net loss from the allocated FTRs on line S_{23} and the net gain from the acquired FTRs on lines S_{12} and S_{34}, the total net benefit to the merchant transmission company is \$264.75 - \$242.29 = \$22.46, so the merchant transmission company would still see a net benefit from adding the constraining line to the system. Recall also that the construction of the Wheatstone bridge increases the system cost by \$323.30, which is larger in magnitude than the profits (net of side payments) earned by the investor. Thus, the system sees a net loss in social surplus (a deadweight loss) from the construction of link S_{23}.

4. Discussion and Conclusions

Although restructuring in the electric power sector has largely been focused on generation, with the liberalization of markets for electric energy, arguments have been made that the transmission segment of the industry could be efficient under a competitive model. Central to the success of commoditization of transmission is a competitive market for transmission contracts that will allocate generation resources efficiently and encourage investment in new transmission assets in the right places. Two market-based models have been proposed for such a "merchant transmission" industry. Both use the difference in locational prices as signals for investment. The "flowgate rights" model would place a positive value on transmission contracts only for congested lines; the "financial transmission rights" model would use point-to-point nodal price differences for any nodes, regardless of their geographic proximity or the presence of congestion.

Under the contract network regime suggested by Hogan (1992), flowgate rights have been criticized for giving independent players an incentive to modify the grid in detrimental ways. The theorems of Bushnell and Stoft (1996) would support the FTR model. The efficiency of the FTR model has been criticized on economic grounds by Joskow and Tirole (2005) who argue that the assumptions used by Bushnell and Stoft are unrealistically strict.

We find that, regardless of the economic assumptions made, the efficiency of a contract network with point-to-point financial transmission rights is not independent of the network topology. The counterexamples provided here using the Wheatstone network show that even if contract markets are complete and competitive, independent players can still invest in the grid in ways that are profitable, but not socially beneficial. The counterexamples also show that grid investments must be evaluated on a case-by-case basis; simply expanding the grid will not benefit all parties, even in the presence of a robust transmission contract market. The results also caution a Transco that making investments to upgrade their grid is more difficult than relieving the most congested line.

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