

Transmission Rights and Market Power on Electric Power Networks I: Financial Rights*

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1 Introduction

In many countries, infrastructure sectors that have historically been vertically integrated natural monopolies subject to public regulation, such as electric power, railroads, and natural gas production and distribution, are being restructured. Most restructuring programs distinguish between potentially competitive sectors (e.g. electricity generation, railroad rolling stock, and natural gas production), where prices and entry will be deregulated, and natural monopoly or “network infrastructure” segments (e.g. electric transmission networks, railroad track and terminal networks, and natural gas pipeline and distribution networks) which continue to be subject to some form of public control of prices, entry, and service quality. Importantly, suppliers in the competitive segments require access to the network infrastructure segments in order to supply their services to consumers in competition with their rivals.

The demand for utilization of infrastructure networks often varies widely from hour to hour, day to day and month to month. During some time periods, one or more points or “interfaces” on the network can become congested as suppliers’ demand to use the interface would exceed its capacity if the price for using the interface were zero. The competitive market value of the output of the suppliers in the competitive segments depends on where the suppliers

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are located and whether they must “transport” their products over congested portions of the network. In general, market prices for the competitively supplied services will be higher on the side of the network constraint which is a net importer of competitive services (“the high side”) than on the side of the network constraint which is a net exporter of services supplied by the competitive segments of the industry (“the low side”). Prices for and the profitability of services supplied by the competitive segment can vary widely over time and across locations on the network as supply and demand conditions fluctuate. Network congestion can affect the attributes of the distribution of prices and profits at different locations. The associated variations in prices create a demand by risk averse buyers and sellers for instruments to hedge price fluctuations.¹ These prices also provide the economic signals that should guide investment in additional infrastructure capacity. We do not discuss investment issues in this paper, but focus on networks with fixed capital (capacity) stocks.

In order to facilitate efficient utilization of scarce network interface capacity a mechanism must be implemented to ration the use of the congested network efficiently. Market mechanisms that rely on “congestion prices” to ration the use of scarce network capacity are generally favored over administrative rationing mechanisms. The development of mechanisms to determine efficient network congestion prices is complicated by several important factors. First, the operator/owner of the network is a monopoly and cannot be relied upon itself either to set the right prices or to make the right level of investments if it is unregulated. Accordingly, if the operator/owner of the network is to be relied upon to set the right congestion prices and to make the right network investments, the design of the regulatory mechanisms applied to the network operator are critical to its performance. Asymmetric information necessarily limits the ability of regulators both to provide incentives for the network operator to make efficient pricing and investment decisions and to keep the network operator from extracting rents from network users. Second, supply and demand conditions on the network vary widely and rapidly over time. The appropriate market clearing prices to manage congestion also vary widely and

¹A form of risk aversion is generated by firms’ need to insure against liquidity shocks when financial markets are plagued by agency problems and credit rationing. See Holmström-Tirole (1998). In the U. S., electricity marketers and unregulated generators have aggressively promoted the need for “firm transmission rights” that will allow them to insure themselves against the costs of network congestion.

rapidly along with these changing supply and demand conditions. Third, the configurations of most infrastructure networks create potential network externality problems. That is, utilization decisions at one point on the network affect supply conditions and congestion on other points on the network.

An increasingly popular approach to the challenges associated with allocating efficiently congested network interfaces and to creating hedging instruments related to fluctuations in congestion prices is to decentralize congestion pricing by creating and allocating some form of tradable *property rights* which give a holder either a physical right to use the congested interfaces or a financial right to be compensated for congestion charges assessed to allocate their use.² In the case of an electric power network, which is the focus of this paper, the two types of tradable property rights are being discussed. The first approach is to create and allocate “physical rights” to use the network. Under this approach, the capacity of each of the potentially congested interfaces is defined and rights to use this capacity are created and allocated in some way to suppliers and consumers. A supplier must possess a physical right to have its supplies scheduled or “transported” over the congested interface. Once it has such a physical right, there is no additional charge for using the congested interface. The markets for these physical rights then determine the market clearing price for congestion. Increases in the capacity of congested interfaces resulting from new investments, also create new physical rights to use this capacity and these rights may be sold by the investors who add the network capacity to third parties.³

²Historically in the U.S., vertically integrated utilities had “physical” transmission rights reflecting their ownership of transmission assets that were components of congested interfaces and interface capacity ratings assigned to these interfaces by regional reliability councils (Joskow-Schmalensee 1983). The allocation and use of physical rights under this system relied on a “contract path” model that ignored loop flow problems. These rights were used by vertically integrated utilities primarily to support their own wholesale purchases and sales of electricity. Regulators could not force them to sell these rights to third parties. If they did sell these transmission rights, prices were capped on the average accounting cost of the transmission lines they owned. The Energy Policy Act of 1992 expanded federal authority to require utilities to sell unused physical transmission capacity to third parties. The standard terms and conditions for making these rights available are defined in Federal Energy Regulatory Commission Orders 888, 888a, 888b, and 889. These orders also are built on a physical rights/contract path model. However, restructured electric power sectors in California, Pennsylvania-New Jersey-Maryland (PJM) and New York are built around “network” models, and tradable “financial rights” rather than physical rights are being proposed as the instrument for providing “firm transmission service.”

³The transportation of natural gas by interstate pipeline systems in the U.S. relies on a “point to point” physical rights system. These rights may be traded, but at the present time the prices at which they can be

An alternative approach is to create and allocate “financial rights” associated with each congested interface (or a portfolio of congested interfaces).⁴ Under the ideal market structure for utilizing the financial rights approach, buyers and sellers submit bids to the network operator to buy and sell power at different locations (“nodes”) on the network. The network operator then chooses the lowest cost bids to balance electricity supply and demand subject to the physical laws that govern electric power networks and the capacity of the network to carry power reliably. The bid price of the last bidder selected (or the first bidder rejected) at a node becomes the market clearing price at this node. So, an upstream supplier which is delivering competitive electric generation services to customers downstream of the congested interface receives a lower net price than do suppliers located downstream in proximity to consumers. The difference between the downstream price and the upstream price is the congestion price. Those who have obtained financial rights over the congested interface receive a share of the congestion revenues proportionate to the share of the total interface capacity each rights holder has covered by financial rights. So, if a generator upstream of the congested interface has covered all of its deliveries by acquiring financial rights it is in the same position (ignoring the sunk costs of acquiring the rights) as a similarly situated generator who is a physical rights holder and has acquired rights to just enough capacity to cover its deliveries, other things equal. The financial or physical rights fully insulate the upstream supplier from making any net congestion payments for the quantity “exported” that it has covered by acquiring a right.

The actual organization of restructured electricity markets around the world often differs from this idealized structure. For example, while the system in England and Wales relies on a bid-based system for determining energy prices, it does not provide directly for nodal pricing of energy to reflect congestion (or losses). Argentina has adopted a framework closer to the

traded are subject to a cost-based cap specified by the U.S. Federal Energy Regulatory Commission (“FERC”). When congestion costs are high, these caps prevent the secondary rights market from allocating these physical rights efficiently. Gas transporters appear to be able effectively to evade these caps by buying gas on one side of a congested pipeline segment and then reselling it on the other side of the congested segment since the price of gas is unregulated. See U.S. Energy Information Administration, *Natural Gas 1996: Issues and Trends*, DOE/EIA-0560(96), December 1996, Washington, D.C.; U.S. Federal Energy Regulatory Commission, Notice of Proposed Rulemaking, *Regulation of Short-term Natural Gas Transportation Services*, July 29, 1998.

⁴The Independent System Operators (ISO) in California and PJM have proposed to U.S. federal energy regulators (FERC) the use of financial rights rather than physical rights. See also Harvey et al. (1996) and Chao-Peck (1996).

idealized model, but recognizes a limited number of potentially congested interfaces for nodal pricing purposes. The system being implemented in PJM is built around a bid-based nodal pricing and dispatch model, but generators are also allowed to enter into individual bilateral contracts with buyers and simply schedule their generation with the ISO without going through the bidding and dispatch process. Schedules pursuant to bilateral contracts are then assessed a congestion charge based on the difference between the nodal prices at the supply and demand nodes specified in the bilateral contract and based on the clearing prices resulting from the bidding and dispatch process.⁵ California and New York also have a mixture of a bid-based dispatch and pricing framework and a bilateral contract or self-scheduling framework with separate congestion charges assessed for schedules across congested interfaces.

It is not our objective here to discuss the full set of reasons why a physical rights mechanism might be preferred to a financial rights mechanism or vice versa. The relevant considerations include the transactions costs associated with using, trading and enforcing the different types of rights to facilitate efficient supply of the competitive service given network constraints, the need to adjust the supply of rights to reflect rapid changes in the quantity of network capacity actually available at any particular point in time, market power in both the rights market and the energy market, and other considerations. We focus here on (a) how the allocation of financial rights may affect competition or enhance seller and buyer market power in the markets for electric generation when a transmission network is congested and (b) how rights markets with different microstructures allocate financial rights among generators and consumers and determine rights prices. In a companion paper [Joskow-Tirole 1998] we perform a symmetrical analysis of physical rights and compare the properties of physical and financial rights under different market conditions.

Much of the analysis in these papers examines a simple two-node network, so that the broader set of transactions cost and institutional issues that may distinguish the performance of financial and physical rights systems can be ignored. This enables us to focus on market power issues related to financial and physical transmission rights. However, we also provide

⁵Thus, while PJM involves a mix of bid-based dispatch and bilateral contracts, physical and financial rights do not coexist. The bilateral contracts are just akin to a pair of inelastic bids at the two corresponding nodes.

a brief analysis of a three-node network which allows us to examine whether and how the introduction of the kind of “loop flows” that characterize many electric power networks affects our results. We find that our results vis-à-vis the relationships between the allocation of rights and market power are robust to loop flow considerations, although loop flow introduces some interesting twists to the analysis.

We show that who owns the firm transmission rights (financial or physical) is endogenous, as are the effects of the availability of transmission rights on market power. Buyers and sellers at different locations (nodes) on the network compete for these rights, which cannot a priori be assumed to belong to a particular player. The willingnesses to pay of different players depends on their locations on the network and whether or not they have market power. However, who acquires the rights depends not only on willingness to pay for the rights, but also on the microstructure of the markets in which rights are traded.

We find that allocating financial rights to a generator with market power located in the importing region enhances its market power. The more rights that the generator with market power in the importing region is allocated, the more its market power is enhanced and the higher is the delivered price of energy paid by consumers. The number of rights that will be allocated to the generator with market power depends on the microstructure of the market for financial rights. In particular, it depends on whether the rights market is organized in a way that mitigates free riding by others on the increased congestion rents that a generator with market power can earn by increasing energy prices in the importing region to levels above their “no rights” level. Allocating rights to a generator with market power in the exporting region does not enhance its market power or affect delivered prices paid by consumers. This is the case because a generator with market power in the exporting region can already capture the scarcity rents associated with transmission congestion. Indeed, the presence of a generator with market power in the exporting region mitigates the market power enhancing effects of financial rights allocated to a generator with market power in the importing region.

We also find that financial rights can affect the behavior of electricity consumers as well. Financial rights allocated to a buyer of energy with market power (a monopsony) located in the

importing region will reduce the buyer's incentives to exercise such market power. On the other hand, allocating financial rights to a monopsony buyer of energy located in the exporting region would enhance its market power. The ultimate allocation of rights continues to depend on the microstructure of the rights market and the relative valuations of the rights by generators and consumers with market power energy market.

The paper proceeds as follows. Section 2 specifies the attributes of the simple two-node network and derives the competitive equilibrium prices, quantities and the ISO's (Independent System Operator) merchandising surplus in the absence of financial rights. Sections 3 and 4 examine how the allocation of financial rights (ignoring the cost of buying these rights) affects the behavior of suppliers and consumers at different locations when they have seller or buyer market power. This analysis takes place in the context of three different microstructures for the markets for financial and how they affect the allocation to different stakeholders and the market prices for the rights. Section 5 discusses regulatory issues and challenges that arise regarding the interaction between the allocation of financial and market power. Section 6 generalizes the analysis to allow for loop flow problems. Section 7 concludes with a summary of the main policy implications. Our companion paper conducts a symmetrical analysis for physical transmission rights, highlighting differences between financial rights and physical rights.

2 A simple competitive electricity model with congestion

We focus initially on a restructured electricity sector that consists of a group of unintegrated and unregulated generating companies and an ISO which operates the transmission network, manages a spot energy market, and dispatches generators based upon their bids to supply generation services so as to balance the supply and demand for generation services in an efficient manner, taking into account physical constraints on the transmission network. The demand side can be thought of either as demand placed in the wholesale market by distribution companies which then resell the generation services to end-use consumers or as retailing intermediaries who buy energy in the wholesale market and then resell directly to end-use consumers who

have paid for access to “unbundled” distribution “wires” services. If the generation service suppliers and buyers behave competitively, the bidding process truthfully reveals the marginal cost curves and demand functions to the ISO. The ISO knows the physical constraints on the transmission network and, therefore, is in a position to enable an efficient dispatch of the generators given transmission constraints. The efficient dispatch may exhaust the capacity on some links, leading to congestion and congestion charges for using the congested link defined by the difference in nodal prices for electricity. This industry structure goes along naturally with a financial transmission rights system which players can rely on to hedge the uncertain costs associated with congestion charges.

We work initially with a simple two-node (no loop flow) network where there are a set of low-cost generators (G_1) in the North which produce output q_1 and have an aggregate cost function $C_1(q_1)$, with $C'_1 > 0$ and $C''_1 > 0$. We assume initially that these generators behave competitively when they submit supply bids to the ISO. There is no demand in the North and we refer to the North as being either the upstream location or the exporting region. The market clearing price for generation sold in the North is p_1 . In the South, there are electricity consumers and a set of generators (G_2) that have higher production costs (within the relevant range) than do the generators in the North. We refer to the South as the downstream location or the importing region. We assume initially that these generators too behave competitively. The market clearing price for generation in the South is p_2 . (In the next section we examine cases where there is seller or buyer market power at each node.) Consumers have a demand function $Q = q_1 + q_2 = D(p_2)$ with $D' < 0$ and where p_2 is the price for all generation service paid by consumers in the South.

Finally, there is a transmission line linking the North with the South which has a fixed capacity equal to K . The nondepreciated capital and operating costs of this link are assumed to be recovered separately from consumers in lump sum charges net of revenues produced by selling physical or financial transmission rights⁶ and we do not consider these costs further in

⁶In both California and in the Pennsylvania-New Jersey-Maryland (PJM) restructured systems, revenues from sales of transmission rights are returned to the owners of the transmission capacity to help to defray their capital and operating costs. This approach could create problems if the distribution companies have market power and retain the revenue from the rights sales. This is not what is intended to occur, however. The ISO

our analysis. To further simplify things, we also ignore thermal losses on the network. We focus on situations where demand is sufficiently high that it cannot all be fully served by generators in the North because the transmission capacity constraint is binding. That is, some supplies from the less efficient generators in the South are required to balance supply and demand at the competitive prices. Thus, the marginal cost of generation in the North must be lower than the marginal cost of generation in the South when K is binding and “nodal prices” p_1 and p_2 , which under perfect competition will be equal to the marginal costs in the North (C'_1) and the South (C'_2) respectively, will differ from one another with $p_1 < p_2$. Note, however, that consumers in the South pay the nodal price p_2 for all of their consumption ($Q = q_1 + q_2$). Accordingly, if the capacity of the transmission line is a binding constraint, scarcity rents $K(p_2 - p_1)$ accrue to the ISO, absent an alternative allocation of rights to collect these rents. We refer to these rents below as the ISO’s “merchandising surplus.”

We recognize that this is a highly simplified characterization of an electric power network. However, it is important to understand the effects of different types of transmission rights in a simple network before we go into more complex networks. Moreover, the two-node network model captures important congestion attributes of real electric power networks or sub-networks in England and Wales, Argentina, and New Zealand. It is also in this type of simple network where physical rights are the most likely to represent a practical alternative to financial transmission rights because the transactions costs and network externality problems associated with physical rights are less severe in such a simple network. We extend this analysis to a three-node network which takes loop flow into account to test whether and how loop flow (Kirchhoff’s laws) affects the results that we derive for the simple two-node case.

Consider first the case where generators behave competitively and bid their marginal cost curves to the energy/generator dispatch market run by the ISO. Assume initially that there are neither financial nor physical transmission rights as we have described them above. Any generator can offer to supply energy over the network, but the ISO only selects the lowest cost suppliers to meet demand given the bids it receives and taking into account transmission

defines the quantity of rights to be auctioned for each potentially congested link and defines the auction rules. The revenues are then treated as pure pass-through credits to end-use consumers connected to the network.

capacity limits. Under these assumptions the nodal prices in the North and the South are given by the following equations:

$$p_1^* = C_1'(K),$$

$$p_2^* = C_2'(D(p_2^*) - K) > p_1^*$$

$$q_1 = K$$

$$D(p_2^*) = q_1 + q_2 = K + q_2.$$

In this case, the ISO (effectively) sells $K + q_2$ units of output for p_2^* per unit to consumers, but only pays out $p_1^*q_1 + p_2^*q_2$ to the generators. Accordingly, it earns a “merchandising surplus” of $(p_2^* - p_1^*)K$. One can alternatively think of these net revenues as congestion payments $(p_2^* - p_1^*)$ made by the suppliers in the North to use the scarce transmission interface.

Remark: In what follows we ignore price uncertainty and focus on the effects of market power on the allocation of transmission rights and the associated equilibrium prices, quantities, and production costs with different market microstructures. Most of the previous literature on which we build (Bushnell 1998, Oren 1997, Hogan 1992) also ignore uncertainty and simply focus on situations when the link(s) is congested. This may seem odd, however, since one motivation for both financial and physical rights is to create instruments that allow buyers and sellers to “hedge” variations in profits (due both to variations in equilibrium supply prices and/or congestion charges) caused by congestion on the network. It is useful to focus first on how market power affects the demand for rights and, given the characterization of market power, how rights markets with different microstructures allocate these rights. We can then proceed to examine whether and how the purchase of rights for hedging purposes can be distinguished from the purchase of rights for the purpose of enhancing market power. We begin to explore this latter set of issues in section 5 below.

Now we define more precisely what we mean by “financial” transmission rights:

Financial rights : Financial rights give the holders a proportionate share of the congestion payments or merchandising surplus received by the ISO when the transmission constraint K is binding. The owners of these rights may be generators, consumers, or speculators. Generators

do not require financial rights to be dispatched by the ISO. But without them they must pay congestion charges when they supply over a congested link. There are K rights issued and the owner of one unit of financial rights entitles the owner to $\eta = (p_2 - p_1)$, or the difference in the nodal prices. Total payments given to rights holders are equal to $(p_2 - p_1)K$ ($(p_2^* - p_1^*)K$ in equilibrium).

If there is no market power in the generation market, the introduction of financial rights into this simple system has no effect on the prices for energy or the allocation of resources. The ISO's revenue from congestion rents or its merchandising surplus is now transferred to the owners of financial rights. The nodal prices for energy are as defined above and the competitive market value of the financial transmission rights is simply equal to the difference in nodal prices. Nodal energy prices and the price of financial rights are therefore given by

$$p_1^* = C'_1(K) \tag{1}$$

$$p_2^* = C'_2(D(p_2^*) - K) > p_1^* \tag{2}$$

$$\eta^* = p_2^* - p_1^*. \tag{3}$$

These equilibrium conditions for a competitive electricity market with tradable financial transmission rights provide a benchmark against which we can compare other market outcomes. In particular, we want to explore the interaction between market power in the electricity market and the allocation of financial transmission rights to sellers and buyers of electricity and how alternative microstructures for the rights market ultimately affect the allocation of rights among electricity sellers and buyers under alternative assumptions about market power.

3 Financial rights and market power

We now proceed to examine the value of financial rights to different rights holders under alternative assumptions about seller and buyer market power. We will then proceed to examine how the value of rights under these alternative assumptions about the market structure of the power market interacts with the microstructure of the financial rights market to determine the allocation and prices of financial transmission rights.

3.1 Market power at the expensive node: No financial rights

We assume here that the generators in the South (G_2) are owned by a single firm that has market power, while the generators in the North (G_1) behave competitively. The single generator in the South now maximizes profits given its residual demand curve, defined by consumer demand for electricity in the South net of the supply of electricity from the North. The price in the South is higher than in the perfectly competitive environment and so the transmission link is congested ($q_1 = K$) a fortiori.

The nodal price, quantities produced, and generator profits in the North are the same as in the competitive cases analyzed earlier:

$$p_1 = C_1'(K) = p_1^*.$$

However, when G_2 holds no financial rights, G_2 now chooses p_2 by maximizing profit against its residual demand curve

$$q_2 = D(p_2) - K.$$

G_2 's profit function is the profit associated with generation supplies:

$$\mathcal{G}(p_2) = p_2[D(p_2) - K] - C_2(D(p_2) - K).$$

We assume that $\mathcal{G}(\cdot)$ is strictly concave. The profit maximizing price p_2^m is higher and the quantity q_2^m produced in the South lower than they would be if G_2 behaved competitively:

$$p_2^m > p_2^* \text{ and } q_2^m < q_2^*.$$

The price of the rights is

$$\eta^m = p_2^m - p_1^*.$$

3.2 Market power at the expensive node: Impact of holding financial rights

We still assume that there is a single generator in the South with market power but allow this generator to hold financial rights. Recall that the value of financial rights is given by the

difference between the nodal prices for energy in the North and in the South. Since market power in the South increases energy prices in the South, congestion rents and the value of financial rights,

$$\mathcal{F}(p_2) = (p_2 - p_1^*)K,$$

must increase as well. That is, when the transmission link is congested, the value of financial transmission rights varies directly with the contraction of output and the increase in delivered energy prices in the South associated with the exercise of market power in the South.

Assume that G_2 holds a fraction $\alpha_2 \in [0, 1]$ of the K financial rights available. It now faces the following profit function to maximize:

$$\begin{aligned} \pi_2(\alpha_2) &= \max_{p_2} \{ \mathcal{G}(p_2) + \alpha_2 \mathcal{F}(p_2) \} \\ &= \max_{p_2} \{ p_2 [D(p_2) - K] - C_2(D(p_2) - K) + \alpha_2 [p_2 - C'_1(K)] K \} \\ &= \max_{p_2} \{ \Pi_2(\alpha_2, p_2) \}. \end{aligned}$$

Note that $\partial \Pi_2(\alpha_2, p_2) / \partial \alpha_2 \partial p_2 = K > 0$: The larger the fraction α_2 of rights held by the generator, the stronger its incentive to jack up the price in the South. The optimum $p_2(\alpha_2)$ is increasing continuously⁷ in α_2 from $p_2(0) = p_2^m$ to $p_2(1)$ (which maximizes $\{p_2 D(p_2) - K C'_1(K) - C_2(D(p_2) - K)\}$). The profit maximizing price for G_2 to set for energy in the South increases directly with α_2 , and as α_2 increases the quantity produced by G_2 decreases as well. G_2 now has two revenue streams: one stream of revenue from sales of energy (\mathcal{G}) and a second stream of revenues from the congestion rents (\mathcal{F}) that it is entitled to by virtue of holding the financial rights. The more G_2 internalizes the congestion rent, the higher the congestion rent by virtue of G_2 's control of p_2 . When G_2 has financial rights, it effectively reduces the elasticity of the residual demand curve and increases its market power. Let $\eta(\alpha_2) \equiv p_2(\alpha_2) - C'_1(K) = p_2(\alpha_2) - p_1^*$.

When $\alpha_2 = 1$, the monopoly in the South faces the *total demand* ($D(p_2)$) rather than the residual demand ($D(p_2) - K$) it faces when it holds no financial rights. That is, if the monopoly generator in the South holds all the financial rights, it maximizes its profit (G_2 's net revenues from supplying energy *plus* its revenues from congestion rents) as if it had a monopoly over the

⁷ $\mathcal{G}(\cdot) + \alpha_2 \mathcal{F}(\cdot)$ is strictly concave since we assumed that $\mathcal{G}(\cdot)$ is.

entire demand function. In doing so, G_2 sacrifices some profits it would otherwise earn from supplying electricity (\mathcal{G}) in order to increase the profits it receives in the form of “dividends” (\mathcal{F}) on the financial rights it owns as a result of its ability to increase the price p_2 in the South.

The actual allocation and prices of financial rights will depend on the attributes of the market for these rights, in particular on whether the rights market operates in such a way as to lead G_2 successfully to bid for all of the rights. We examine the attributes of the market for financial rights and the resulting allocations when we discuss the microstructures of financial rights markets below.

3.3 Other types of market power in the energy market

3.3.1 Generator market power at the cheap node

Suppose that G_1 is a monopoly in the North, while production in the South is competitive and there is no buyer market power. In contrast with the case of generator market power at the expensive node, financial rights holding by the generator with market power at the cheap node has no impact. To see this, suppose first that G_1 holds no financial rights. As is well-known from the literature (e.g., Oren 1997, Stoft 1997), financial rights are then worthless: Financial rights on the line of a two-node network can have positive value only if the capacity is fully used. Suppose that $q_1 = K$ and $p_1 < p_2$. Then G_1 can bid to supply a fixed amount $K - \varepsilon$ (where ε is small) and raise p_1 discontinuously to p_2 (which is hardly affected).

In a sense, G_1 effectively already “owns” the transmission rights even if formally owns no financial rights. So G_1 ’s holding transmission rights has no effect on prices or quantities and does not enhance its market power.

Remark: If there is a monopoly in the North as well as in the South, then the monopoly in the North will capture all of the congestion rents (by bidding a fixed quantity $q_1 = K - \varepsilon$ for ε substantially small) and the value of financial rights will be zero. Thus, adding a monopoly generator in the North when there is a monopoly generator in the South *mitigates* the market power enhancing effect of financial rights on the market power of the monopoly generator in the South and leads to *lower* prices p_2 in the South compared to the case when there is competitive

generation in the North. That is, even if the monopoly generator in the South holds a fraction α_2 of financial rights, the equilibrium price in the South is $p_2(0) = p_2^m$ rather than $p_2(\alpha_2)$.

3.3.2 Consumers with buyer market power

Finally consider the case where there is buyer market power (a monopsony) in the South. If the monopsony holds financial rights, its monopsony power actually decreases since the value of financial rights declines as the price p_2 in the South declines. [This does not mean that the monopsony will not acquire the rights; after all, its demand behavior impacts the value of rights, and so its acquiring rights help internalize this externality and creates gains from trade.]

In contrast, if there were a monopsony in the North and competitive behavior in the South, the behavior of the monopsony in the North could be affected if it held financial rights. By reducing the price in the North (which is feasible if marginal cost in the North is strictly increasing), the monopsonist increases the difference between the nodal prices and the congestion rents it receives. This leads to further distortion of demand in the competitive upstream market (compared to monopsony without rights) and a reduction in welfare. So, if there are consumers with market power in the exporting region, allocating to them financial rights increases their incentives to reduce purchases, enhances their market power and reduces welfare.

3.3.3 Summing up

While several cases must be considered depending on who has market power, the general logic is simple and intuitive: Financial rights holdings by a producer in the importing region or by a consumer in the exporting region aggravates their market power since financial rights give them an extra incentive to curtail their output or demand to make the rights more valuable. In contrast, financial rights holdings by a monopsony in the importing region mitigate its market power by giving it an incentive to raise price in the importing region. Last, financial rights holdings by a monopolist in the exporting region have no impact on market power, since the monopolist can already capture the congestion rents in the absence of rights.

We will from now on focus mainly on the case of monopoly power in the South. The treatment of the other cases is a straightforward extension of this benchmark situation, and

will be considered in various levels of detail.

4 Microstructure of markets for financial rights

The allocation of financial rights, and ultimately their impact on generation markets, depends on the attributes of the market for these rights as well as on the willingness to pay of generators and consumers. We offer a preliminary exploration of the attributes of the financial rights market and their implications for the allocation and pricing of these rights in this section.

We return now to the case in which G_2 is a local monopolist in the South, supply at the cheap node in the North (G_1) is competitive and all demand is in the South. We assume initially that consumers (distributors acting as agents for consumers or end-use consumers directly) in the South are not in the market for financial rights, or, if they are, that the ownership of these rights is too dispersed to create countervailing power to G_2 in the purchase and sale of the rights.

From our discussion of the effects of ownership of financial rights on G_2 's behavior we know that the value of financial rights increases with G_2 's holdings of such rights. In this respect, G_2 resembles the raider or large shareholder of the corporate finance literature (Grossman-Hart 1980, Shleifer-Vishny 1986, Admati et al 1994, Burkart et al 1998).⁸ G_2 would like to get all of the financial rights, but pay as little as it can for them. We know from the corporate finance literature that the realization of gains from trade between the initial holders of the financial rights (shares) and the value enhancing raider (G_2) depends on the extent of free riding and therefore on the microstructure of the rights market. Here, the initial financial rights (share) holders would like to hold on to their rights and capture their full value resulting from a larger difference in nodal prices. However, the value of the rights is maximized only if G_2 acquires all of them.

There is a wide variety of possible trading structures for financial rights. We consider three cases which (a) are interesting in their own right and (b) represent two polar cases and one

⁸A slight difference (which simplifies the analysis) with the raider in a corporate control situation is that the impact of holdings moves continuously instead of jumping at 51% of the rights.

intermediate case of free riding. The three cases are:

a) *No Free Riding*: Rights are initially held by a *single owner* who is neither a generator nor a consumer. The single owner bargains with potential purchasers over the price at which the rights will be transferred.

b) *Full Free Riding*: In this case the initial ownership of rights is dispersed among non-stakeholders and stakeholders without market power. G_2 makes a *tender offer* at some price η . The tender offer is unconditional.

c) *Partial Free Riding*: Here we assume that all of the rights are auctioned off to the highest bidders by the ISO, as proposed for California.⁹

We also want to examine the effects of allowing consumers (distributors acting as agents for their end-use customers or end-use customers directly) to buy financial rights. We discuss each of these cases in turn.

4.1 Financial rights initially held by a single nonstakeholder owner (no free riding)

4.1.1 No consumer coalition

In this case, since G_2 has the highest value for the rights (in terms of profits, not total surplus) in the absence of bidding by consumers, G_2 will acquire all of the rights at a price negotiated with the initial owner. Accordingly, G_2 's market power is enhanced and the equilibrium price p_2 is higher than it would be in the absence of financial rights. The negotiated market price for the financial rights will lie somewhere between $\eta^m = \eta(0)$ and $\eta(1)$. G_2 and the initial owner share the “surplus”

$$[\mathcal{G}(p_2(1)) + \mathcal{F}(p_2(1))] - [\mathcal{G}(p_2(0)) + \mathcal{F}(p_2(0))].$$

⁹The finance literature has looked at alternative environments in which the gains from trade between the raider and the initial shareholders are partially realized. In Kyle-Vila (1991) the presence of liquidity traders allows the raider to disguise her purchases (as long as she restricts her order flow) and prevents full free riding. In Holmström-Nalebuff (1992), the value of the firm increases discontinuously when the raider obtains a controlling share. It is shown that if initial shareholders hold several shares each, then in a symmetric (mixed-strategy) equilibrium of the tendering subgame, shareholders cannot fully free ride.

The division of the monopoly rents associated with G_2 's ownership of all of the rights depends on the relative bargaining power of G_2 and the initial owner.

Remark: It is important that the financial rights be in *positive net supply* through the market. Suppose in contrast that the congestion rents are allocated to a party who is prevented from selling them and participating in the financial market (i.e. the owner cannot contract directly or indirectly with G_2). The rights would then de facto be in zero net supply. Would a group of investors want to enter into a “gambling contract” with G_2 specifying that the investors will pay $(p_2 - p_1)t$ to G_2 once nodal prices are realized, where $t > 0$ is the scale of the financial deal (“gambling” refers to the fact that G_2 ' two components of profit $\mathcal{G}(p_2)$ and $(p_2 - p_1)t$ both increase with p_2)? The answer is no: The aggregate profit of G_2 and the investors, $\mathcal{G}(p_2(\alpha_2)) - \mathcal{G}(p_2(0))$, where $t = \alpha_2 K$ is the size of the side deal, would then be negative.

4.1.2 Consumer coalition

Next consider the case where we allow consumers to form a coalition to bid against G_2 for the rights and assume that they solve their collective action problem. The coalition thus has market power in the rights market, but (due to antitrust enforcement, say) consumers do not collude in the energy market. Suppose that the initial owner of the rights auctions them off as a single bundle to the highest bidder using a second-price (English) auction.¹⁰ In this case G_2 's willingness to pay is:

$$[\mathcal{G}(p_2(1)) + \mathcal{F}(p_2(1))] - \mathcal{G}(p_2(0)),$$

and the consumers' willingness to pay is:

$$\int_{p_2(0)}^{p_2(1)} D(p_2) dp_2 + \mathcal{F}(p_2(0)).$$

The consumers' willingness to pay is higher:

$$\begin{aligned} & \int_{p_2(0)}^{p_2(1)} D(p_2) dp_2 - [\mathcal{G}(p_2(1)) + \mathcal{F}(p_2(1)) - \mathcal{G}(p_2(0)) - \mathcal{F}(p_2(0))] \\ &= - \int_{p_2(0)}^{p_2(1)} (p_2 - C'_2) D'(p_2) > 0, \end{aligned}$$

¹⁰The type of auction appears to be irrelevant.

since $\mathcal{G}' + \mathcal{F}' = D(p_2) - C_2' D' + p_2 D'$; and so consumers outbid G_2 . Social surplus is higher as a result of consumers outbidding G_2 .

There are two obstacles to consumers' winning the auction and obtaining the financial rights. First, they must solve their collective action problem. Second, a distribution company would be subject to a prudency review which would destroy its incentives to buy the rights even though it benefits consumers. If it were successful in buying up the rights and mitigating G_2 's market power, it might appear to the regulators ex post that the distributor paid "too much" for the financial rights. This is the case because consumers appear to "lose money" by buying the rights:

$$\mathcal{F}(p_2(0)) - [\mathcal{G}(p_2(1)) + \mathcal{F}(p_2(1)) - \mathcal{G}(p_2(0))] < 0.$$

That is, if the regulator compared the amount the distributor paid for the rights with their ex post value, measured by the ex post difference in nodal prices, it might conclude that the distributor overpaid and penalize it for the overpayment. Such an evaluation incorrectly ignores the fact that by purchasing the financial rights the distributor mitigates G_2 's market power and conveys the benefits of lower prices to consumers.¹¹

4.2 Tender offer by G_2 (full free riding)

It is clear that when G_2 makes an unconditional tender offer to dispersed owners (without market power in either market) who initially hold the rights, it does not want to purchase any rights: Suppose G_2 offers to buy whatever is tendered at a price η such that

$$\eta(0) < \eta \leq \eta(1).$$

The fraction α_2 of rights tendered is given by:

$$\eta = \eta(\alpha_2) = p_2(\alpha_2) - p_1^*.$$

G_2 's profit is then given by

$$\mathcal{G}(p_2(\alpha_2)) + \alpha_2 \mathcal{F}(p_2(\alpha_2)) - \alpha_2 \eta K = \mathcal{G}(p_2(\alpha_2)) < \mathcal{G}(p_2(0)),$$

¹¹As we mentioned earlier, if there were a generation monopolist at the cheap node in the North, the value of the financial rights would be zero since the generation monopolist in the North would capture all of the congestion rents in its profit-maximizing energy price.

where $p_2(0)$ maximizes G_2 's profits from supplying generation service.¹²

The point made in this section is completely general. Any player who makes a tender offer buys the rights at a price equal to their ex post price. The value of the rights goes up or at least stays constant after a stakeholder with market power (consumer or producer in the North or the South) purchases a fraction of the rights from nonstakeholders or stakeholders with no market power. However, the utility of the stakeholder with market power purchasing the rights decreases and, as a result, it will purchase no rights in this case. This is the case because G_2 must sacrifice some profits associated with the supply of generation service in order to jack up the price of energy p_2 . However, it cannot recoup these lost profits through the higher dividends on any rights it buys resulting from such a price increase because the value of these dividends would be reflected in the price it would pay for the rights. Since there is full free riding on any enhanced value of rights that G_2 can create by further contracting its output and increasing p_2 , it is not profitable for it to buy any rights.

4.3 Auctioning of the rights by the ISO (partial free riding)

Assume that there is no consumer coalition and the ISO auctions off all of the rights simultaneously. We analyze a *discriminatory* auction, that is an auction in which i) bidders announce a price and a maximum quantity they are willing to buy at this price, ii) rights are allocated to the highest bidders¹³, and iii) bidders pay their bids. We assume that the market is deep in the sense that risk neutral arbitrageurs, the market makers, stand ready to arbitrage away any profit opportunity.

Note first that G_2 's bid cannot be deterministic. Suppose G_2 bids $\eta > \eta(0)$ and purchases $\alpha_2 K$ rights. Either $\alpha_2 = 0$ and then market makers overpay for the rights (they pay above η for rights whose value is $\eta(0)$). Or $\alpha_2 > 0$, and $\eta \geq \eta(\alpha_2)$ (if $\eta < \eta(\alpha_2)$, then a market maker

¹²With conditional offers, we are back to the absence of free riding: G_2 can offer to pay $\eta = p_2(0) - p_1^* + \varepsilon$ (where ε is small) and stipulate that the offer is valid only if *all* rights are tendered. Then everyone tenders. Note, though, that with a conditional offer it makes a difference whether the rights are held by financiers or by stakeholders (we are grateful to Bruno Biais for this point). The no-free riding point holds only if the rights are held by financiers. Suppose for example that a competitive consumer in the South holds a single right. By refusing to tender this right the consumer forgoes the profit ε on the sale, but lowers the price in the South from $p_2(1)$ to $p_2(0)$ by defeating the tender offer.

¹³The rationing rule used in case of a tie will turn out to be irrelevant.

could make a profit by bidding for one right at a price between η and $\eta(\alpha_2)$; so G_2 's profit is at most $\mathcal{G}(p_2(\alpha_2)) < \mathcal{G}(p_2(0))$. That is, G_2 would be better off not bidding for rights. But if G_2 does not bid for rights, market makers (or stakeholders without market power) are willing to pay $\eta(0)$, in which case G_2 can buy all rights at a price just above $\eta(0)$ and increase its profit, a contradiction. Hence G_2 must randomize in equilibrium. Furthermore, G_2 optimally buys all rights available at his bid.¹⁴

The market makers face a *winner's curse* problem: They tend to get rights precisely when G_2 does not and so when rights are not very valuable. The consequence of this winner's curse is that *the competitive market makers' demand function* is not flat at some price, but rather *downward sloping*. A higher bid by a market maker is costly and so must be compensated by a higher value of the right conditionally on the bid being a winning bid. The distribution of the number of rights held by G_2 conditionally on bid η being a winning bid indeed shifts to the right when η grows, if the market makers' demand function is downward sloping.

In equilibrium G_2 randomizes over the interval $[\eta(0), \bar{\eta}]$, where $\eta(0) < \bar{\eta} < \eta(1)$, according to density $h(\eta)$ and cumulative distribution function $H(\eta)$. [That is, the probability that G_2 's bid is less than η is $H(\eta)$.] The market makers' aggregate demand is given by a decreasing function $\hat{d}(\eta)$, with $\hat{d}(\eta(0)) = K$ and $\hat{d}(\bar{\eta}) = 0$. For the purpose of the analysis, it will be convenient to define the fraction of rights $\hat{\alpha}_2(\eta)$ that is acquired by G_2 when bidding η :

$$\hat{\alpha}_2(\eta)K = K - \hat{d}(\eta),$$

with $\hat{\alpha}'_2 > 0$, $\hat{\alpha}_2(\eta(0)) = 0$, $\hat{\alpha}_2(\bar{\eta}) = 1$.

G_2 's behavior in the rights market

In order for G_2 to be indifferent between all bids in $[\eta(0), \bar{\eta}]$, it must be the case that they all yield G_2 the same profit, equal to the profit $\mathcal{G}(p_2(0))$ obtained by bidding $\eta(0)$ and obtaining no rights:

$$\mathcal{G}(p_2(0)) = \mathcal{G}(p_2(\hat{\alpha}_2(\eta))) + \hat{\alpha}_2(\eta)\mathcal{F}(p_2(\hat{\alpha}_2(\eta))) - \eta\hat{\alpha}_2(\eta)K. \quad (4)$$

Equation (4) defines an increasing function $\hat{\alpha}_2(\eta)$ and thereby a decreasing demand $\hat{d}(\eta)$ by

¹⁴This is a consequence of the fact that his profit is convex in the number of rights purchased at a given price.

the market makers. The upper bound of the support of G_2 's strategy, $\bar{\eta}$, is given by

$$(\eta(1) - \bar{\eta})K = \mathcal{G}(p_2(0)) - \mathcal{G}(p_2(1)).$$

Market makers' zero-profit condition

Consider a market maker playing a bid for one right at price $\eta \in [\eta(0), \bar{\eta}]$. With probability $1 - H(\eta)$, G_2 's bid is higher and the market maker's bid is not selected. With probability $H(\eta)$, the market maker receives the right. His profit when G_2 's bid is $\tilde{\eta} < \eta$ is $[p_2(\hat{\alpha}_2(\tilde{\eta})) - p_1^*] - \eta$, and so the zero-profit condition for all η can be written as: For all $\eta \in [\eta(0), \bar{\eta}]$,

$$\int_{\eta(0)}^{\eta} [[p_2(\hat{\alpha}_2(\tilde{\eta})) - p_1^*] - \eta] h(\tilde{\eta}) d(\tilde{\eta}) = 0.$$

This condition is obviously satisfied at $\eta = \eta(0)$. For it to be satisfied over the whole interval, the derivative of the left-hand side must be equal to zero, or

$$\frac{h(\eta)}{H(\eta)} = \frac{1}{[p_2(\hat{\alpha}_2(\eta)) - p_1^*]}. \quad (5)$$

Knowing $\hat{\alpha}_2(\cdot)$ from (4), equation (5) defines the bidding strategy $H(\cdot)$ for G_2 .¹⁵

The number of rights purchased by G_2 is random and intermediate between those purchased under full free riding (none) and no free riding (all).

5 Regulatory issues associated with financial rights

We have shown that certain players with market power, namely a generator at the expensive node or consumers at the cheap node, may bid for financial rights and then enhance their value by restricting output or consumption. In both instances, the firm with market power takes a gambling rather than a hedging position, and welfare is reduced because their ownership of transmission rights increases prices and increases the cost of supplying electricity. This necessarily raises the question of whether regulatory oversight can mitigate this source of

¹⁵Integrating (5) yields $H(\eta) = \exp(-\int_{\eta}^{\bar{\eta}} \ell(\tilde{\eta}) d\tilde{\eta})$, where $\ell(\cdot)$ is the right-hand side of (5). Using (4) and the first-order condition defining $p_2(\alpha_2)$, it can be seen that $\ell(\eta)$ is of the order $1/(\eta - \eta(0))$ in the neighborhood of $\eta(0)$ and so $H(\eta(0)) = 0$.

inefficiency. *One might consider preventing firms with local market power from buying transmission rights when they involve gambling rather than hedging. That is, positions whose value covaries positively with the value of the player's position in the absence of these rights would be prohibited.*

While a regulatory rule built around this basic principle is likely to provide a useful conceptual framework for designing regulatory surveillance programs, there are several practical problems in applying it in practice in a way that increases welfare. First, in an environment in which there is uncertainty about the nodal price differential, the implications of the previous discussion is that generators in the South and consumers in the North may take on more risk (“underhedge”) than they would if purchasing financial rights did not enhance their market power. While one can prohibit taking gambling positions, it becomes difficult to assess the extent of underhedging in practice, though one might be able to do so in specific circumstances.¹⁶

Second, in our model, one possible benchmark for measurement of “gambling behavior ” is that, in the absence of financial holdings by the player with local market power, this player’s profit is positively correlated with the value of congestion rents. So, a simple rule might be that generators are not allowed to acquire financial rights if their value is positively correlated with the value of the firm’s generation profits.

To show that this benchmark and the associated simple rule are not necessarily appropriate, let us return to our basic model with a constrained link of capacity K , a competitive supply in the North with cost function $C_1(q_1)$, a monopolist with cost function $C_2(q_2)$ in the South, with consumers demanding $D(p_2)$ in the South. Let us add an exogenous and random supply of power at the two nodes. For example, there may be hydroelectric supplies at both locations, and the amount of energy they can produce is contingent on random variations in rainfall from year to year. Let θ denote the random supply in the North and $\varepsilon\theta$ denote the random supply in the South. The two supplies are thus perfectly correlated. There is much more hydroelectric

¹⁶The regulatory strategy would then be similar to that adopted for the England-Wales system in the early 1990s when the two largest generators created from the existing CEBG were forced to sell a substantial fraction of their output forward using contracts for differences (CFD). For theoretical analyses of the impact of CFD’s on market power in systems with uniform prices, see Green (1992), Allaz-Villa (1993) and Allaz (1992). Such analyses in turn are closely related to the Coase conjecture (see. e.g., Tirole 1988).

supply in the North if ε is small, however.

The price in the North,

$$p_1 = C_1'(K - \theta)$$

is a decreasing function of realized hydroelectric energy supplies θ . Similarly, the price in the South in the absence of financial holdings by the local monopolist in the South is,

$$p_2 = \arg \max_{p_2} \{ [D(p_2) - \varepsilon\theta - K] p_2 - C_2(D(p_2) - \varepsilon\theta - K) \}$$

is a decreasing function of θ , and so is the local monopolist's profit. But if ε is small enough, p_2 hardly moves with θ , and so

$$\frac{\partial}{\partial \theta} (p_2 - p_1) > 0.$$

Thus, from a statistical viewpoint, the local monopolist can hedge by purchasing financial rights. But at the same time we showed above that such purchases increase its market power. This obviously complicates the regulator's surveillance problem.

Another surveillance index might be to examine whether it can be demonstrated that the acquisition of financial rights by a local monopoly generator led to an increase in the difference in nodal prices. In our analysis above, the voluntary purchase of financial rights by players with local market power both increased the value of these rights (by increasing the difference in nodal prices) and reduced output and economic welfare. The two effects do not always go together, however. The following example shows that the purchase of financial rights by players with market power may increase welfare and congestion rents simultaneously.¹⁷

Consider a two-node system with no production in the South and no consumption in the North. The South imports its entire demand from the North over the congested link with capacity K . The price in the South is then defined by:

$$K = D(p_2^k).$$

A generator with market power in the North can produce an arbitrary amount q_1 at a constant marginal cost c_1 . The generator with market power faces a group of more expensive fringe

¹⁷This example builds on Stoft's (1997, 1998) analysis of strategic expropriation of the rights' value. By adding an inefficient fringe to his analysis, we can show that the expropriation does not just lead to a redistribution of wealth, but also to a reduction in welfare if the inefficient fringe supplies in equilibrium.

suppliers also located in the North. These fringe suppliers have marginal cost $c_1^f > c_1$ and can produce quantities up to $q_1^f < K$. Thus, economic efficiency requires that these fringe suppliers not produce and the low cost supplier serve all demand.

Suppose first that there are no financial rights. Then the dominant firm will maximize profits taking supplies from the competitive fringe into account. If the profit maximizing price exceeds c_1^f , then the competitive fringe supplies q_1^f and the dominant firm's profit is bounded above by:

$$\pi_1 = (p_2^k - c_1)(K - q_1^f),$$

since the nodal price in the North cannot exceed that in the South. The monopolist can actually obtain π_1 by manipulating her supply curve in the following way. The dominant firm offers a fixed supply $K - q_1^f - \varepsilon$, where ε is arbitrarily small. The line is then not congested and $p_1 = p_2 = p_2^k$.

Alternatively, the profit maximizing price could be below c_1^f and the dominant firm would produce the entire amount K . By undercutting slightly the fringe, the dominant firm gets

$$\pi_1^* = (c_1^f - c_1)K.$$

Production inefficiency occurs when $\pi_1^* < \pi_1$ since the fringe supplies. This will be the case when the competitive fringe's output is relatively small or its production cost is relatively low.

Let's assume that $\pi_1^* < \pi_1$, but let us suppose that the dominant firm holds the financial rights to the link. The payoff attached to the first strategy is unaffected because the rights have no value. In contrast, the payoff to the second strategy (ignoring the sunk cost of purchasing these rights) is now

$$\pi_1^* + (p_2^k - c_1^f)K = (p_2^k - c_1)K > \pi_1^*.$$

Production efficiency now holds since the dominant firm gets the rents from owning the financial rights and has no incentive to "expropriate" rents from third party owners of these rights. This example thus shows that in fashioning a regulatory rule to mitigate the market power enhancing effects of financial rights, we cannot rely on the assumption that increases in the value of

financial rights resulting from the behavior of a generator with market power necessarily leads to a reduction in output and welfare. The two effects do not necessarily go together.

6 Loop flows

While some networks or subnetworks are well approximated by the radial structure that we have studied until now, more complex networks exhibit loop flows associated with the fact that electrons follow the path of least resistance. For example, in a three-node network (e.g., Figure 1), a power injection at one node (e.g., node 1 in Figure 1) and an equal amount withdrawal at another node (e.g., node 3 in Figure 1) affect not only the congestion on the line linking the two nodes, but also the congestion on the other two lines (node 1 to node 2 and node 2 to node 3) as well. On electrical networks with multiple interconnected links, the patterns of electricity flows follow physical laws known as Kirchhoff's laws (Schweppe et al. 1988). When power is injected at one node and withdrawn (consumed) at another, the power supplied to the network is distributed across multiple interconnected links and not simply over the link that provides a direct connection between the injection node and the consumption node. The distribution of the power flows over these multiple interconnected links is simply referred to as "loop flow." We provide below a simple intuitive discussion of the physics of loop flows and specify the characteristics of these flows on a simple three-node network with links of equal impedance. This section shows that our insights carry over in the presence of loop flows and gains a few new insights. Following an extensive literature on the topic,¹⁸ we illustrate the ideas by means of a simple three-node network with two nodes of (net) production and one node of (net) consumption. We ignore losses and assume that the three links have equal impedance. We begin with the case in which the transmission line between the two generation nodes is congested, which as we will see is the direct analog of the two-node network and then describe how the analysis changes for different patterns of congestion.

¹⁸See, e.g., Nasser (1997), Oren et al (1995), and Oren (1996).

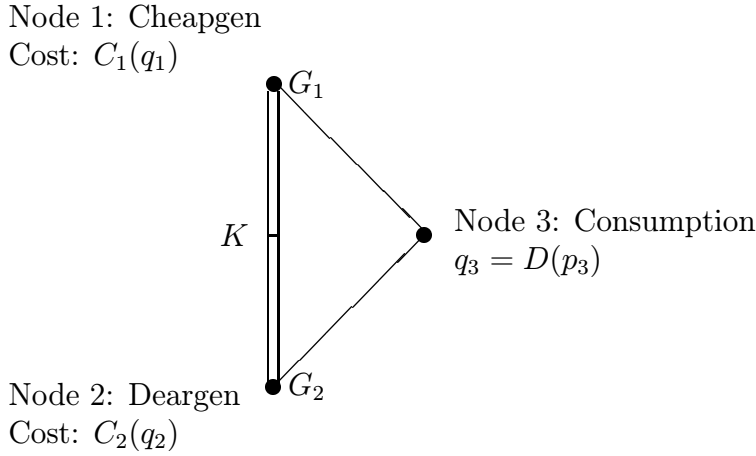


Figure 1

6.1 Absence of financial rights

Consider the network described in Figure 1. As in the two-node network, nodes 1 and 2 are the low- and high-marginal- cost production nodes respectively ($C'_1 < C'_2$ over the relevant range). Furthermore, production is competitive at node 1 and produced by a monopoly G_2 at node 2. Consumption occurs now at node 3. There, consumers demand $q_3 = D(p_3)$, with inverse demand function $p_3 = P(q_3)$. The line between nodes 1 and 2 has capacity K and is congested, while the other two lines have excess capacity.

We assume that there are no losses on the lines, and so

$$q_1 + q_2 = q_3. \tag{6}$$

The laws of electricity (Kirchhoff's) determine the flows through the three transmission lines. A reader unfamiliar with electric networks can think about electricity balance in the following terms: Electricity flowing from node $i \in \{1, 2\}$ to node 3 must follow the path of least resistance. This implies that the resistances encountered along the two possible paths (direct, and indirect through the other production node) are equal.¹⁹ Because the indirect path is twice as long as the direct path, so is the resistance. This implies that a unit production at one node generates a one-third flow through along the indirect path and twice as much along the direct

¹⁹This is Ohm's law: the difference in potential between two nodes is equal to the product of resistance and intensity.

path.²⁰ Because we focus here on the congestion of the line between the two generating nodes, the constraint becomes

$$\left| \frac{q_1}{3} - \frac{q_2}{3} \right| \leq K,$$

or using the fact that there is a lower marginal cost and so more production in the North than in the South

$$q_1 - q_2 \leq 3K. \tag{7}$$

Under bid-based dispatch, the Independent System Operator dispatches productions, q_1 and q_2 , and consumption q_3 so as to maximize social surplus (consumer surplus minus total production cost, as revealed by the players) subject to the feasibility constraints $\{(6), (7)\}$.²¹ Letting η denote the shadow price of constraint (7), the nodal prices satisfy at the optimum:

$$p_1 = p_3 - \frac{\eta}{3}, \tag{8}$$

and

$$p_2 = p_3 + \frac{\eta}{3}. \tag{9}$$

And so

$$p_3 = \frac{p_1 + p_2}{2}. \tag{10}$$

To understand (8) and (9), note that in the absence of a transmission constraint everything would be produced at node 1, since production there is both competitively supplied and cheaper than production at node 2. A congested line limits the production at node 1. An extra unit produced at node 1 generates an added load of one-third on the congested line and so must be subject to a “tax” equal to $\eta/3$ (i.e., one third of the shadow price of the constraint). Conversely, a unit production at node 2 unloads the constraint by one third and should therefore receive a “subsidy” equal to $\eta/3$. The “tax” paid by generators at node 1 is the price consumers pay at node 3 less $1/3$ of the shadow price of congestion ($\eta/3$). That is, the equilibrium price generators at node 1 see is less than the equilibrium price consumers pay at node 3. The

²⁰These flows may be fictitious. Indeed, if generators at nodes 1 and 2 produce the same output and therefore generate the same, but opposite fictitious flows through the line located between them, no power actually flows through that line since the two fictitious flows cancel.

²¹See Scheweppe et al. (1988) for the generalization of the following analysis to an arbitrary electrical network.

“subsidy” provided to generators at node 2 is the price consumers pay at node 3 plus 1/3 of the shadow price of congestion. That is, the equilibrium price generators see at node 2 is greater than the equilibrium price consumers pay at node 3.

Using (6), (7) and (10), we thus obtain:

$$p_2 = 2P(2q_2 + 3K) - p_1.$$

Competitive behavior at node 1 further implies that

$$p_1 = C'_1(q_1) = C'_1(q_2 + 3K).$$

We therefore obtain the profit from generation for the monopoly at node 2 (which we here write for convenience as a function of q_2 rather than p_2):

$$\mathcal{G}(q_2) \equiv p_2 q_2 - C_2(q_2),$$

or

$$\mathcal{G}(q_2) \equiv [2P(2q_2 + 3K) - C'_1(q_2 + 3K)] q_2 - C_2(q_2). \quad (11)$$

In the absence of financial rights, G_2 selects $q_2 \geq 0$ so as to maximize $\mathcal{G}(q_2)$. It is interesting to note that G_2 receives two benefits from withholding output in comparison with the case where it is price taker. Recall that $p_2 = p_3 + (\eta/3)$. By reducing q_2 , G_2 increases the consumer price $p_3 = P(2q_2 + 3K)$; actually the standard contractionary effect (the elasticity of demand) is doubled since, unlike the two-node case, a reduction in the production in the South forces an equal reduction of the output in the North. In other words production in the South and the North are *local complements*, where “local” refers to the fact that for large transmission capacities the two outputs become substitutes. Second, a reduction in output q_2 increases congestion and thereby the subsidy $\eta/3 = p_3 - p_1$ received for production in the South. [This subsidy increases because p_3 increases and also, if production in the North exhibits decreasing returns to scale, because the cost of the marginal plant in the North decreases, making q_2 -enabled production in the North more desirable.]

6.2 Impact of financial rights

With more than two nodes, there are at least two ways of introducing financial rights:

- *Link-based rights*: Link-based rights are financial rights associated with a transmission line and paying a *dividend equal to the shadow price of the congestion on that line*. Such rights are for example being put in place in California.

In our context, the only linked-based rights with positive value are those attached to the link between nodes 1 and 2. Suppose that K such rights are issued; then the total dividend is ηK . This total dividend corresponds exactly to (and therefore can be covered by) the merchandizing surplus, that is

$$p_3 q_3 - p_1 q_1 - p_2 q_2 = (p_3 - p_1) q_1 + (p_2 - p_1) q_2 = \frac{\eta}{3} (q_1 - q_2) = \eta K$$

(since $q_1 - q_2 = 3K$).

- *Fictitious-bilateral-trades-based rights*: Financial rights were first designed by Hogan (1992) in a different way. He considered the set of bilateral trades that are feasible (meaning here that they satisfy (6) and (7)). Such trades may, but need not be those that actually occur. For example, suppose that producers at node i ($i = 1, 2$) fictitiously sell \bar{q}_i units in bilateral contracts with consumers at node 3. Those trades are feasible if $\bar{q}_1 - \bar{q}_2 \leq 3K$. These fictitious trades create by definition \bar{q}_1 financial rights between *nodes* 1 and 3, yielding dividend $p_3 - p_1$ each, and \bar{q}_2 financial rights between *nodes* 2 and 3, yielding dividend $p_3 - p_2$ each, where prices refer to the ex post equilibrium prices for the market outcomes (and thus not necessarily to the prices corresponding to the fictitious trades). The total dividend to be paid for prices (p_1, p_2, p_3) is therefore

$$(p_3 - p_1) \bar{q}_1 + (p_3 - p_2) \bar{q}_2 = \frac{\eta}{3} (\bar{q}_1 - \bar{q}_2) \leq \eta K.$$

Thus the dividend can again be covered by the merchandizing surplus.²²

Without loss of generality, we here consider link-based rights. Suppose that K such rights

²²This result extends to arbitrary networks: see Hogan (1992) and the appendix of Chao-Peck (1996). The two types of rights are equivalent as long as a) the amount of link-based rights is equal to the capacity of the line, and b) the fictitious trades in the Hogan approach exhaust the transmission constraint.

are held by a nonstakeholding investor who then (as in section 4.1) resells them to the monopoly producer in the South. The value of these rights is

$$\mathcal{F}(q_2) = \eta K = 3[P(2q_2 + 3K) - C'_1(q_2 + 3K)]K.$$

The value of financial rights decreases with q_2 for the now familiar two reasons: decrease in consumer price and increase in the marginal cost in the North due to local complementarity.

G_2 thus solves

$$\max_{q_2} \{\mathcal{G}(q_2) + \mathcal{F}(q_2)\},$$

and, as in the radial network case, restricts output further than in the absence of financial rights. Indeed, the result according to which G_2 optimizes against the *full* demand curve generalizes, since

$$\begin{aligned} \mathcal{G}(q_2) + \mathcal{F}(q_2) &= p_3 q_3 - p_1 q_1 - C_2(q_2) \\ &= P(2q_2 + 3K)(2q_2 + 3K) - q_1 C'_1(q_1) - C_2(q_2). \end{aligned}$$

With the required adjustments, the insights of section 4.1 thus carry over from the two-node network to the three-node network; so do the insights of sections 4.2 and 4.3.

6.3 Other patterns of congestion

Let us now assume that one of the direct links between a production node and the consumption node is congested while the other links are not: see figure 2. We keep the notation “K” for the capacity of the congestion link even though the identity of that link has changed.

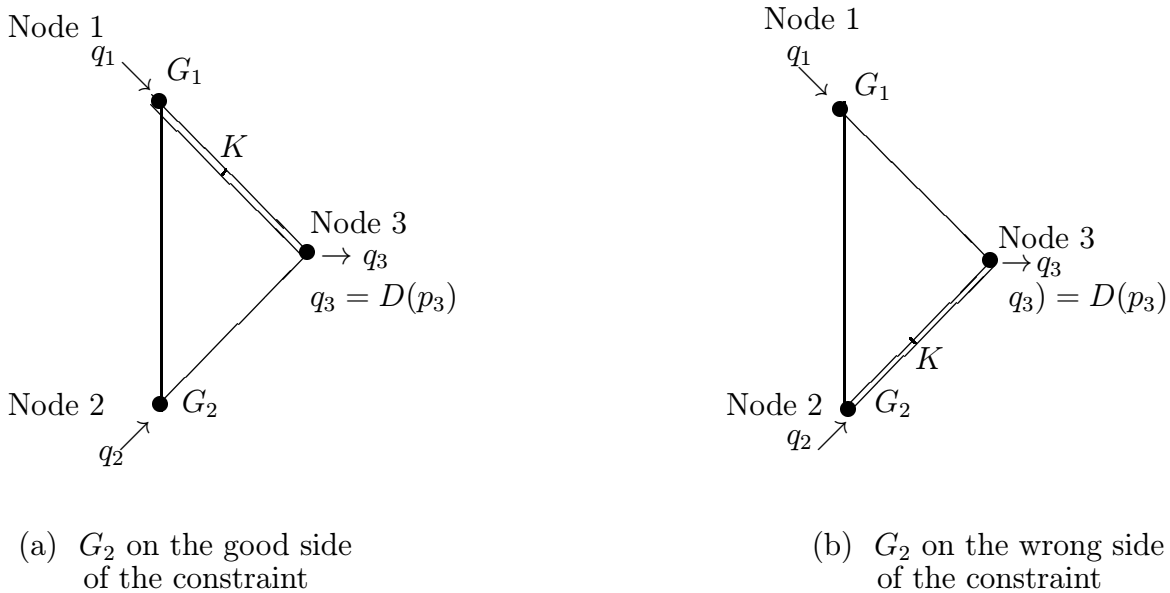


Figure 2

In case (a), the capacity constraint on the line between nodes 1 and 3 can be written as

$$\frac{2}{3}q_1 + \frac{1}{3}q_2 \leq K,$$

where K now denotes the capacity of that line. Note that the two outputs are now *local substitutes*. A contraction in output (q_2) at the expensive node leads to an increase in output (q_1) and an associated increase in the marginal cost at node 1. The reader can check that²³

$$\mathcal{F}(q_2) = \left[\frac{P\left(\frac{3K+q_2}{2}\right) + C'_1\left(\frac{3K-q_2}{2}\right)}{2} \right] q_2 - C_2(q_2),$$

and

$$\mathcal{G}(q_2) = \frac{3}{2} \left[P\left(\frac{3K+q_2}{2}\right) - C'_1\left(\frac{3K-q_2}{2}\right) \right] K.$$

Again, G_2 optimizes against the full demand curve (that is, maximizes $p_3q_3 - q_1C'_1(q_1) - C_2(q_2)$), when owning the financial rights. The impact of G_2 's ownership of financial rights is a priori more ambiguous than in section 6.2. An output contraction by G_2 raises the consumer price, but also by a substitution effect, increases the marginal cost in the North. The net effect on the shadow price of the congested line is a priori unclear, unless returns to scale in the North

²³Letting η denote the shadow price of the congested line, the nodal prices are

$$p_1 = p_3 - \frac{2\eta}{3} \text{ and } p_2 = p_3 - \frac{\eta}{3}.$$

decrease slowly, in which case G_2 's ownership of financial rights enhances market power. If the marginal cost of the generators in the North were constant, allocating financial rights to G_2 would lead it to contract output further than it would in the absence of financial rights.

Case (b) is more interesting. There, G_2 is on the wrong side of the capacity constraint, and does not produce in the absence of financial rights: Its marginal cost is higher than that of producers in the North, and furthermore G_2 makes twice as much use of the congested line as they do and therefore gets taxed twice as much.²⁴

Suppose now that G_2 owns the financial rights. Despite its double disadvantage, G_2 may produce so as to enhance the value of financial rights. Straightforward computations show that

$$\begin{aligned}\mathcal{F}(q_2) + \mathcal{G}(q_2) &= p_3 q_3 - q_1 C_1'(q_1) - C_2(q_2), \\ &= P(3K - q_2)(3K - q_2) - (3K - 2q_2)C_1'(3K - 2q_2) - C_2(q_2).\end{aligned}$$

and so

$$\left. \frac{d(\mathcal{F}(q_2) + \mathcal{G}(q_2))}{dq_2} \right|_{q_2=0} \equiv -3P'(3K)K + 6KC_1''(3K) + [2C_1'(3K) - P(3K) - C_2'(0)].$$

The term in brackets in the right-hand side of the derivative is approximately equal to 0 if i) the line is hardly congested when G_2 does not produce,²⁵ and ii) $C_2'(0)$ is close to $C_1'(3K)$. Under i) and ii), G_2 's two handicaps relative to G_1 are small, and so G_2 gains by increasing its load and making the line appear more congested.

This artificial loading of the line by its owner is reminiscent of the example given in section 5.2, in which the monopoly owner in the North (thus on the wrong side of the constraint in the two-node network) has an incentive to increase its supply when owning the financial rights on the congested line. The welfare implications of this strategic load are however quite different. Increased supply in section 5.2 eliminated the inefficient fringe in the North and improved

²⁴The capacity constraint is now

$$\frac{q_1}{3} + \frac{2q_2}{3} \leq K,$$

and the nodal prices are

$$p_1 = p_3 - \frac{\eta}{3} \text{ and } p_2 = p_3 - \frac{2\eta}{3}.$$

²⁵That is, $p_3 = P(3K)$ is close to $p_1 = C_1'(3K)$.

welfare. Here, increased supply has two perverse effects : By locating some production near the constraint, it reduces total supply to the consumers; and it substitutes expensive power for cheap power, resulting in production inefficiency.

7 Conclusion

When there is seller and/or buyer market power in an unregulated electricity market, the allocation of financial transmission rights can enhance market power and induce production inefficiency. Whether and how financial rights can have such effects depends on numerous factors including the configuration of the underlying market power problems (location, buyer vs seller) and the microstructure of the market for transmission rights. The allocation of financial rights appears most likely to have adverse welfare effects (ignoring the value of hedging to reduce risk) when rights are allocated to a supplier with market power at the expensive node (the importing region) or to a buyer with market power at the cheap node (the exporting region). The extension to a three-node network which allows us to consider the effects of loop flows enriches the analysis by revealing more complex interactions between generators. However, it does not affect our basic conclusions about the impact of financial transmission rights on market power. Unfortunately, simple hard and fast rules for regulatory surveillance of the allocation of transmission rights are not readily apparent. Nevertheless, our sense is that regulators can usefully focus their attention on large concentrated accumulations of rights by generators in the importing region and by buyers in the exporting region.

In a companion paper (Joskow-Tirole 1998) we perform a symmetrical analysis of how the allocation of *physical* transmission rights and the structure of the associated rights market affect seller and buyer market power in the electric energy market. In that paper we also compare the performance of physical and financial rights from a market power perspective. The basic results for physical transmission rights are similar to those for financial rights. Physical rights introduce the possibility that electricity sellers with market power in the importing region or electricity buyers with market power in the exporting region will withhold physical rights from the market to reduce the effective transmission capacity of a congested line in order to

enhance their market power. Such behavior creates production inefficiency. The companion paper explores transmission capacity release rules as a regulatory mechanism to mitigate such withholding behavior.

Taken together, the results in these papers show that when firm transmission rights are in positive net supply their allocation can interact with pre-existing electricity seller or electricity buyer market power in ways that can enhance that market power, induce production inefficiencies, and reduce welfare. Accordingly, as restructured electricity sectors consider the creation and allocation of financial and physical transmission rights, it is important that care be taken to ensure that they do not have these deleterious effects.

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