# Economic Inefficiency of Passive Transmission Rights in Congested Electricity Systems with Competitive Generation

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*The main thesis of this paper is that passive transmission rights such as Transmission Congestion Contracts (TCCs) that are compensated ex-post based on nodal prices resulting from optimal dispatch by an Independent System Operator (ISO) will be preempted by the strategic bidding of the generators. Thus, even when generation is competitive, rational expectations of congestion will induce implicit collusion enabling generators to raise their bids above marginal costs and capture the congestion rents, leaving the TCCs uncompensated. These conclusions are based on a Cournot model of competition across congested transmission links where an ISO dispatches generators optimally based on bid prices. We characterize the Cournot equilibrium in congested electricity networks with two and three nodes. We show that absent active transmission rights trading, the resulting equilibrium may be at an inefficient dispatch and congestion rents will be captured by the generators. We also demonstrate how active trading of transmission rights in parallel with a competitive energy market can prevent the price distortion and inefficient dispatch associated with passive transmission rights.*

## INTRODUCTION

The electric power industries around the world are undergoing a revolutionary transition from vertically integrated regulated or government run monopolies to a competitive industry. The transmission network plays an essential role in this transition by providing the critical interconnection between geographically dispersed markets. It is, therefore, generally agreed that open access via the transmission network is the key to a competitive electricity industry. Two recent

*The Energy Journal*, Vol. 18, No. 1. 

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books by Einhorn and Siddiqi (1996) and by Gilbert and Kahn (1996) contain articles that provide general overviews and specific details on the restructuring of electric power industries in countries such as the UK, New Zealand, Chile, Argentina and Norway. The approaches adopted in the different countries vary in terms of the market organization, system operation, transmission charges, congestion management, investment incentives, etc. These differences are often motivated by characteristics of the existing system (e.g., generation mix, network topology), historical realities, asset ownership, operational practices and philosophical perspectives. Nevertheless, there are many common issues associated with the implementation of open access competitive electricity systems that are driven by the physical nature of electric power networks. Thus, while the work in this paper is primarily motivated by recent proposals and regulatory initiatives in the US, the results have much broader theoretical and practical relevance.

The US electricity system is characterized by a high degree of interconnection and diverse ownership of transmission assets and generation resources. Consequently, the implementation of open transmission access in the US hinges upon the establishment of property rights and usage protocols for the transmission network along with mechanisms for ownership compensation and usage charges. The Federal Energy Regulatory Commission (FERC) (April 24, 1996) has recently proposed a set of guidelines for transmission capacity reservation and use that would implement the basic requirements for open transmission access to support a competitive electricity market. The FERC proposal defines transmission service in terms of firm transmission capacity from specific points of delivery to specific points of receipt on the transmission grid. Capacity reservations can be traded among market participants and reconfigured as long as the reconfiguration does not infringe on other capacity reservations. Unutilized capacity reservations or incremental use of capacity when the transmission system encounters constraints, may be compensated or charged for, based on opportunity costs.

In a recent article, Harvey, Hogan and Pope (1996) advocate the implementation of FERC's Transmission Capacity Reservation (TCR) by means of a nodal spot market with Transmission Congestion Contracts (TCCs). The authors reinterpret the original Network Contracts idea introduced by Hogan (1992) in terms of the language and principles articulated in the FERC proposal. Specifically, the authors propose a market structure in which node-specific generation and demand are bid competitively into a central pool and are dispatched centrally by an Independent System Operator (ISO), so as to meet some optimality criteria and satisfy transmission constraints. The resulting market clearing prices at each node (adjusted for losses) become the nodal spot prices paid to generators and charged to consumers at the respective nodes. In this framework the right (or obligation) to inject power at one node and take out power at another node takes the form of a TCC, which is a financial contract that entitles (or obligates) its holder to receive (or pay) the nodal spot price difference between the respective nodes. In this design transmission rights ownership plays a passive role in the market while the active trading takes place in generation. The market value of TCCs (which is determined ex-post) is established implicitly by the competitive generation in conjunction with optimal dispatch by the ISO.

In their paper, Harvey, Hogan and Pope (1996) argue that trading, reconfiguration and opportunity cost compensation of TCRs can be accomplished within a pool-based system by turning these TCRs over to the ISO in return for TCCs. The optimal dispatch by the ISO can be viewed as an optimal reconfiguration which maximizes the value of the TCRs and the opportunity costs (or value) resulting from such reconfiguration accrues to the TCC holders. The argument that transmission trading is implicit in economic dispatch fails, however, to recognize the strategic implication of replacing active trading in transmission capacity with passive ownership compensated ex-post based on the energy trading outcomes. The analysis supporting the above argument and its conclusion hinge on the premises that the energy market does not react to the way in which transmission property rights are being exercised, and that in the absence of locational market power in generation bid prices will be driven to marginal costs. These premises are based on economic theory that has not dealt explicitly with the implication of congested distribution channels and has not been substantiated by any empirical evidence. On the contrary, limited experimental results suggest that in the absence of active market participation by transmission rights owners, bid prices for generation may deviate from marginal costs which will defeat the TCC-based approach.

The purpose of this paper is to highlight the importance of active trading in transmission capacity and the possible implications on competition in generation of passive transmission ownership (i.e., no ex-ante charges or active market participation through bidding or trading of rights). By using a Cournot model of competition in a congested transmission network we illustrate that even in the absence of local market share concentration in generation, passive transmission can result in implicit collusion among generators who will capture the congestion rents and preempt the TCCs. The price distortions will result in short term inefficiency due to suboptimal dispatch and misplaced incentives for long term market decisions. Since our primary goal is to expose a fallacy in the theoretical underpinning of TCCs and their proposed use, we employ simple stylized counterexamples constructed so as to highlight the theoretical flaws of that approach. It is conceivable that the phenomena highlighted by this paper might be diluted and possibly obscured by adding realism and complexity. However, it is out of the scope of this paper to evaluate what works in practice or to determine whether TCCs offer a workable ad-hoc mechanism for transmission capacity trading. Absent theoretical efficiency properties TCCs may have no advantage over simpler ad-hoc transmission pricing schemes such as a postage stamp approach.

The remainder of this paper is organized as follows: In Section two we discuss the use of Cournot models of competition in the context of market power analysis and analyze the strategic implications of a passive congested transmission link separating the supply sources from the demand. In the third section we extend our analysis to Cournot competition in a three node system with two supply nodes and one demand node. The fourth section examines the price distortions and short term efficiency implications of the Cournot equilibrium. In the fifth section we show how active transmission trading can alleviate the economic inefficiencies resulting from passive transmission rights. The sixth section contains a brief perspective on alternative approaches and concluding remarks.

## COURNOT COMPETITION OVER A CONGESTED TRANSMISSION LINK

A common aspect of pool-based market organization paradigms for competitive electricity is the reliance on competitive generation (in conjunction with central control of the transmission system) to achieve an economically efficient outcome. The above design is based on the rationale that competition in generation will drive prices at each location on the network to marginal cost while centralized control of the transmission system could (with proper institutional design) achieve optimal dispatch. The UK system, the generic POOLCO described by Ruff (1994) and the California Power Exchange/ ISO design advocated by Joskow (1996) are all based on the above rationale.

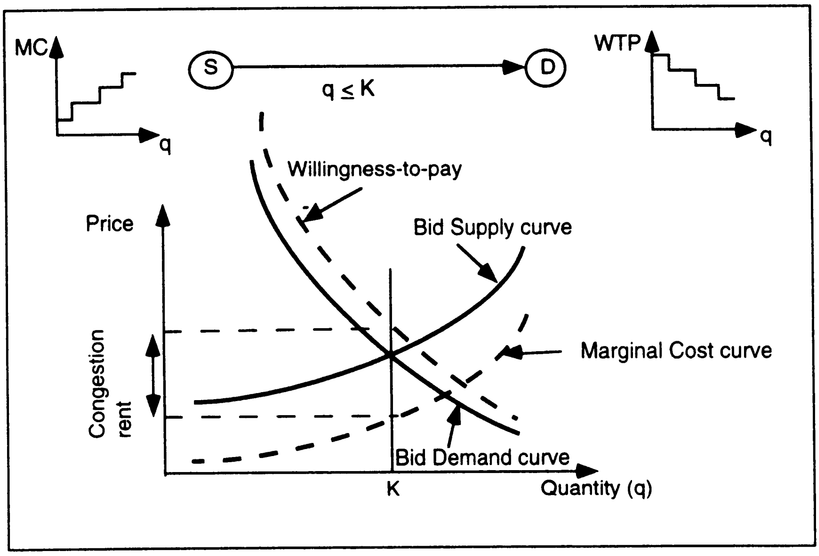
From a theoretical perspective, the assumption that prices will be driven to marginal cost would be supported by a Bertrand competition model. However, empirical evidence from the UK system indicates that electricity spot prices systematically exceed marginal costs (see e.g., Newbery (1996)) suggesting that a Bertrand competition model is unrealistic in this context. Green and Newbery (1992) attribute the high price markup in the UK system to the fact that there are only two generating companies that can exercise market power. They analyze the market power of the duopoly and the potential effect of more competitors using the theoretical framework of supply function equilibria introduced by Klemperer, and Meyer (1989). In a recent empirical study, Wolak and Patrick (1996) demonstrated the effect of rules and market structure on market power in the UK system. These studies, however, do not address effects of locational concentration or transmission constraints.

The possible strategic exploitation of transmission constraints by generators in order to gain market power has been explored by Hogan (1995) who considered possible strategic interactions between a local monopoly generator facing a competitive generation fringe across a congested network. The later analysis has been expanded in a recent report by Cardell, Hitt and Hogan (1996). The effect of transmission constraints on market power has also been examined by Borenstein, Bushnell, Kahn and Stoft (1995, 1996) in the framework of Cournot equilibrium among generators across a congested transmission system.

An implicit assumption in all the models attempting to analyze market power (with or without transmission effects) is that departure from marginal cost pricing is due to some form of general or locational market share concentration. It is implied by the above assumption that in a congested network, elimination of locational market power through diversification of generation ownership at each location would drive prices to marginal cost and achieve economic efficiency. The above implication is reflected in the analysis of horizontal market power for the proposed California electricity market by Joskow, Frame and Hieronymous (1996) which is based on evaluating a market concentration index (HHI) within each congestion zone. This perspective might be rooted in the fact that a simple Cournot oligopoly model produces marginal cost prices when the number of competitors is very large. As we shall demonstrate, however, this conclusion may not be valid when the competitors are separated from the demand by a congested transmission network.

Recent experimental results reported by Backerman, Rassenti and Smith (1996), suggest that factors other than locational market power may cause prices in congested electricity networks to deviate from marginal costs. The paper describes a uniform price double auction experiment conducted at the Economic Science Laboratory at the University of Arizona, with multiple sellers and buyers trading across a constrained passive link (i.e., there are no ex-ante transmission charges or active trading by transmission rights holders). The authors observed that the bidders on both sides will independently adjust their prices so as to capture the congestion rents. Figure 1 illustrates conceptually how the bid supply curve and bid demand curve (in solid lines) can deviate from the corresponding cost and willingness-to-pay functions (in dashed line) so as to capture all the congestion rent. This observation suggests that in a congested electricity network, even in the absence of locational market power, prices may deviate from marginal costs due to implicit collusion among generators (and possibly large consumers) that is induced by the rational expectation of congestion.

**Figure 1. Buyers and Sellers Capture Congestion Rent**




To model this phenomenon, we employ a simple two node system consisting of a supply node and a demand linked by a transmission line with a maximum line flow capacity $K$. The demand node is represented by a down sloping inverse demand function $P(q)$ with price elasticity $\varepsilon(p)$[1], while at the supply node there are $n$ symmetric suppliers with an identical marginal cost $c$. Figure 2 illustrates the model and the demand function $P^*(q)$ as seen at the supply node (whereas $P(q)$ is the demand function at the demand node). Because the line capacity is public knowledge the demand function is seen as becoming inelastic at transmission capacity $K$.

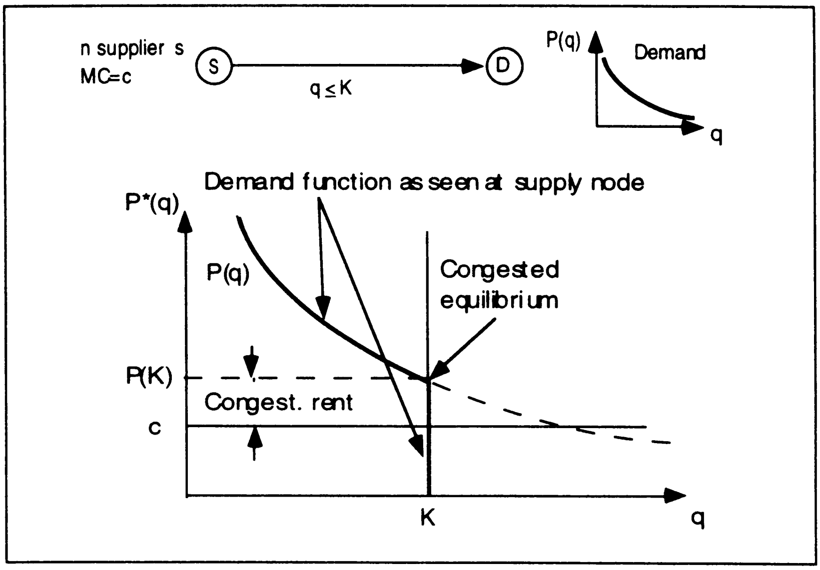
In Cournot competition each supplier $i$ takes the supply quantities $q_j$ of each of its competitors as fixed and sets the market price $p$ by selecting its own quantity $q_i$. Hence the optimization problem defining the best response of supplier $i$ is:

$$\underset{q_i}{Max}\ \pi_i = q_i[P(q_i + \sum_{j \neq i} q_j) - c]$$

$$subject\ to\!:\ 0 \leq q_i \geq K - \sum_{j \neq i} q_j$$

1. $\varepsilon(p) = p/qP'(q)$

**Figure 2. Cournot Competition Over a Congested Supply Channel**




Invoking symmetry in the first order necessary conditions for the above problem and using $Q$ to denote total supply (by all competitors), yields the Cournot equilibrium conditions:

$$Q = K \, and \, \frac{d\pi_i}{dq_i} = p\left(1 + \frac{1}{n\varepsilon(p)}\right) - c \geq 0$$

Or

$$Q < K \, and \, \frac{d\pi_i}{dq_i} = p\left(1 + \frac{1}{n\varepsilon(p)}\right) - c = 0$$

Note that the above conditions do not determine a unique price when the equilibrium is on the vertical segment of the perceived demand function since the above conditions can be satisfied by any pair $(p,Q)$ such that $Q=K$ and $c \leq p \leq P(K)$, assuming $c \leq P(K)$. However, profit maximization by each competitor implies that the equilibrium price corresponding to $Q=K$ must be at its highest possible level $p=P(K)$ regardless of $n$. It thus follows that when the equilibrium is on the downsloping portion of the demand curve, the price decreases as the number of competitors increases until it either drops to marginal cost or to $P(K)$, whichever is larger. The equilibrium price does not decrease further regardless of $n$. Thus for sufficiently large $n$, a congested Cournot equilibrium is at the kink of the effective demand curve, or in general:

$$p = Max[c, P, (K)], q = Min[P^{-1}(c), K] \text{ and } q_i = Q/n \quad \text{for all } i$$

The key implication of the above example is that although none of the generators have market power by any measure of concentration, rational expectation of congestion leads to implicit collusion which leads to pricing at the level that the market will bear for the constrained supply quantity. Consequently, the congestion rents are extracted by the active traders (in this case the generators.) Passive owners of transmission rights in the form of TCCs that are compensated ex-post based on nodal price differences will be disappointed to discover that no rents have been accrued. This conclusion is consistent with Coase Theorem (1960) which supports the argument that in the absence of transaction costs and with public knowledge of transmission capacity, bargaining among buyers and sellers will capture all the congestion rents. Implicit collusion bàsed on rational expectations is a realistic phenomenon in an environment were daily bids are submitted on each day of the year. As demonstrated by the evolution of the supply curves in the UK (see Newbery (1995)) the repetitive nature of power auctions allows learning-by-doing and refinement of the bidding strategies so as to exploit market power or other rent extraction opportunities.

The above analysis suggests the crucial role of active trading by transmission rights owners vs. ex-post collection of residual rents from the competitive generation market. Active trading of transmission rights can take place in parallel with energy trading in a decentralized market framework as described by Chao and Peck (1996), or through any ex-ante settlement such as a set fee or prenegotiated price. It is the separation of the transmission ownership from the generation ownership in conjunction with the ex-post settlement aspect of TCCs that allows their preemption by the generation owners.

In the two node example described in this section, no short term efficiency loss arises from overpricing of generation. The only short term distortion is a redistribution of rents among the stakeholders. In the long run, however, the price distortion will misplace generation investment incentives by encouraging more generation at the supply node. Furthermore, the preemption of TCC value by generators creates a free rider effect with respect to transmission investment rewarded with TCCs (as proposed by Bushnell and Stoft (1995)). While both generators and consumers could benefit from expanding the transmission line by increasing sales or reducing prices, the free rider effect dilutes the incentives for such investments. A stakeholder making such an investment unilaterally can only capture a proportional share of the benefit through use of the transmission line while additional property rights in the form of TCCs whose remuneration are determined ex-post by the ISO are virtually worthless.

In a more complicated system passive transmission ownership can also lead to short term inefficiency, as will be demonstrated in the subsequent sections.

## COURNOT EQUILIBRIUM IN A CONGESTED THREE-NODE NETWORK

In this section we consider a three node case as illustrated in Figure 3. The model consists of one consumption node, represented by an inverse demand function $P(q)$, and two supply nodes: Node 1 (CHEAPGEN) where there are $n_1$ symmetric generators with marginal cost $c_1$ and Node 2 (DEARGEN) where there are $n_2$ symmetric generators with marginal cost $c_2$ (we assume $c_1 < c_2$). For simplicity we assume a lossless DC network with equal impedance on all lines and a lineflow limit of $K$ on the link connecting the two generation nodes. Because of the cost symmetry at each supply node we may assume that in equilibrium there will be a single bid price at each node, $p_1$ and $p_2$ respectively, where $p_1 \leq p_2$.

Given the prices bid at each node and the publicly known demand function, the ISO determines the optimal dispatch, i.e., the total injection at each of the supply nodes, so as to maximize the bid-based social surplus estimate subject to the transmission constraints. Hence, in equilibrium the ISO's optimization problem for this example is:

$$\underset{Q_1,Q_2}{Max}\int_0^{Q_1+Q_2} P(q)dq - p_1Q_1 - p_2Q_2 \text{ (Social surplus estimate)}$$

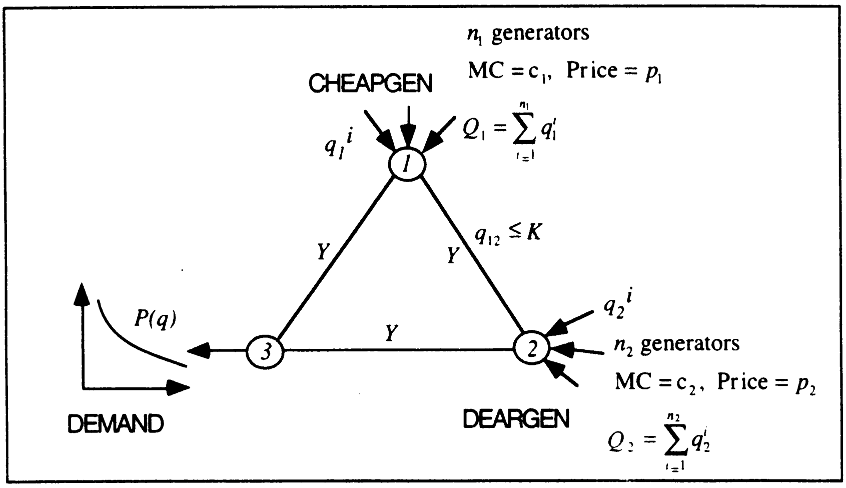
$$\textit{Subject to: } Q_1 - Q_2 \leq 3K \text{ (Kirchoff law)}$$

$$Q_1 \geq Q_2 \geq 0 \text{ (Equilibrium condition)}$$

The solution to the ISO problem determines the price and quantity at the demand node:

$$Q_3 = Q_1 + Q_2 \text{ and } p_3 = P(Q_3)$$

**Figure 3. Competition in a Three Node Network**




The optimal dispatch solution takes on two possible forms depending on whether power is or is not generated at DEARGEN (this will depend on the relationships between the various problem parameters).

Case I (no power from DEARGEN):

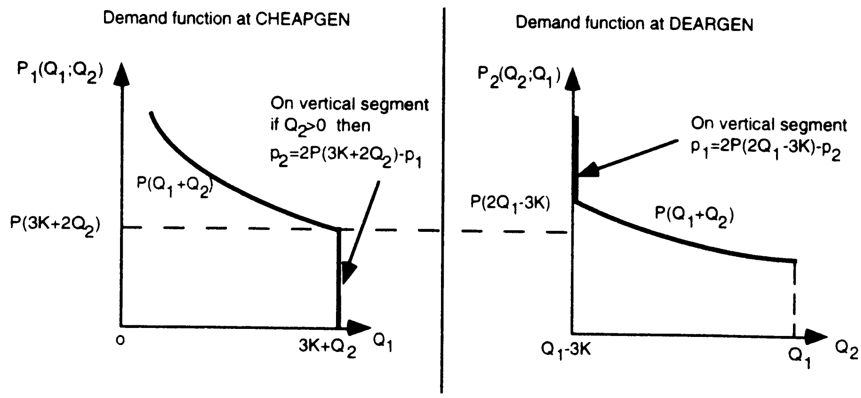
$$Q_2 = 0$$
$$Q_1 = P^{-1}(p_1) < 3K \text{ and } p_3 = p_1$$
$$\text{or } Q_3 = 3K \text{ and } p_3 = P(3K) \geq p_1$$

Case II (Both nodes generate)

$$Q_2 > 0$$
$$p_3 = p_1 = p_2, Q_1 + Q_2 = P^{-1}(p_3), Q_1 - Q_2 \leq 3K$$
$$\text{or } p_3 = \frac{(p_1 + p_2)}{2}, Q_1 = \frac{[P^{-1}(p_3) + 3K]}{2}, Q_2 = \frac{[P^{-1}(p_3) - 3K]}{2}$$

Note that for this example, under optimal dispatch, both nodes will supply power simultaneously only if the bid prices are equal or if the network is congested (it is possible, however, to have congestion with only the cheaper node generating). Furthermore, when both supply nodes generate, the selling price at Node 3 (under optimal dispatch) is the average of the bid prices at DEARGEN and CHEAPGEN. The ISO's behavior is public knowledge and can be taken into consideration by the competitors at each node. Thus, we can derive an effective demand function at each of the supply nodes conditioned on the total injection at the other supply node as illustrated in Figure 4.

**Figure 4. Conditional Demand Functions at Supply Nodes**




The conditioning of each demand function on the injection at the other supply node is consistent with the conjectural variation of Cournot competition. Accordingly each competitor selects its supply quantity and sets market prices so as to maximize its profit taking as given the quantities of all other suppliers (at its own node as well as the other node). The ISO's response is accounted for in the nodal demand function shown above. On the down sloping segments of the demand curves (where there is no congestion), selection of quantities by a competitor sets the uniform market price at all nodes. On the vertical segments of the demand function (congestion case) prices at the two supply node may diverge but the average price of the two supply nodes sets the price at the demand node (through the optimal dispatch by ISO).

In deriving an equilibrium for this three node system we need again to differentiate between the case where only CHEAPGEN generates power and the case where both nodes generate. This depends on the relationship between the demand function and the marginal prices at the two supply nodes. When no power is generated at DEARGEN the demand function seen at CHEAPGEN is the same as in the two node case but with total flow capacity of $3K$. Hence, the corresponding symmetric equilibrium can be obtained from the results of the two node case using a line capacity of $3K$ instead of $K$. For a sufficiently large $n_1$ the equilibrium is given by:

$$p_l = Max[c_1, P(3K)],\ Q_1 = Min[P^{-1}(c_1), 3K],\ q_1^i = \frac{Q_1}{n_1} \text{ for all } i$$

Next we consider the case where the two supply nodes generate. First let us consider the possibility of having an uncongested equilibrium on the down sloping segments of the two demand functions shown in Figure 4. This would require that the bid prices at both supply nodes are equal. Such an equilibrium price $p$ would have to satisfy the two simultaneous equations:

$$p\left(1 + \frac{1}{n_1 \varepsilon(p)}\right) - c_1 = 0 \text{ and } p\left(1 + \frac{1}{n_2 \varepsilon(p)}\right) - c_2 = 0$$

For a sufficiently large number of competitors at both nodes, as the equilibrium price approaches marginal cost, these equations become inconsistent (due to the marginal costs differences). Hence, such an equilibrium can be ruled out for a sufficiently large number of generators at both supply nodes.

It remains to consider only congested equilibria which correspond to the vertical segments of the effective demand functions. We argue that for a sufficiently large number of generators at both supply nodes the only possible Nash equilibrium is at the kinks of both demand curves, where $Q_1 - Q_2 = 3K$.

For CHEAPGEN we may use the best response argument made for the two node case to prove that for a sufficiently large number of suppliers the local Cournot equilibrium (conditional on $Q_2$) is at the kink. Competitors at DEARGEN would prefer a higher price on the vertical segment of their demand function (above the kink) which would correspond to a lower price at CHEAPGEN. However, such prices would not support a Nash equilibrium since any generator at CHEAPGEN can unilaterally (and profitably) force the equilibrium price to be at the kink (without affecting any of the other supply quantities) by slightly "backing off" from the vertical segment of the demand function. It follows that the only possible congested Cournot-Nash equilibrium with generation at both supply nodes is at the kinks of the demand function shown in Figure 4, i.e.,

$$p_1 = P(2Q_2 + 3K) \text{ and } p_2 = P(2Q_1 - 3K)$$

Furthermore, since under Cournot competition, each competitor acts as a unilateral price setter (no side payments are allowed) the prices at each supply node are bounded below by the corresponding marginal costs. However, congestion implies that: $Q_1 - Q_2 = 3K$ and consequently the congested equilibrium satisfies

$$p_1 = p_2 = p_3 = P(2Q_1 - 3K) = P(2Q_2 + 3K) \geq c_2 \geq c_1$$

Suppose, that $P(2Q_1 - 3K) > c_2$, then for large $n_2$, $p_2 \rightarrow c_2$ which would imply that $Q_2 > Q_1 - 3K$, thus contradicting the congestion hypothesis. Consequently, a limiting congested equilibrium (for sufficiently large number of generators at each node) must satisfy the necessary conditions:

$$p_1 = p_2 = p_3 = c_2,\ Q_1 - Q_2 = 3K,\ Q_1 + Q_2 = P^{-1}(c_2)$$

The proof that these conditions indeed define a Cournot-Nash equilibrium follows from the fact that no competitor can increase its profits unilaterally given that everyone else holds their quantities fixed.

We can now summarize the three possible limiting Cournot equilibria (for large number of competitors at each of the supply nodes) which depend on the relationship between the demand function and the marginal generation costs:

$$i)\quad P(3K) \leq c_1 \rightarrow Q_2 = 0,\ Q_1 = P^{-1}(c_1),\ p_3 = p_1 = c_1$$

$$ii)\ c_1 \leq P(3K) \leq c_2 \rightarrow Q_2 = 0,\ Q_1 = 3K,\ p_3 = p_1 = P(3K)$$

$$iii)\ c_2 \leq P(3K) \quad \rightarrow Q_2 = \frac{[P^{-1}(c_2) - 3K]}{2},\ Q_1 = \frac{[P^{-1}(c_2) + 3K]}{2},\ p_3 = p_1 = p_2 = c_2$$

As in the two node case none of these equilibria produce residual congestion rents to be paid to TCC holders. All such rents in this case are captured by the CHEAPGEN generators through implicit collusion. In case i) there is no congestion, There is no generation at DEARGEN and competition drives bid prices at CHEAPGEN to marginal cost. In case ii) there is congestion but DEARGEN does not generate and the bid price at CHEAPGEN equals the market price at the demand node which is between the marginal costs at the two supply nodes. In this case the congestion rent which totals $3K \cdot [P(3K) - c_1]$ is captured as profits by the CHEAPGEN suppliers. In Case iii) There is congestion and both supply nodes are generating. The equilibrium price at all nodes equals the marginal cost at DEARGEN and the congestion rent which is captured as profit by the CHEAPGEN suppliers equals $(c_2 - c_1) \cdot [P^{-1}(c_2) + 3K]$.

## SHORT TERM EFFICIENCY LOSSES

Unlike in the two node case, the Cournot equilibrium derived above for three nodes may correspond to an inefficient dispatch. The efficient dispatch is given by the ISO optimal dispatch solution corresponding to bid prices that equal marginal cost. Thus, the different efficient dispatch cases obtained by substituting $p_1 = c_1$ and $p_2 = c_2$ in the ISO problem are:

$$i)\qquad P(3K) \le c_1 \rightarrow p_3 = c_1,\ Q_2 = 0,\ Q_1 = P^{-1}(c_1)$$

$$ii)\ c_1 \le P(3K) \le \frac{c_1 + c_2}{2} \rightarrow p_3 = P(3K),\ Q_2 = 0,\ Q_1 = 3K$$

$$iii)\ \frac{c_1 + c_2}{2} \le P(3K) \rightarrow p_3 = p_1 = p_2 = \frac{c_1 + c_2}{2},\ Q_2 = \frac{[P^{-1}(\frac{c_1 + c_2}{2}) - 3K]}{2},\ Q_1 = \frac{[P^{-1}(\frac{c_1 + c_2}{2}) + 3K]}{2}$$

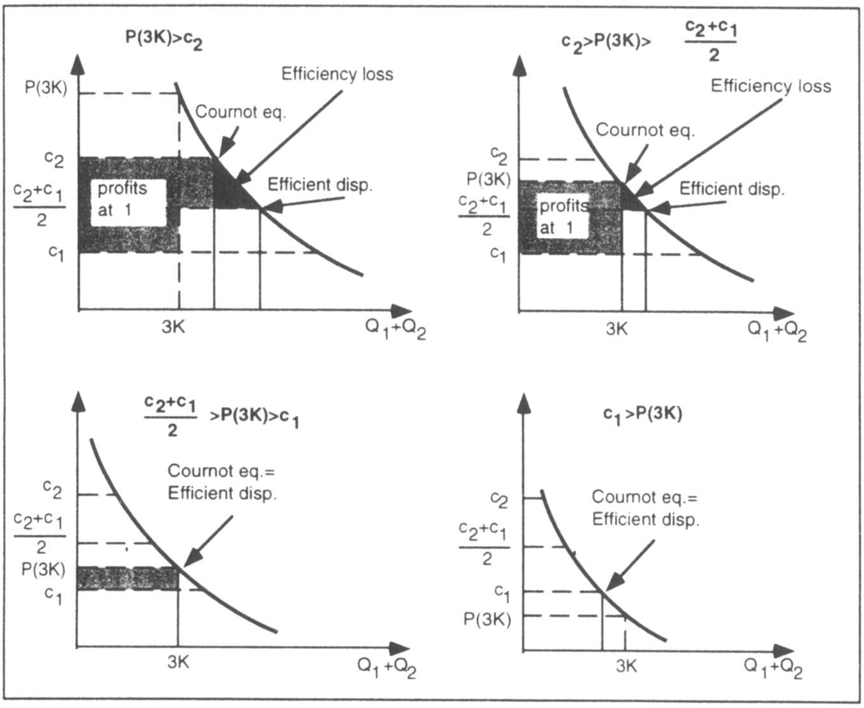
Figure 5 compares the Cournot equilibrium with the socially efficient dispatch for the different cases arising from the relationship between the demand function and the marginal costs at the two supply nodes. The black areas indicate the efficiency losses due to price distortion in the equilibrium solution and the gray area marks the rents captured by the CHEAPGEN suppliers.

In the two bottom cases of Figure 5 there is no efficiency loss but the congestion rents are captured by the CHEAPGEN suppliers. In the two upper cases, however, the Cournot equilibrium results in a deadweight loss which cannot be avoided through a unilateral response at either of the supply nodes. At CHEAPGEN, while generators could benefit from increasing their generation, they are prevented from doing so by the congestion constraints while at DEARGEN, a unilateral increase in generation would reduce the price below the marginal cost at that node.

## REVISITING THE THREE-NODE EXAMPLE WITH ACTIVE TRANSMISSION RIGHTS

In the previous section we illustrated the potential inefficiency in the energy market due to passive transmission rights whose market value is determined post dispatch. One can think of several ways of implementing active transmission rights which would allow their owners to collect rents. However,

**Figure 5. Efficiency Loss and Suppliers Profits at Cournot Equilibrium**




simple approaches that come to mind such as a preset postage stamp transmission tariff are unlikely to induce efficient dispatch. A more elaborate market mechanism with attractive theoretical properties has been recently proposed by Chao and Peck (1996) in which energy and transmission capacity rights are traded simultaneously in parallel markets. We will adopt a simplified variant of the above mechanism (assuming a DC model with no losses) to illustrate how active trading of transmission capacity rights may alleviate the short term economic inefficiency of the Cournot equilibrium in our three node example.

In the Chao-Peck mechanism, the ISO sets trading rules (based on power flow analysis) in the form of a matrix of credits and debits of directional transmission capacity permits on every network link corresponding to injection (or ejection) from any node to (or from) a reference node. With no losses, each unit injected at a particular node requires capacity permits for the flow it induces on each link and is credited with a matching number of permits in the opposite direction (to its induced flow) for the counterflow it enables. Link owners receive permits in the amount of the link capacity in both directions.

Transmission permits are traded competitively so only the scarce permits for congested links (in the direction of the net flow) will realize a significant positive price.

In our three node example (Figure 3) we will use the demand node as the reference node. Hence, according to Kirchoff's law, a 1 MW injected at Node 1 requires a 1/3 MW transmission permit from Node 1 to Node 2 and from Node 2 to Node 3 and a 2/3 MW permit from Node 1 to Node 3. Similarly a 1 MW injected at Node 2 requires a 1/3 MW permit from Node 2 to Node 1 and from Node 1 to Node 3 and a 2/3 MW permit from Node 2 to Node 3. Each MW injected at Nodes 1 or 2 receive matching permits for the counterflow it enables. For example 1 MW injected at Node 2 is credited with a 1/3 MW permit from Node 3 to 1 and from Node 1 to 2 and a 2/3 MW from Node 3 to 2.

In our variant of the Chao-Peck mechanism we will assume that the energy market is still being managed by the ISO who dispatches the generators optimally based on their bid prices with the added provision that any injection must comply with the trading rules specified above regarding transmission capacity rights.[2] Consequently, in submitting a bid, a generator will take into consideration the incremental cost (or revenue) for transmission permits used or generated by the injection. These permits must be acquired or sold in the parallel transmission permits market.

We will consider here only the case where the demand function satisfies $P(3K) > c_2$. For this case we have shown that the Cournot equilibrium with passive transmission rights is inefficient. Furthermore, both the efficient dispatch and the Cournot equilibrium involve generation at both supply nodes and congestion on the link from Node 1 to Node 2. Competition in the permits market will drive permit prices to zero on all uncongested links. Hence, when only the link from CHEAPGEN to DEARGEN is congested, generators at CHEAPGEN need to buy 1/3 MW permit on that link for every MW generated while generators at DEARGEN can sell 1/3 MW permit on that link for every MW generated. The total number of permits purchased is therefore, $Q_1/3$ which equals $K+Q_2/3$, the number of permits owned by the original capacity owners plus the permits acquired by the DEARGEN generators for counterflow generation.

2. According to Chao and Peck (1996), enforcement of the trading rules by the ISO and the presence of a parallel market in transmission permits will ensure an optimal dispatch equilibrium in the energy market without further intervention by the ISO (e.g., through bilateral trading). Assuming an ISO managed auction with optimal dispatch based on bid prices might be an unnecessary restriction on the energy market operation in this framework. We introduce this restriction only for analytical convenience as it allows us to use the Cournot equilibrium results from the previous sections in demonstrating the effect of active transmission rights trading.

Suppose that the market price of a 1 MW transmission permit from Node 1 to 2 is $r$ then the effective marginal cost per MW of energy sold at DEARGEN is $c_2 - r/3$ while the effective marginal cost at CHEAPGEN becomes $c_1 + r/3$. For $0 \leq r < 3(c_2-c_1)/2$ the effective marginal cost at CHEAPGEN is lower than the effective marginal cost at DEARGEN. Furthermore, $P(3K) > c_2 - r/3$. Thus, according to the analysis in the third section (which is still valid) the limiting Cournot equilibrium for the energy market (i.e., for large number of generators at both supply nodes) is defined by:

$$Q_2 = \frac{[P^{-1}(c_2 - \frac{r}{3}) - 3K]}{2}, Q_1 = \frac{[P^{-1}(c_2 - \frac{r}{3}) + 3K]}{2}, p_3 = p_1 = p_2 = c_2 - \frac{r}{3}$$

The corresponding number of transmission capacity permits $T_{12}$ from node 1 to 2 traded in the transmission capacity market is:

$$T_{12}(r) = \frac{Q_1}{3} = \frac{[P^{-1}(c_2 - \frac{r}{3}) + 3K]}{6}$$

Since the inverse demand function is downward sloping, $T_{12}(r)$ is increasing in $r$ over the range $0 \leq r < 3(c_2-c_1)/2$. This increase occurs due to the fact that over the affformentioned price range demand for transmission capacity exceeds the supply and, therefore, the number of permits traded track the supply curve. Consequently, it is possible for a Cournot competitor in the energy market at DEARGEN to unilaterally increase its output and offset the resulting drop in energy price by bidding up the price of the byproduct transmission permit it receives. The demand for permits by CHEAPGEN producers will support such a price increase and will hence drive up the permit prices up to the point where the effective marginal costs at both supply nodes are equalized. When the effective marginal costs at both supply nodes are equal, the Cournot equilibrium in the energy market is not unique with respect to injection quantities. However, among all possible equilibria corresponding to equal effective marginal costs, there is a unique one in which the link from Node 1 to Node 2 is congested. Without congestion on that link the market for transmission permits will not support the permit prices needed to equalize the effective marginal costs and hence an uncongested equilibrium with equal effective marginal costs at both supply nodes is impossible.

It follows that a simultaneous limiting Cournot equilibrium in the energy market and in the transmission permits market must be such that the effective marginal costs for energy sold at both supply nodes are equal and the link from CHEAPGEN to DEARGEN is congested. This implies a unique equilibrium solution where:

$$r=\frac{3(c_2-c_1)}{2}, p_3=p_1=p_2=\frac{c_1+c_2}{2}, Q_2=\frac{[P^{-1}(\frac{c_1+c_2}{2})-3K]}{2}, Q_1=\frac{[P^{-1}(\frac{c_1+c_2}{2})+3K]}{2}$$

The injections at the supply nodes as well as the price and consumption quantity at the demand node in the above equilibrium are identical to the optimal dispatch solution. Furthermore, the total congestion rent of $3K(c_2-c_1)/2$ is collected by owners of the congested link who sell their $K$ capacity units (with no ISO intervention) at the equilibrium rate of $r=3(c_2-c_1)/2$. The equilibrium marginal revenue for energy, net of transmission cost or income at each supply node, equals the corresponding marginal energy cost.

## CONCLUSION

Externalities resulting from the physical laws governing the flow of electricity make transmission capacity an essential input factor or a by product of generation in the provision of electric power in an interconnected grid. The Federal Energy Regulatory Commission has recognized the crucial role of transmission service in the provision of competitive electricity and established guidelines for defining and trading that input factor. Some current proposals claim, however, that an explicit transmission service market is unnecessary and efficient transmission trading can be achieved indirectly in a pool framework through a competitive generation market and optimal dispatch by an ISO. This assertion is based on the premise that competitive generation can drive generation prices to marginal costs and any departure from marginal cost bidding is attributable to market power.

In this paper we demonstrated the importance of active participation of transmission rights owners in the market in order to achieve the desired efficient outcome of competition. Through simple stylized examples it was shown that even in the absence of market concentration, the expectation of congestion and passive transmission rights can lead to implicit collusion among generators and departure from marginal cost pricing. This invalidates the key premise underlying the indirect implementation of transmission rights trading through optimal dispatch by the ISO. We show that passive transmission rights (in the form of TCCs) will be preempted by the active traders who will adjust their prices so as to capture the congestion rents. Price distortions due to congestion and passive transmission ownership can result in short and long term inefficiency.

We have demonstrated that short term efficiency losses resulting from price distortion, may be mitigated by market mechanisms that would allow side payments among generators. The Chao and Peck (1996, 1997) approach provides such a mechanism through parallel pre-dispatch markets for transmission rights and energy forwards administered through a power exchange.[3] A key feature is that through active market trading, the owners of rights on congested links can capture rents on these links, and a set of efficient prices will emerge to guide investment in future transmission capacity. Furthermore, a generator creating counterflow on a congested link is entitled to the rights of the relieved congestion, which can be sold in the transmission rights market. This creates the mechanism for side payments that are needed to move the Cournot equilibrium to the socially efficient dispatch.

In our particular three node example, we have demonstrated how generators at DEARGEN can subsidize their sales of power below marginal cost by selling their counterflow rights on the congested link to generators at CHEAPGEN. With sufficiently competitive generation at each node such trading results in an efficient market equilibrium. In this framework TCCs can serve as valuable hedging instruments whose prices will be determined (correctly) by the active transmission rights market rather than being priced as derivatives of the energy market.

It should also be noted that short term efficiency losses resulting from passive transmission rights can be, alternatively, mitigated through direct negotiation among the generators (possibly facilitated by brokers) that will result in incremental "congestion neutral" profitable transactions. Such a scheme has been described by Wu and Varaiya (1995) who advocate a "minimal" ISO that manages congestion by enforcing feasibility of the proposed generation schedules and who provides coordinating information on feasible incremental multilateral transactions. However, while such an approach could potentially eliminate the deadweight loss, it does not deal with transmission pricing and ownership compensation.

In summary, the analysis presented in this paper offers an explanation for the recent experimental results with trading over passive congested links. The stylized examples are intended as counterexamples that expose a fundamental flaw in the theoretical argument advocating the use of TCCs as means for implementing FERC policy rulings regarding transmission capacity reservations trading. Even with a three node system there are many ways of organizing supply and demand and many questions that were not addressed by our analysis. For example, local demand at the cheap generation node may

3. After the market concludes, the system operator performs the actual dispatch to implement these contracts and to ensure the security of the system. The differences between the actual dispatch and the forward contracts will be reconciled subsequently in a settlement procedure.

intensify local competition and drive prices down at that node. Furthermore, bids in the form of supply functions over multiple time periods which include congested and uncongested periods will also reduce the implicit collusion effect. We have not examined the effect of asymmetry in generation costs at a particular node and the effect of demand side bidding. It should be noted, however, that the experiments at the University of Arizona ESL which revealed the capture of congestion rents by the trading parties, included supply and demand side bidding of multiple blocks with different marginal costs and values (but with no loop flow effects.)

The main objective of this paper was to raise questions and challenge some premises underlying important policy recommendations that are not fully supported by either theory or empirical evidence. From a theoretical standpoint one counterexample is sufficient to disprove a theory and we have done so. From a practical perspective, the issues we have raised may not be fatal in a realistic system. However, considering the high stakes involving the policy decisions in this area, further experimental economic studies are needed to evaluate the performance of alternative market mechanisms. Hopefully this work will also stimulate fundamental research on oligopolistic competition and competitive bidding in congestion prone distribution networks.

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