Chapter 5
Generator Ownership of Financial Transmission Rights and Market Power

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5.1 Introduction

Game theory is well suited to analyze a situation with strategic interdependence of multiple decision makers. Electricity markets include both physical and operational attributes. Likewise, electricity markets are characterized by a relatively small number of large market players, limited competitiveness and strategic behavior. Cournot models compete in quantities while Bertrand models compete in prices. Supply function equilibrium function models assume market players compete both in quantity and price. These are realistic assumptions for electricity markets where market players submit a price-quantity schedule. However these models are complex to solve and may not incorporate all technical attributes of electricity markets. Cournot models are easily solvable and yield under reasonable conditions a unique Nash equilibrium. They are also more suitable for short term analysis.

Competition is introduced in most electricity markets around the world. Markets are also increasingly coupled with interconnectors and thus may exhibit stronger price convergence. To supply more power to a region a decision maker has three choices: build power plant assets, reduce local consumption or build transmission assets. Transmission assets may bring increased competitive benefits to a market. The main objective of transmission rights is to hedge against locational price differences. But an FTR is also a transmission property right. Such a right brings the benefits associated

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with transmission capacity and facilitates efficient use of scarce resources. Property rights are also a mechanism to reward transmission investments.

Among researchers (Joskow and Tirole 2000; Léautier 2000; Gilbert et al. 2004) there is consensus about the need to mitigate market power for any FTR auction to be efficient. Joskow and Tirole (2000) study a radial line network under different market structures for both generation and FTRs. They demonstrate that FTR market power by a producer in the importing region (or a consumer in the exporting region) aggravates their monopoly (monopsony) power, because dominance in the FTR market creates an incentive to curtail generation (demand) to increase the value of the FTRs. Allocation of FTRs to a monopoly generator depends on the structure of the market (Joskow and Tirole 2000). When the FTRs are allocated initially to a single owner that is neither a generator nor a load, the monopoly generator will want to acquire all FTRs. When all FTRs initially are distributed to market players without market power, the generator will buy no FTRs. When the FTRs are auctioned to the highest bidders, the generator will buy a random number of FTRs. Extending this analysis, Gilbert et al.(2004) analyze ways of preventing perverse incentives by identifying conditions where different FTR allocation mechanisms can mitigate generator market power during transmission congestion. In an arbitraged uniform price auction, generators will buy FTRs that mitigate their market power, while in a pay-as-bid auction FTRs might enhance their market power. Specifically, in the radial line case, market power might be mitigated by not allowing generators to hold FTRs related to their own energy delivery. In the three-node case, mitigation of market power implies defining FTRs according to the reference node with the price least influenced by the generation decision of the generator. In practical implementations of the FTR model, market power mitigating rules are designed (Rosellón 2003). The Federal Energy Regulatory Commission (FERC) has included market power mitigation rules in the standard market design (FERC 2002). FERC indicates that insufficient demand-side response and transmission constraints are the two main sources for market power. FERC differentiates between high prices because of scarcity and high prices resulting from exercising market power. Using a merit-order spot market mechanism FERC proposes to use a bid cap for generators with market power in a constrained region and a "safety net" for demand side response. Regulated generators are also subject to a resource adequacy requirement. Chandley and Hogan (2002) claim that this mechanism is inefficient because the use of penalties for under-contracting (with respect to the resource adequacy requirement) would not permit prices to clear the energy and reserve markets. Moreover, long-term contracting should be voluntary, and based on financial hedging, not on capacity.

Borenstein et al. (2000) studied the economic benefits of linking markets with a transmission line. Their work demonstrated that there may be no direct relationship between the level of competition and the actual physical line utilization. For a sufficiently large transmission line capacity, a competitive outcome may be achieved even if the flow is zero. A market outcome similar to two merged markets would be replicated. Borenstein et al. (2000) applied their duopoly model to the California electricity market. Willems (2002) conducted a similar study but included the role of the network operator to enhance the competition level. Leautier (2000) studied regulatory contracts for transmission system operators and introduced a contract that incentivizes the operators to optimally expand the transmission network. Stoft (1999) studied market power arising from generation shipped to consumers over congested transmission lines. He included FTRs and the congestion rent distribution. Joskow and Tirole (2000) conducted a more general study of market power and transmission rights and suggested possible regulatory mechanisms. Cho (2003) researched the competitive equilibrium in a network with limited transmission capacity and a developed a tool to identify an efficient equilibrium. He included transmission right markets for specific electricity market structures. Gilbert et al. (2004) studied the market power effects of transmission rights. Their initial analysis focused on a simple two-node network and was extended to meshed networks.

This chapter analyzes the FTR ownership effects on the strategic behavior of electricity generators in a Cournot framework developed by Joung (2008). We follow Borenstein et al. (2000) with two identical but geographical distinct markets. Each market has an identical monopoly supplier and cost function. The model setup is similar to Borenstein et al. but also includes FTRs. Various FTR models are introduced and market efficiency is studied under FTR ownership. Joskow and Tirole studied FTRs in a two node market model and Pritchard and Philpott (2005) considered a similar model. However the market structure was simplified by assuming that only one market had consumers while the other only had producers. The market power structures were limited to monopolistic and oligopolistic competition in one market while the other market remained competitive. Thus the competitive effects of FTRs were not considered in the more typical case where producers in both markets are imperfectly competing. Likewise Cho (2003) analyzed FTRs in a two stage model where stage 1 included the transmission market with strategic behavior and stage 2 the energy market with price taking behavior. He demonstrated that inefficient equilibria may exist. However real world electricity markets differ from the proposed model and the results are thus not directly applicable. Gilbert et al. (2004) proposed a three stage model with transmission right allocation, trading and energy market output allocation. The model is solved backwards starting with the energy market. However the two node model has limitations since there is competition only among generators located in one market while the other market is perfectly competitive. Similar to Joskow and Tirole (2000) this does not consider the case when generators in different markets are imperfectly competing. Likewise the transmission line is always assumed to be congested. These limitations influence the results of each stage of the game and therefore limit the analysis of the energy market.

Game-theoretic studies focused on the competitive effects of FTRs have tried to consider mixed strategy equilibria. Borenstein et al. (2000) utilized a numerical method, Gilbert et al. (2004) presented analytic results for mixed strategy equilibria but the model limitations excluded the competitive effects of FTRs when generators in different markets are imperfectly competing.

This chapter studies the interactions between two incompletely competitive markets. In particular, this chapter investigates the competitive effects of FTR ownership of generating firms for their market strategy formulation. A Cournot framework is applied and the best response curves provide implications for FTR ownership effects in

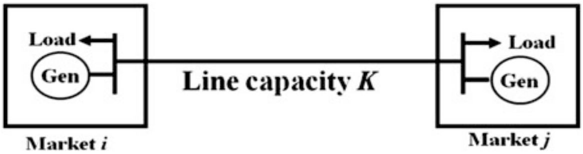


Fig. 5.1 Two market model

an unconstrained Cournot equilibrium. Allocation of outward directional FTRs to generators could result in a lower needed transmission line capacity than in Borenstein et al.'s work (2000) to achieve full competition. These FTRs which are directed from the generator to other markets hedge the generator's exposure to prices in its own home market and therefore mitigate its market power. If the generator possesses an FTR from another market to its own, the FTR causes a negative effect on competition. The FTR increases exposure to prices in the generator's home market and increases its market power. The model is also extended to include the analysis of asymmetric markets and where one market is competitive.

5.2 Two Market Model

We consider a model of two markets. Demand in each market is assumed to be characterized by an affine inverse-demand function. In each market there is a single generating firm. These two markets are linked by a single transmission line whose capacity is K. The transmission line is operated by a third entity and the electricity pricing follows the nodal pricing rules (Schweppe et al. 1988). Both generating firms try to maximize their profits by employing quantity strategies (Cournot competition). Figure 5.1 conceptually depicts the market model.

To make competitive analysis more tractable, we assume two markets are identical. That is, demand in each market is assumed to be identical and to be characterized by the same inverse-demand function denoted by P: $\Re_+ \rightarrow \Re_+$., and we also assume that both generating firms have an identical cost function C: $\Re_+ \rightarrow \Re_+$. Asymmetric markets will be discussed as an extension of the symmetric market model.

In order for the model to be more concrete, we make the following assumptions:

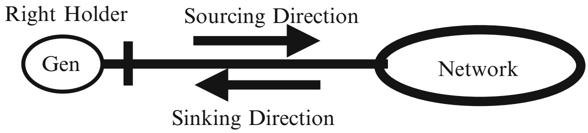
- The inverse demand $P(q)$ in each market is represented by an affine curve with a negative slope:

$$P(q) = -\alpha q + \beta, \text{ where } a, \beta \in \Re_+, \tag{5.1}$$

- Generating firms' generating costs $C(q)$ are represented by a convex quadratic function:

$$C(q) = \frac{a}{2}q^2 + bq + c, \text{ where } a, c \in \Re_+, \text{ and } b \in \Re. \tag{5.2}$$

Fig. 5.2 FTR directions



5.3 FTR Models

In this chapter, three FTR models are defined: the reference model, the FTR option model, and the FTR obligation model. The reference model considers the case in which neither firm has any FTRs.

The FTR option model is the market model with generators' owning FTR options. An FTR option is a financial contract for collecting the amount of money determined by the locational price difference and the share of the right. This option gives the owner the right to collect a portion of the congestion rents when the price difference is positive, but does not require payment when the price difference is negative.

The FTR obligation model is the market model with generators' owning FTR obligations. An FTR obligation is a similar financial contract to an FTR option, but it has negative payoff if the nodal prices reverse. That is, if the price difference is positive, a holder collects the congestion rents of the transmission line, while for the negative price difference, the holder makes a payment. Obligation-type rights also have two possible directions.

We define the "direction" of FTRs from the point of view of the generating firm that holds the transmission rights. We say the "sourcing" direction for FTRs that are in the direction from the market where the right holding generating firm is located to the other market. That is, the payoff of sourcing FTRs is defined by the nodal price in the other market minus the nodal price at the generator. The opposite direction is called the "sinking" direction. That is, the payoff of sinking FTRs is defined by the nodal price at the generator minus price in the other market. These two directions are illustrated in Fig. 5.2.

5.4 Competitive Effects of FTRs

In this section, we derive analytical expressions for the best response of each firm for different FTR models: the reference model without financial transmission rights (in Sect. 5.4.1), the FTR option model (in Sect. 5.4.2), and the FTR obligation model (in Sect. 5.4.3). We also analyze the competitive effects of the corresponding financial transmission rights for each model using best response analysis.

Following Borenstein et al. (2000), for the best response analysis, we define two categories of optimal responses: optimal aggressive output and optimal passive output. First, suppose that firm i is in the situation such that the opponent, firm j, is producing nothing (more generally, that firm j is producing so little energy that there is transmission congestion on the line in the direction from market i to market j). In this case, the best response of firm i is to produce its optimal quantity given that the line is congested from i to j. Under the nodal pricing scheme, this quantity will be the same as the monopoly output for firm i when the market is isolated but with the demand shifted to the right by K. This is called the optimal aggressive output for i and denote it with a superscript $+$.

Now, suppose that firm i is in the situation such that the opponent, firm j, is producing a great amount of electric power (more generally, firm j is producing enough energy to cause line congestion from market j to market i). In this case, the best response of firm i is to produce its optimal quantity given that the line is congested in the direction from market j to market i. Under the nodal pricing scheme, this quantity will be the monopoly output for firm i when the market is isolated with the demand shifted to the left by K. This monopoly quantity is called the optimal passive output for i and will be denoted with a superscript $-$.

Besides the optimal aggressive and passive outputs, one more category of best response behavior is needed to cover the uncongested case. Since the resulting quantity is equivalent to the unconstrained Cournot best response output for the merged markets, this output is called the Cournot best response output and is denoted with a superscript C.

5.4.1 Reference Model

If the electricity market is perfectly competitive and there is no market power, the introduction of FTRs into the market has no effect on the prices for energy or the dispatch of generators. As a reference model, the case is considered such that neither firm has any rights on the transmission line. The reference case will be denoted with a superscript r. In this case, the optimal aggressive and passive outputs, and the Cournot best response output, which are denoted by $q^{r+}(K)$, $q^{r-}(K)$, and $q_i^{rC}(q_j)$ respectively, are expressed by (5.3), (5.4), and (5.5).[1]

$$q^{r+}(K) = \frac{\beta + \alpha K - b}{2\alpha + a}, \tag{5.3}$$

$$q^{r-}(K) = \frac{\beta - \alpha K - b}{2\alpha + a}, \tag{5.4}$$

$$q_i^{rC}(q_j) = -\frac{\alpha}{2(\alpha + a)} q_j + \frac{\beta - b}{\alpha + a}. \tag{5.5}$$

Here, it can be observed that the function q^{r+} is increasing in its argument while the function q^{r-} and the function q_i^{rC} are both decreasing in their argument (Note that q^{r+}

[1] There is no case where (5.3) and (5.4) are achieved in an equilibrium in a symmetric model; however, in an asymmetric model, passive/aggressive equilibria are possible, in which case a pair of (5.3) and (5.4) will be an equilibrium output pair.

and q^{r-}. are functions of line capacity K, while q_i^{rC} is a function of production by the other firm, q_j.).

This reference model is equivalent to the symmetric two-firm model of Borenstein et al. (2000). This section serves to review their results. The line will be congested only when the difference between the outputs of two firms is greater than $2K$, since otherwise, by transferring a smaller amount of electricity than the line capacity K, the two markets' prices would be equalized.

Let us consider the best response of firm i with respect to the other firm j's strategy, q_j. When firm j is producing any amount up to $q^{r+}(K) - 2K$, firm i can maximize its profit by producing the fixed amount $q^{r+}(K)$. As firm j's output increases above $q^{r+}(K) - 2K$, however, firm i can maximize its profit and still export K by producing $2K$ more than firm j. That is, firm i maximizes its profit by producing $q_j + 2K$, accounting for the segment of slope 1 in the best responses shown in Fig. 5.2. Note that as q_j keeps increasing, firm i's resulting payoff from maintaining an aggressive response is decreasing. As firm j's output continues to increase, two situations can be thought of.

On the one hand, if K is small, then producing the optimal passive output $q^{r-}(K)$ becomes more profitable for firm i before the value of $q_i = q_j + 2K$ reaches the unconstrained Cournot best response $q_i^{rC}(q_j)$. This is shown by the dashed curve in Fig. 5.3.

On the other hand, if the line capacity is large enough, say, K' as shown in Fig. 1.3 as the solid curve, then firm i's best response will change from $q_j + 2K$ to $q_i^{rC}(q_j)$. However, even in this situation, as q_j keeps increasing, producing $q^{r-}(K)$ will eventually be more profitable for firm i than producing $q_i^{rC}(q_j)$. This accounts for the transition in the best responses to $q^{r-}(K')$ and $q^{r-}(K)$, respectively, for high enough q_j.

To summarize, the situations for the two values of line capacity are illustrated in Fig. 5.3. The solid curve shows the case of relatively large capacity K' where firm i's optimal response includes some values equal to the Cournot unconstrained best response. The dashed curve shows the case of relatively small capacity K where the best response never includes values equal to the Cournot unconstrained best response.

As shown in Fig. 5.3, the best responses of both firms will have different characteristics according to the transmission line capacity K. Specifically, increase of physical line capacity implies both increase of the optimal aggressive output $q^{r+}(K)$ and decrease of the optimal passive output $q^{r-}(K)$. Borenstein et al. (2000) shows that this, in turn, implies an increase in the competition-promoting effects of the transmission line:

- Decrease in the equilibrium price of the mixed strategy equilibrium, and
- Increase in the range of market demand conditions that result in the pure strategy Cournot equilibrium.

The results of Borenstein et al. (2000) also shows that if K is very small, then there is no pure strategy equilibrium, while if K is large enough, the Cournot duopoly equilibrium will be reached as the unique equilibrium. That is, the equilibrium is

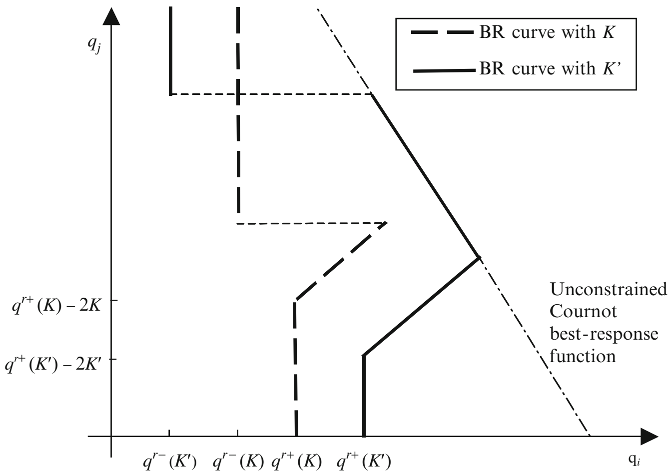


Fig. 5.3 Best response curves for firm i ($K < K'$)

specified by (5.5), with zero flow along the line but with the line providing the full competitive benefits of merged markets.

5.4.2 FTR Option Model

An FTR option is a financial contract for collecting the amount of money determined by the locational price difference and the share of the right. This option gives the owner the right to collect a portion of the congestion rents when the price difference is positive, but does not require payment when the price difference is negative. FTR options have been implemented in PJM first (PJM 2011) and are being introduced in several other markets in the United States, recently including the Electric Reliability Council of Texas (ERCOT) "nodal" market in 2010 (ERCOT 2011).

An FTR option has a specified exercise direction and if the nodal price difference is positive in this direction, then the FTR provides a positive payoff. There is zero payoff for price differences in the other direction. This means that each firm i has two possible directions for his FTR option in this two market model; that is, a direction from market i to j (the sourcing direction) and one from j to i (the sinking direction).

Let η_i^{ij} and η_i^{ji} denote generating firm i's FTR option share from market i to j and from market j to i, respectively, such that $\eta_i^{ij}, \eta_i^{ij} \in [0, 1]$. That is, η_i^{ij} describes the share of sourcing FTR, while η_i^{ji} describes the share of sinking FTRs. We use superscript *uo* to denote options.

We have:

Lemma 1. *Let q_i^{uoij+}, q_i^{uoij-}, and q_i^{uoijC} be the optimal aggressive, passive, and Cournot responses for firm i holding share η_i^{ij}. Let q_i^{uoji+}, q_i^{uoji-}, and q_i^{uojiC} be the* *optimal aggressive, passive, and Cournot responses for firm i holding share* η_i^{ji}. *Then:*

$$q_i^{uoij+}\left(K,\eta_i^{ij}\right)=q^{r+}\left(\left(1+\eta_i^{ij}\right)K\right), \tag{5.6}$$

$$q_i^{uoij-}(K)=q^{r-}(K), \tag{5.7}$$

$$q_i^{uoijC}\left(q_j\right)=q_i^{rC}\left(q_j\right), \tag{5.8}$$

$$q_i^{uoji+}(K)=q^{r+}(K), \tag{5.9}$$

$$q_i^{uoji-}\left(K,\eta_i^{ji}\right)=q^{r-}\left(\left(1+\eta_i^{ji}\right)K\right), \tag{5.10}$$

$$q_i^{uojiC}\left(q_j\right)=q_i^{rC}\left(q_j\right). \tag{5.11}$$

Proof. See Appendix.

Lemma 1 suggests that the ownership of an FTR option is equivalent to expanding the capacity of the line in one direction. This specific relationship is mainly from the linearity of demand. When the demand linearity is relaxed, this relationship would change, but a similar qualitative effect would be expected.

To summarize, an FTR option results in the change of either the optimal aggressive output (see (5.6)) or optimal passive output (see (5.10)) compared to the reference model. By possessing an η_i^{ij} FTR option, firm i's optimal aggressive output increases as indicated by (5.6), observing that by (5.3), q^{r+} is increasing in its argument. By possessing an η_i^{ji} FTR option, firm i's optimal passive output decreases as indicated by (5.10), observing that by (5.4), q^{r-} is decreasing in its argument. The change of the best response due to an FTR option is illustrated in Fig. 5.4. Note that, in order to differentiate two different response curves in Fig. 1.4, there are some line segments that are illustrated as being close together although they are in fact coincident.

As shown in Fig. 5.4, according to its direction, each FTR option has one of two different effects: either increase of the optimal aggressive output as shown in Fig. 5.4a or decrease of the optimal passive output as shown in Fig. 5.4b. This, in turn, affects the range of conditions for realization of the pure strategy equilibrium. Here, we focus on the effect on the occurrence of three forms of equilibrium: the unconstrained Cournot equilibrium, passive/aggressive equilibrium, and mixed strategy equilibrium Borenstein et al. (2000). We do not consider overlapping equilibria as described in the work of Borenstein et al. (2000).

Increase of the optimal aggressive output has no effect on achieving the unconstrained Cournot equilibrium since the unconstrained Cournot best response region is the same as that in the reference case and the range of conditions for the unconstrained Cournot equilibrium will be also the same as shown in Fig. 5.4a. On the other hand,

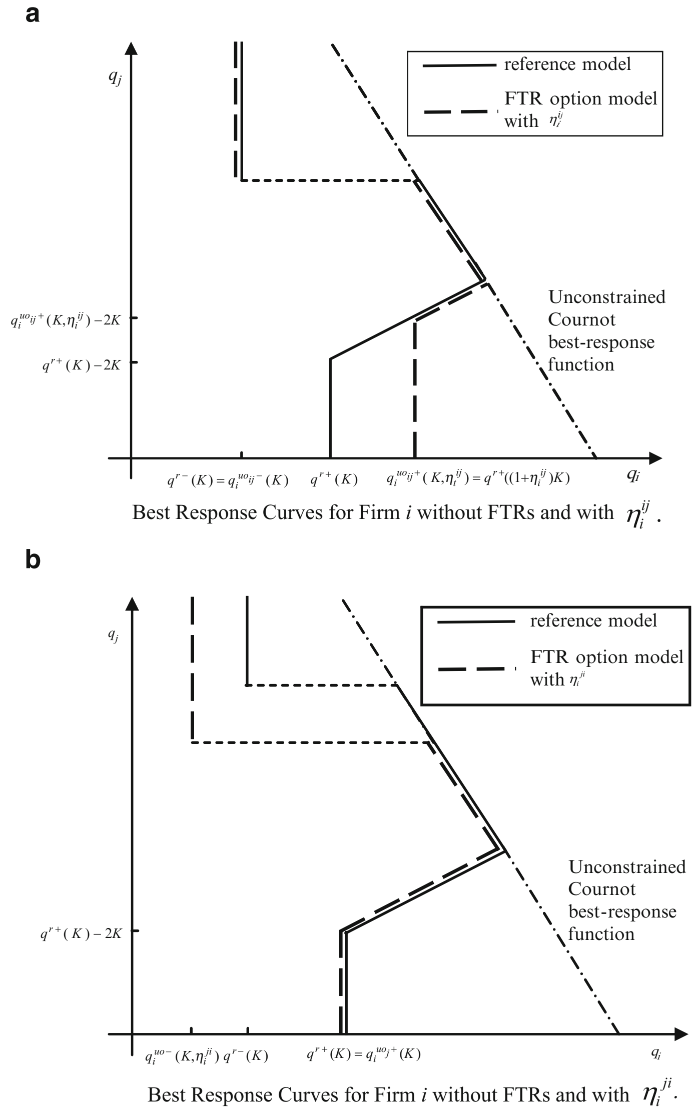


Fig. 5.4 Comparison of best response curves. (**a**) Best response curves for firm i without FTRs and with η_i^{ij}. (**b**) Best response curves for firm i without FTRs and with η_i^{ji}

decrease of the optimal passive output reduces the unconstrained Cournot best response region since the right holder becomes more inclined to the optimal passive output. That is, the transition of its best response from the unconstrained Cournot response to the optimal passive output occurs at a smaller value of the other firm's output as shown in Fig. 5.4b.

Consider a case where, without FTRs, the capacity of the transmission line is enough to achieve the unconstrained Cournot equilibrium. Figure 5.5a illustrates this case. From the previous argument, if firm i possesses an η_i^{ij} FTR option and/or firm j possesses an η_j^{ji} FTR option, then the resulting equilibrium will be the same as the unconstrained Cournot equilibrium in the reference case as shown in Fig. 5.5b.

In contrast, suppose that firm i possesses an η_i^{ji} FTR option. In this case, the resulting equilibrium may change from the unconstrained Cournot equilibrium to a mixed strategy equilibrium. This is illustrated in Fig. 5.5c. Figure 5.5c shows that by i possessing an η_i^{ji} FTR option, the change of best response curve of firm i may result in a mixed strategy equilibrium instead of the unconstrained Cournot equilibrium that is achieved without FTRs (Fig. 5.5a). A similar effect can occur if firm j possesses an η_j^{ij} FTR option.

However, for the range of $\eta_i^{ji} \in [0, 1]$, the introduction of FTR options cannot create enough asymmetry to yield a passive/aggressive equilibrium.

Lemma 2. *Suppose that, without FTRs, the capacity of the transmission line is enough to achieve the unconstrained Cournot equilibrium. In this case, by firm i's possessing an* η_i^{ji} *FTR option, the resulting equilibrium cannot change to a passive/aggressive equilibrium.*

Proof. Suppose that, with firm i's possessing an η_i^{ji} FTR option, a passive/aggressive equilibrium is achieved. Then, the price difference $P_{ij}(q_i, q_j)$, between two markets is obtained as:

$$\begin{aligned} P_{ij}\left(q_i^{uoji-}, q_j^{r+}\right) &= P\left(q_i^{uoji-} + K\right) - P\left(q_j^{r+} - K\right) \\ &= \left(\frac{\left(2 + \eta_i^{ji}\right)\alpha}{2\alpha + a} - 2\right)\alpha K < 0 \end{aligned} \tag{5.12}$$

This contradicts the assumption of achieving a passive/aggressive equilibrium since, with negative price difference, FTR options will not generate any additional payoffs and, therefore, firm i's best response will not become the optimal passive output.

Q.E.D.

5.4.3 FTR Obligation Model

An FTR obligation is a similar financial contract to an FTR option, but it has negative payoff if the nodal prices reverse. That is, if the price difference is positive, a holder collects the congestion rents of the transmission line, while for the negative price difference, the holder makes a payment. Obligation-type rights also have two possible directions. FTR obligations are implemented in several markets in the Eastern US, including PJM (PJM 2011), New York ISO (New York ISO 2011), and

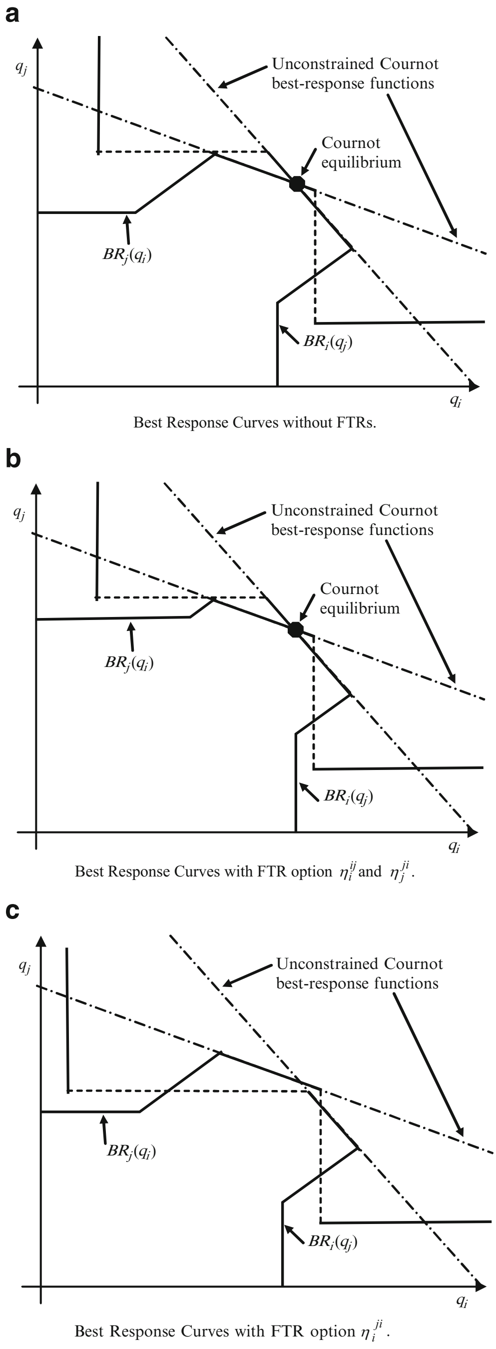


Fig. 5.5 Illustration of the effects of FTR options on the Cournot equilibrium. (**a**) Best response curves without FTRs. (**b**) Best response curves with FTR option η_i^{ij} and η_j^{ji}. (**c**) Best response curves with FTR option η_i^{ji}

New England ISO (New England ISO 2011), and are available in California ISO (California ISO 2011), Midwest ISO (Midwest ISO 2011) and the ERCOT nodal market (ERCOT 2011).

Let the FTR obligation share of firm i be denoted by $\gamma_i \in [-1, 1]$, where the sourcing direction is assumed positive. That is, firm i collects or pays γ_i portion of the total congestion rents. We use superscript *ob* to denote FTR obligations.

We have:

Lemma 3.

$$q_i^{ob+}(k, \gamma_i) = \frac{\beta + (1+\gamma_i)\alpha k - b}{2\alpha + a} = q^{r+}((1+\gamma_i)k), \tag{5.13}$$

$$q_i^{ob-}(k, \gamma_i) = \frac{\beta - (1-\gamma_i)\alpha k - b}{2\alpha + a} = q^{r-}((1-\gamma_i)k), \tag{5.14}$$

$$q_i^{obC}(q_j) = -\frac{1}{2(\alpha + a)} q_j + \frac{\beta - b}{\alpha + a} = q_i^{rC}(q_j). \tag{5.15}$$

Proof. See Appendix.

These results imply that firm i possessing γ_i FTR obligation has the same effects on the firms' strategic behaviors as having two directional transmission lines with different capacities: capacity $(1+\gamma_i)K$ MW from market i to j and capacity $(1-\gamma_i)K$ MW from market j to i. The resulting competitive effects are different depending on the sign of γ_i.

First, suppose that $\gamma_i \geq 0$. This means that, in terms of its effect on competitive behavior, the effective line capacity increases by the amount of $\gamma_i K$ MW in the i to j direction, while the effective line capacity decreases by $\gamma_i K$ MW in the opposite direction. This results in an increase of both the optimal aggressive output and the optimal passive output compared to those in the reference model.[2]

On the other hand, if $\gamma_i < 0$, the opposite results are obtained; that is, the optimal aggressive and passive outputs decrease. Figure 5.6 shows these effects of an FTR obligation.

As shown in Fig. 5.6a, a positive FTR obligation will have positive effect on achieving the unconstrained Cournot equilibrium by increasing the unconstrained Cournot best response region. A negative FTR obligation will have a negative effect on achieving the unconstrained Cournot equilibrium as shown in Fig. 5.6b. Suppose that, without FTRs, the unconstrained Cournot equilibrium is achieved as illustrated in Fig. 5.7a. Here, we consider only the effect of firm i's possession of FTR obligations. In this case, if firm i possesses a positive FTR obligation then the only possible pure strategy equilibrium will be the same unconstrained Cournot equilibrium as shown in Fig. 5.7b.

Now consider a case where, without FTRs, the capacity of the transmission line is not enough to achieve the unconstrained Cournot equilibrium. Figure 5.7c illustrates

[2] Of course, the amount of power transferred over the line remains limited to K.

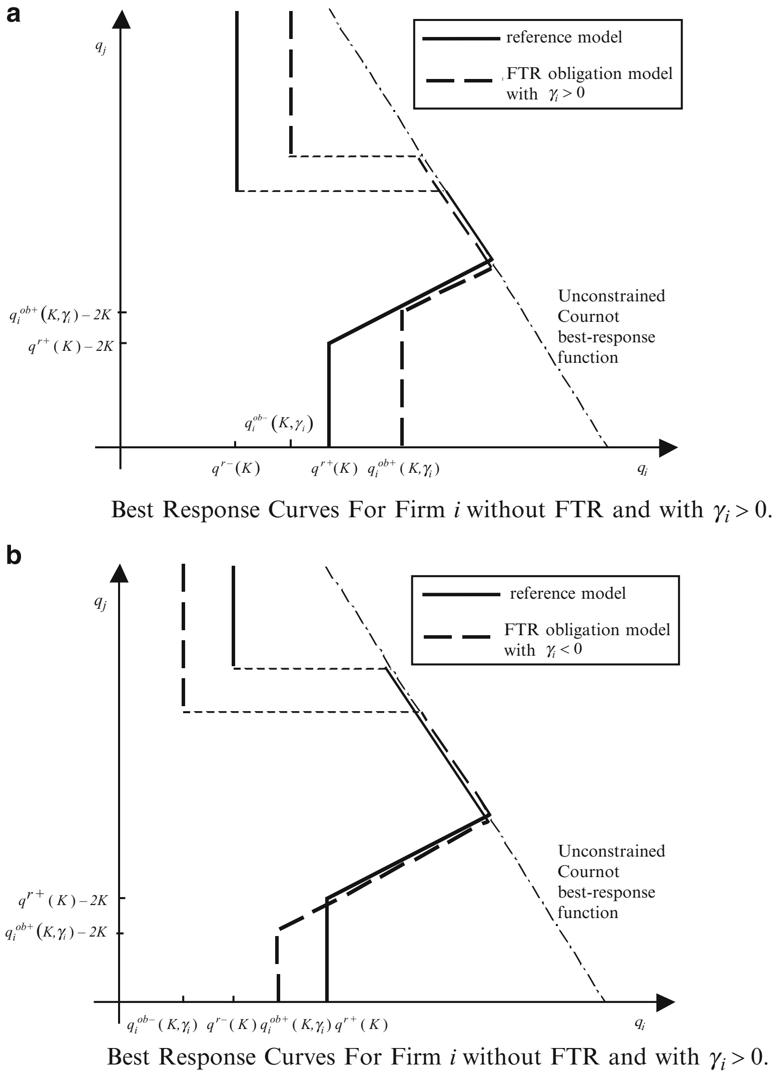
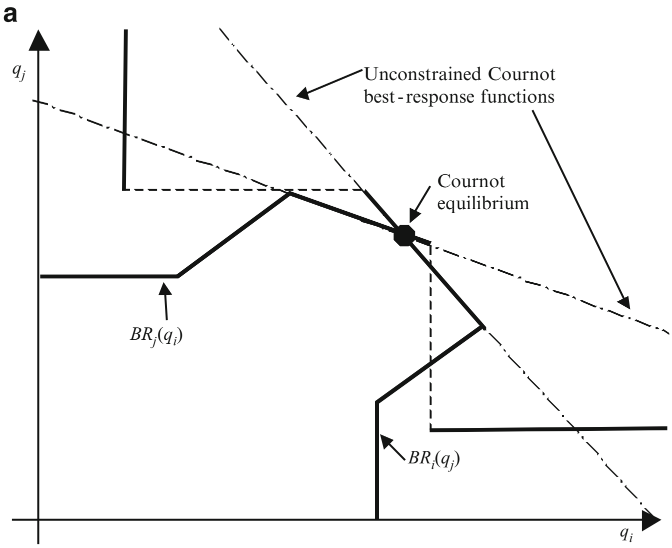
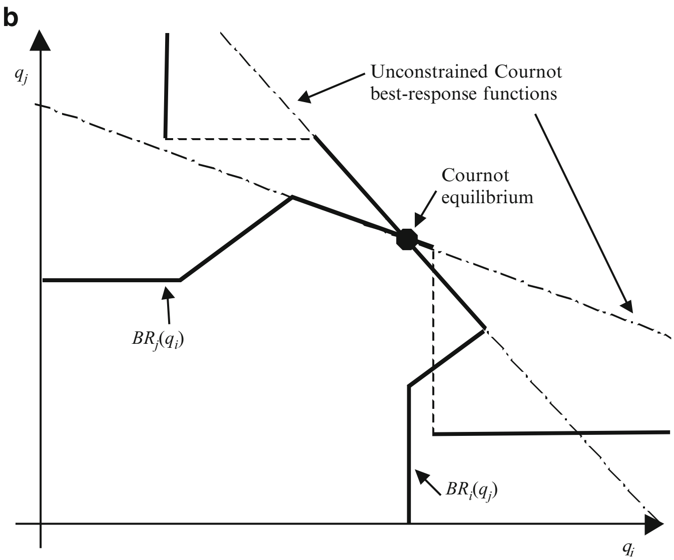


Fig. 5.6 Comparison of best response curves. (**a**) Best response curves for firm i without FTR and with $\gamma_i > 0$. (**b**) Best response curves for firm i without FTR and with $\gamma_i < 0$

this case. As shown in the figure, due to the insufficient line capacity, two best response curves do not intersect at the unconstrained Cournot equilibrium. Without FTRs, only a mixed equilibrium can occur. By Borenstein et al. (2000), the expected price will be higher than in the Cournot equilibrium. Figure 5.7d shows that by i and j each possessing a positive FTR obligation, two best response curves intersects at the unconstrained Cournot equilibrium due to both firms' changed Cournot best response regions. As illustrated in Fig. 5.7d, a positive FTR obligation may result in the unconstrained Cournot equilibrium when it was impossible without FTRs.

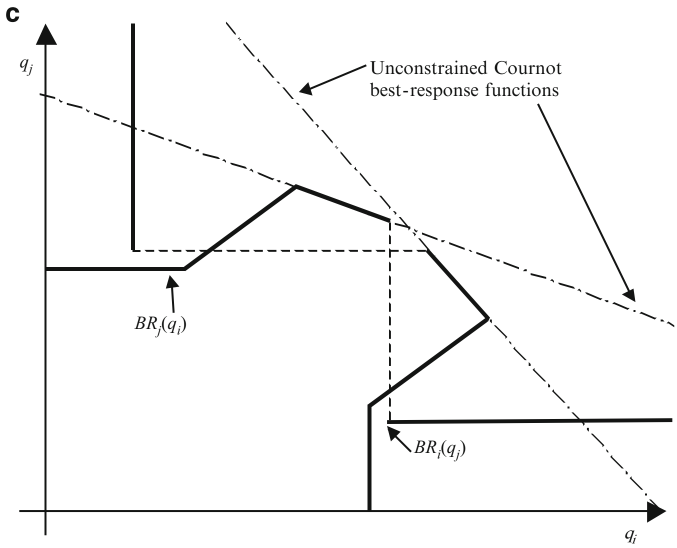


Best Response Curves without FTR.

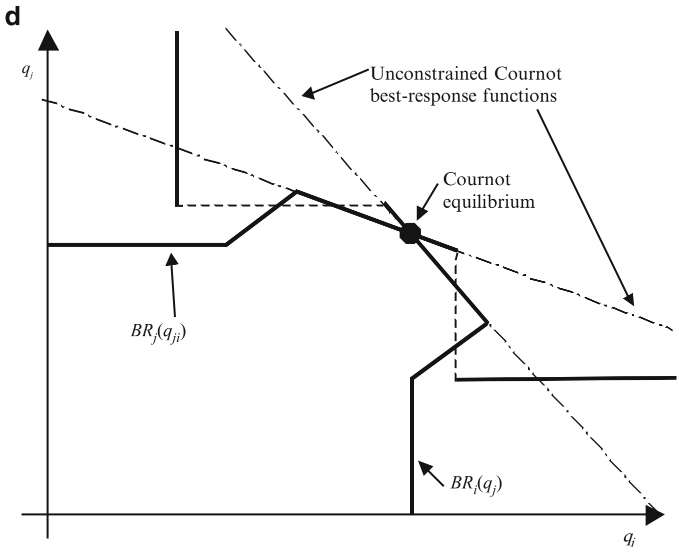


Best Response Curves with Positive FTR Obligations.

Fig. 5.7 (continued)



Best Response Curves without FTR.



Best Response Curves with Positive FTR Obligations.

Fig. 5.7 Illustration of the effects of positive FTR obligations on the Cournot equilibrium. (**a**) Best response curves without FTR. (**b**) Best response curves with positive FTR obligations. (**c**) Best response curves without FTR. (**d**) Best response curves with positive FTR obligations

On the other hand, Fig. 5.8 illustrates that negative FTR obligations may result in a passive/aggressive equilibrium while the unconstrained Cournot equilibrium is achieved without FTRs. Figure 5.8a illustrates that, due to the sufficient line capacity,

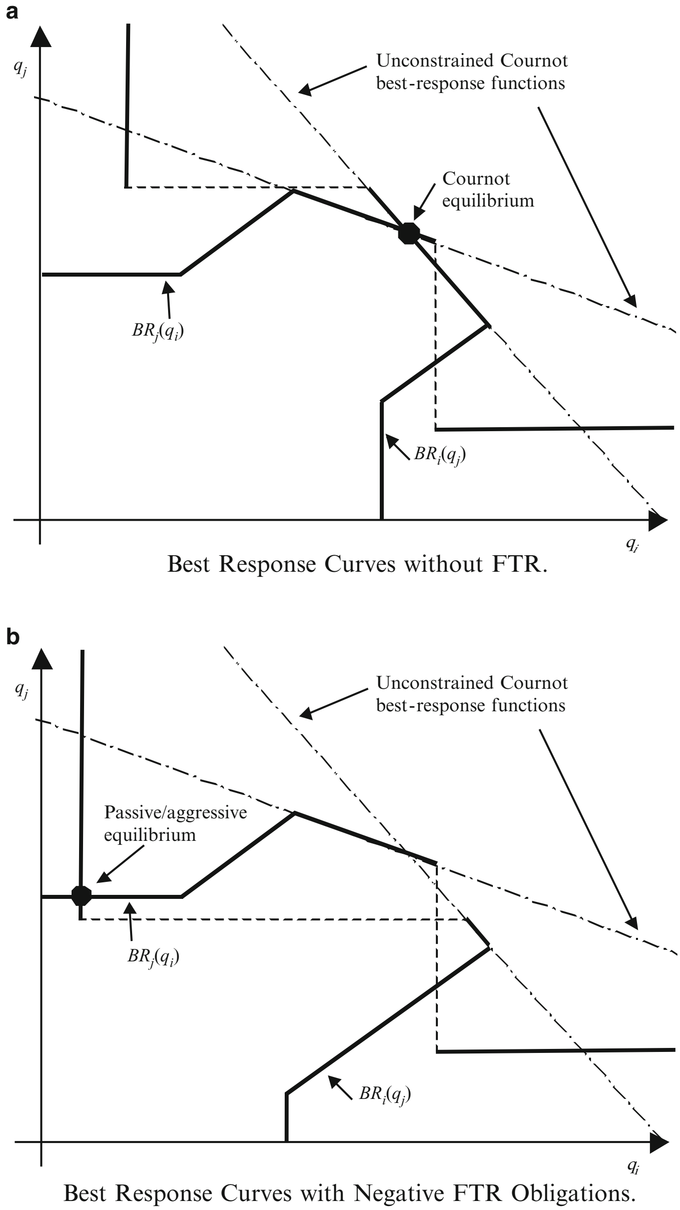


Fig. 5.8 Illustration of the effects of negative FTR obligations on the Cournot equilibrium. (**a**) Best response curves without FTR. (**b**) Best response curves with negative FTR obligations

two best response curves intersect at the unconstrained Cournot equilibrium without FTRs. Here, we consider only the effect of firm i's possession of FTR obligations. As shown in Fig. 5.8b, with i possessing a negative FTR obligation, a passive/aggressive equilibrium is achieved.

5.5 Model Extensions

In this section, we comment on two model extensions: an asymmetric market and a competitive market.

5.5.1 Asymmetric Markets

Borenstein et al. (2000) showed that for the reference model, if markets are asymmetric enough, then even a very thin transmission line can provide a pure strategy equilibrium: a passive/aggressive equilibrium. Moreover, they showed that, with a sufficiently large line, the unconstrained Cournot equilibrium is the unique pure-strategy equilibrium and that this is the same as the case of symmetric markets.

With our other FTR models, under certain conditions, a passive/aggressive equilibrium is possible even in the case where, without ownership of FTRs, the unconstrained Cournot equilibrium is the unique pure-strategy equilibrium. This shows that FTRs may effectively increase asymmetry of markets that, otherwise, is not enough to yield a passive/aggressive equilibrium. However, by the same reasoning as for the reference model, with a sufficiently large line capacity, the unconstrained Cournot equilibrium will be the unique pure-strategy equilibrium even with FTRs.

Consider a case where, without FTRs, asymmetry of markets is small enough to achieve the unconstrained Cournot equilibrium. Figure 5.9a illustrates this case. Suppose that firm i possesses an η_i^{ji} FTR option. In this case, the resulting equilibrium may change from the unconstrained Cournot equilibrium to a passive/aggressive strategy equilibrium. This is illustrated in Fig. 5.9b. Figure 5.9b shows that by i possessing an η_i^{ji} FTR option, asymmetry of markets increases enough to result in a passive/aggressive equilibrium instead of the unconstrained Cournot equilibrium that is achieved without FTRs (Fig. 5.9a).

5.5.2 Competitive Market

In the work of Borenstein et al. (2000), the reference model was compared to a variant in which one of the markets is perfectly competitive. The result was that the effect of a transmission line on the reference model is greater than the effect on a model where one of the markets is competitive. This is mainly because the strategic interaction of two firms in the reference model leads to the Cournot duopoly quantity, while in the other model with a perfectly competitive market, the best response of a firm

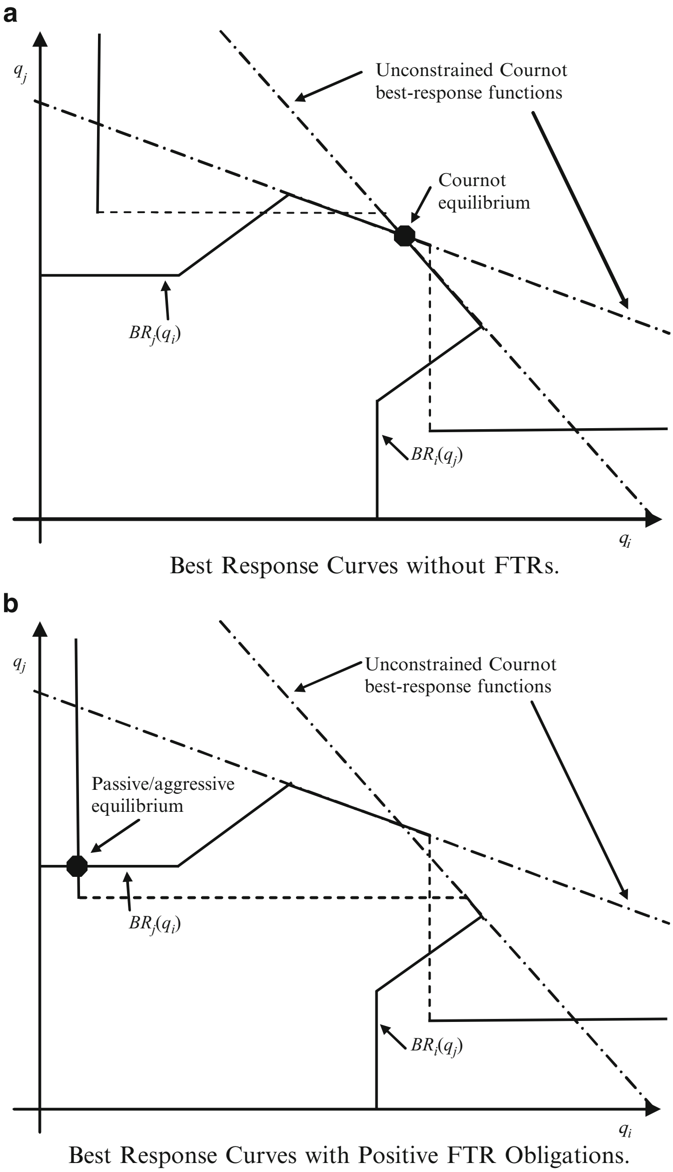


Fig. 5.9 Illustration of the effects of FTR options on the Cournot equilibrium. (**a**) Best response curves without FTRs. (**b**) Best response curves with FTR option η_i^{ji}

confronting the competitive market will be the monopoly quantity, given imports from the competitive market equal to the line capacity.

Joskow and Tirole (2000) studied a similar model with FTRs. In their model, one market has a demand and a strategic supplier, while the other market has only competitive suppliers. Consequently, the direction of line flow is only in the direction to the market with demand and any strategic interaction among firms is not considered. They have shown using this setup that if only the strategic firm in the demand market holds FTRs, then these rights will enhance its market power.

Unlike Joskow and Tirole's model, in FTR models presented in this study, each market has both supply and demand and both directions of line flow must be considered. By assuming that one of the markets is competitive, there is no strategic interplay between firms. To correspond to Joskow and Tirole's model, we assume that firm i is the only strategic firm and that firm j is perfectly competitive. We consider the cases of FTR options and FTR obligations in Sects. 5.5.2.1 and 5.5.2.2.

Since firm j is perfectly competitive, the following equation holds:

$$C'\left(q_j\right) = cq_j + b = p_j, \tag{5.16}$$

where p_j is the price in market j. The price p_j is determined by the supply quantities as follows:

$$p_j = \begin{cases} -\alpha q_j + \alpha K + \beta, & \text{if } q_i < q_j - 2K, \\ -\alpha \dfrac{q_i + q_j}{2} + \beta, & \text{if } q_j - 2K \le q_i \le q_j + 2K, \\ -\alpha q_j - \alpha K + \beta, & \text{if } q_i > q_j + 2K. \end{cases} \tag{5.17}$$

From (5.16) and (5.17), the quantity q_j is represented by (5.18):

$$q_j = \begin{cases} \dfrac{1}{c+\alpha}(\beta + \alpha K - b), & \text{if } q_i < \dfrac{1}{c+\alpha}(\beta - b - (2c+\alpha)K), \\ -\dfrac{\alpha q_i}{2c+\alpha} + \dfrac{2}{2c+\alpha}(\beta - b), & \\ \qquad \text{if } \dfrac{1}{c+\alpha}(\beta - b - (2c+\alpha)K) \le q_i \le \dfrac{1}{c+\alpha}(\beta - b + (2c+\alpha)K), & \\ \dfrac{1}{c+\alpha}(\beta - \alpha K - b), & \text{if } q_i > \dfrac{1}{c+\alpha}(\beta - b + (2c+\alpha)K). \end{cases} \tag{5.18}$$

Consequently, p_j can be rewritten as (5.19):

$$p_j = \begin{cases} \dfrac{\alpha b}{c+\alpha} + \dfrac{c}{c+\alpha}(\beta + \alpha K), & \text{if } q_i < \dfrac{1}{c+\alpha}(\beta - b - (2c+\alpha)K), \\ -\dfrac{\alpha c q_i}{2c+\alpha} + \dfrac{1}{2c+\alpha}(2c\beta + \alpha b), & \\ \qquad \text{if } \dfrac{1}{c+\alpha}(\beta - b - (2c+\alpha)K) \le q_i \le \dfrac{1}{c+\alpha}(\beta - b + (2c+\alpha)K), & \\ \dfrac{\alpha b}{c+\alpha} + \dfrac{c}{c+\alpha}(\beta - \alpha K), & \text{if } q_i > \dfrac{1}{c+\alpha}(\beta - b + (2c+\alpha)K). \end{cases} \tag{5.19}$$

Now, based on the above analytic results, each FTR model is analyzed in the following sections.

5.5.2.1 FTR Option Model

We have:

Lemma 4. *Firm i's optimal output* $q_i^{\eta_i^{ij}}$ (q_i^{ji}) *with* η_i^{ij} (η_i^{ji}) *is:*

$$q_i^{\eta_i^{ij}} = \frac{\beta - b + \alpha\left(1 + \eta_i^{ij}\right)K}{c + 2\alpha}, \tag{5.20}$$

$$q_i^{\eta_i^{ji}} = \frac{\beta - b - \alpha\left(1 + \eta_i^{ji}\right)K}{c + 2\alpha}. \tag{5.21}$$

Proof. See Appendix.

This shows that the larger η_i^{ij}, the larger $q_i^{\eta_i^{ij}}$, while the larger η_i^{ji}, the smaller $q_i^{\eta_i^{ji}}$. Joskow and Tirole's result (2000) corresponds only to (5.21) since they considered only the flow direction from j to i.

5.5.2.2 FTR Obligation Model

We have:

Lemma 5. *Firm i's optimal output with an FTR obligation* γ_i *will be either* $\frac{\beta - b + \alpha(1 + \gamma_i)K}{c + 2\alpha}$ or $\frac{\beta - b - \alpha(1 - \gamma_i)K}{c + 2\alpha}$.

Proof. See Appendix.

Note that $\gamma_i \in [-1, 1]$, where the sourcing direction is assumed positive. By investigating the analytic representation of the optimal output, we can easily see that by possessing larger γ_i, both the optimal aggressive and passive outputs will increase.

Although Joskow and Tirole's model (2000) also considers FTR obligations, their model cannot examine the whole characteristics of FTR obligations, i.e., the negative revenue from FTR obligations, since they limited the direction of line flow. As stated in 3.4.2.1, their model actually corresponds to the FTR option model with η_i^{ji} corresponding to negative γ_i. They concluded that if the firm i "holds financial rights, these rights will enhance its market power", but this conclusion depends on the assumed directions of the flow and FTRs. The conclusion in this subsection is that, by possessing larger positive γ_i, both the optimal aggressive and passive outputs will increase. That is, larger FTR obligations will mitigate the right holding firm's market power in this case.

5.6 Summary and Conclusion

As stated in the work of Borenstein et al. (2000), the full benefits of competition can be achieved by connecting two markets with a sufficiently large capacity line so that each generator would compete over the merged market instead of over a residual market of its own. In this chapter, we have demonstrated how to analyze the impact of ownership of FTRs on competition, and showed that, by introducing FTRs in an appropriate manner, the physical capacity needed for the full benefits of competition can be reduced. It has also shown that, by introducing FTRs, we may reduce the required physical capacity of the transmission line that is necessary to achieve a pure strategy equilibrium, particularly for achieving the unconstrained Cournot equilibrium that gives the full benefits of competition of a merged market. We have provided separate results for FTR option models and for an FTR obligation model in this chapter. This enables the results to be applied to a market using a specific FTR model.

We also extended the FTR models by considering asymmetric markets and by assuming that one of the markets is perfectly competitive. Asymmetry of markets makes it possible for the ownership of FTRs to change market equilibrium from the unconstrained Cournot equilibrium to a passive/aggressive equilibrium. By constraining one market to be competitive, we could show a similar result to that in the work of Joskow and Tirole (2000). Moreover, other results from the same model were also obtained and some of them show that FTRs may reduce the firm's market power while Joskow and Tirole showed only the result of enhancing the firm's market power.

Appendix

This appendix provides proofs of the Lemmas.

Proof of Lemma 1. First, we consider the direction of option share from market i to j. Suppose that there is no congestion. In this case, prices are equated across markets so each market gets half of the total output of both firms. On the other hand, if there is congestion, then the prices of the markets are different. Two congested situations can be differentiated: one is to import K MW with line congestion, and the other is to export K MW with line congestion. Here, I notice that line congestion can occur only when the output difference of both firms is greater than $2K$ MW. More precisely, market i imports with congestion when $q_i < q_j - 2K$, and exports with congestion when $q_i > q_j + 2K$. In this setting, the profit of firm i is represented by the profit function π_i:

$$\pi_i = \begin{cases} P(q_i - K)q_i + \eta_i^{ij} K\left(P\left(q_j + K\right) - P(q_i - K)\right) - C(q_i), & \text{if } q_i > q_j + 2K, \\ P(q_i + K)q_i - C(q_i), & \text{if } q_i < q_j - 2K, \\ P\left(\dfrac{q_i + q_j}{2}\right)q_i - C(q_i), & \text{if } q_j - 2K \le q_i \le q_j + 2K, \end{cases} \tag{5.22}$$

where q_i is firm i's output and q_j is firm j's output.

Using the explicit forms of demand and costs from (5.1) to (5.2), the profit function of firm i is:

$$\pi_i = \begin{cases} q_i(-\alpha q_i + \alpha K + \beta) + \eta_i^{ij} K\left(\alpha\left(q_i - q_j\right) - 2\alpha K\right) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_i > q_j + 2K, \\ q_i(-\alpha q_i - \alpha K + \beta) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_i < q_j - 2K, \\ q_i\left(-\alpha \dfrac{q_i + q_j}{2} + \beta\right) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_j - 2K \le q_i \le q_j + 2K. \end{cases} \tag{5.23}$$

From (5.23) and the definition, firm i's optimal aggressive and passive outputs and Cournot best response output, which are denoted by $q_i^{uo_{ij}+}\left(K, \eta_i^{ij}\right)$, $q_i^{uo_{ij}-}(K)$, and $q_i^{obC}\left(q_j\right)$, respectively, are obtained by (5.24), (5.25), and (5.26):

$$q_i^{uo_{ij}+}\left(K, \eta_i^{ij}\right) = \arg\max_{q_i} \times \left[q_i(-\alpha q_i + \alpha K + \beta) + \eta_i^{ij} K\left(\alpha\left(q_i - q_j\right) - 2\alpha K\right) - \frac{a}{2}q_i^2 - bq_i - c\right], \tag{5.24}$$

$$q_i^{uo_{ij}-}(K) = \arg\max_{q_i} \left[q_i(-\alpha q_i - \alpha K + \beta) - \frac{a}{2}q_i^2 - bq_i - c\right], \tag{5.25}$$

$$q_i^{uo_{ij}C}\left(q_j\right) = \arg\max_{q_i} \left[q_i\left(-\alpha \frac{q_i + q_j}{2} + \beta\right) - \frac{a}{2}q_i^2 - bq_i - c\right]. \tag{5.26}$$

By solving (5.24), (5.25), and (5.26), the optimal aggressive and passive outputs and the Cournot best response output can be explicitly expressed as (5.27), (5.28), and (5.29):

$$q_i^{uo_{ij}+}\left(K, \eta_i^{ij}\right) = \frac{\beta + \left(1 + \eta_i^{ij}\right)\alpha K - b}{2\alpha + a}, \tag{5.27}$$

$$q_i^{uo_{ij}-}(K) = \frac{\beta - \alpha K - b}{2\alpha + a}, \tag{5.28}$$

$$q_i^{uo_{ij}C}(q_j) = -\frac{\alpha}{2(\alpha + a)} q_j + \frac{\beta - b}{\alpha + a}. \tag{5.29}$$

By comparing (5.27), (5.28), and (5.29) with (5.3), (5.4), and (5.5), we can easily observe that (5.6), (5.7), and (5.8) hold.

Similarly, for the case in which firm i possesses an η_i^{ji} FTR option in the other direction, the following results are obtained:

$$q_i^{uo_{ji}+}(K) = \frac{\beta + \alpha K - b}{2\alpha + a}, \tag{5.30}$$

$$q_i^{uo_{ji}-}\left(K, \eta_i^{ji}\right) = \frac{\beta - \left(1 + \eta_i^{ji}\right)\alpha K - b}{2\alpha + a}, \tag{5.31}$$

$$q_i^{uo_{ji}C}(q_j) = -\frac{\alpha}{2(\alpha + a)} q_j + \frac{\beta - b}{\alpha + a}, \tag{5.32}$$

Therefore, we also observe that (5.9), (5.10), and (5.11) hold.
Q.E.D.

Proof of Lemma 3. In the FTR obligation model, the profit of each firm i is represented by the profit function π_i:

$$\pi_i = \begin{cases} P(q_i - K)q_i + \gamma_i K\left(P\left(q_j + K\right) - P(q_i - K)\right) - C(q_i), & \text{if } q_i > q_j + 2K, \\ P(q_i + K)q_i - \gamma_i K\left(P(q_i + K) - P\left(q_j - K\right)\right) - C(q_i), & \text{if } q_i < q_j - 2K, \\ P\left(\dfrac{q_i + q_j}{2}\right)q_i - C(q_i), & \text{if } q_j - 2K \le q_i \le q_j + 2K, \end{cases} \tag{5.33}$$

where q_i is firm i's output and q_j is firm j's output.

Using the explicit forms of demand and costs of (3.1) and (3.2), the profit function of firm i is rewritten such that:

$$\pi_i = \begin{cases} q_i(-\alpha q_i + \alpha K + \beta) + \gamma_i K\left(\alpha\left(q_i - q_j\right) - 2\alpha K\right) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_i > q_j + 2K, \\ q_i(-\alpha q_i - \alpha K + \beta) - \gamma_i K\left(\alpha\left(q_j - q_i\right) - 2\alpha K\right) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_i < q_j - 2K, \\ q_i\left(-\alpha\dfrac{q_i + q_j}{2} + \beta\right) - \dfrac{a}{2}q_i^2 - bq_i - c, & \text{if } q_j - 2K \le q_i \le q_j + 2K. \end{cases} \tag{5.34}$$

From (5.34) and the definition, firm i's optimal aggressive and passive outputs and Cournot best response output, which are denoted by $q_i^{ob+}(K,\gamma_i), q_i^{ob-}(K,\gamma_i)$, and $q_i^{obC}\left(q_j\right)$ respectively, are obtained by (5.35), (5.36), and (5.37).

$$q_i^{ob+}(K,\gamma_i) = \arg\max_{q_i}\left[q_i(-\alpha q_i+\alpha K+\beta)+\gamma_i K\left(\alpha\left(q_i-q_j\right)-2\alpha K\right)-\frac{a}{2}q_i^2-bq_i-c\right], \tag{5.35}$$

$$q_i^{ob-}(K,\gamma_i) = \arg\max_{q_i}\left[q_i(-\alpha q_i-\alpha K+\beta)-\gamma_i K\left(\alpha\left(q_j-q_i\right)-2\alpha K\right)-\frac{a}{2}q_i^2-bq_i-c\right], \tag{5.36}$$

$$q_i^{obC}\left(q_j\right) = \arg\max_{q_i}\left[q_i\left(-\alpha\frac{q_i+q_j}{2}+\beta\right)-\frac{a}{2}q_i^2-bq_i-c\right]. \tag{5.37}$$

By solving (5.35), (5.36), and (5.37), the optimal aggressive and passive outputs and the Cournot best response output can be explicitly expressed as (5.16), (5.17), and (5.18).

Q.E.D.

Proof of Lemma 4. The profit of firm i, $\pi_i^{\eta_i^{ij}}$, with an FTR η_i^{ij} is represented as:

$$\pi_i^{\eta_i^{ij}} = \begin{cases} -\left(\frac{c}{2}+\alpha\right)q_i^2-(b+\alpha K-\beta)q_i-a, & \textit{if } q_i<\frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K), \\ -\left(\frac{c}{2}+\frac{\alpha c}{2c+\alpha}\right)q_i^2-\left(b-\frac{1}{2c+\alpha}(2c\beta+\alpha b)\right)q_i-a, & \\ \qquad \textit{if } \frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K)\le q_i\le\frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K), & \\ -\left(\frac{c}{2}+\alpha\right)q_i^2-\left(b-\alpha\left(1+\eta_i^{ij}\right)K-\beta\right)q_i-a-\frac{\alpha\eta_i^{ij}K}{c+\alpha}(\beta-b+(2c+\alpha)K), & \\ \qquad \textit{if } q_i>\frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K). & \end{cases} \tag{5.38}$$

The profit of firm i, $\pi_i^{\eta_i^{ji}}$, with an FTR η_i^{ji} is represented as:

$$\pi_i^{\eta_i^{ji}} = \begin{cases} -\left(\frac{c}{2}+\alpha\right)q_i^2 - \left(b+\alpha\left(1+\eta_i^{ji}\right)K-\beta\right)q_i - a - \frac{\alpha\eta_i^{ji}K}{c+\alpha}(\beta-b-(2c+\alpha)K), \\ \qquad \textit{if } q_i < \frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K), \\ -\left(\frac{c}{2}+\frac{\alpha c}{2c+\alpha}\right)q_i^2 - \left(b-\frac{1}{2c+\alpha}(2c\beta+\alpha b)\right)q_i - a, \\ \qquad \textit{if } \frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K) \le q_i \le \frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K), \\ -\left(\frac{c}{2}+\alpha\right)q_i^2 - (b-\alpha K-\beta)q_i - a, \qquad \textit{if } q_i > \frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K). \end{cases} \tag{5.39}$$

Since there is no strategic response from market j, firm i faces the above profit function to maximize. Each of $\pi_i^{\eta_i^{ij}}$ and $\pi_i^{\eta_i^{ji}}$ has three different regions with respect to q_i and we need to compare the maximum profit in each region to identify firm i's optimal output. Since we can observe that the possession of FTRs only affects the third row of (5.38) and the first row of (5.39), we need to consider only these two rows in order to assess the effect of FTR rights. So, suppose that the maximum profit is obtained by the third row of (5.38) or the first row of (5.39) with the FTR option η_i^{ij} and η_i^{ji}, respectively. Then, firm i's optimal output $q_i^{\eta_i^{ij}}$ (q_i^{ji}) with η_i^{ij} (η_i^{ji}) will be (5.20) ((5.21)).

Q.E.D.

Proof of Lemma 5. We denote by $\pi_i^{\gamma_i}$ firm i's profit with an FTR obligation γ_i. It is given by:

$$\pi_i^{\gamma_i} = \begin{cases} -\left(\frac{c}{2}+\alpha\right)q_i^2 - (b+\alpha(1-\gamma_i)K-\beta)q_i - a + \frac{\alpha\gamma_i K}{c+\alpha}(\beta-b-(2c+\alpha)K), \\ \qquad \textit{if } q_i < \frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K), \\ -\left(\frac{c}{2}+\frac{\alpha c}{2c+\alpha}\right)q_i^2 - \left(b-\frac{1}{2c+\alpha}(2c\beta+\alpha b)\right)q_i - a, \\ \qquad \textit{if } \frac{1}{c+\alpha}(\beta-b-(2c+\alpha)K) \le q_i \le \frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K), \\ -\left(\frac{c}{2}+\alpha\right)q_i^2 - (b-\alpha(1+\gamma_i)K-\beta)q_i - a - \frac{\alpha\gamma_i K}{c+\alpha}(\beta-b+(2c+\alpha)K), \\ \qquad \textit{if } q_i > \frac{1}{c+\alpha}(\beta-b+(2c+\alpha)K). \end{cases} \tag{5.40}$$

To examine the effect of FTR obligations, we suppose that the maximum profit is obtained either by the first row or by the third row of (5.40). Then, firm i's optimal output will be either $\dfrac{\beta - b + \alpha(1+\gamma_i)K}{c+2\alpha}$ or $\dfrac{\beta - b - \alpha(1-\gamma_i)K}{c+2\alpha}$.

Q.E.D.

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