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Interpreting concentration indices in the secondary market for natural gas transportation: The implication of pipeline residual rights ☆

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Abstract

In 1992, the U.S. Federal Energy Regulatory Commission created a secondary market for natural gas transportation whereby shippers holding firm transportation capacity on interstate natural gas pipelines can compete with the pipeline in the provision of transportation services. However, if a shipper does not use some of its contracted firm transportation capacity, the pipeline can resell that capacity as interruptible transportation. That is, the pipeline has residual rights with respect to firm transportation capacity contracted for by shippers. We demonstrate that these residual rights can have a significant effect on the competitiveness of the secondary market for natural gas transportation. A consequence of these residual rights is that the secondary market for natural gas transportation may be considerably more competitive than indicated by measures of concentration like the widely used Herfindahl–Hirschman Index.

JEL classification: L5; Q4

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1. Introduction

Two of the most important types of transportation services offered by interstate natural gas pipelines in the U.S. are firm transportation service ("FTS") and interruptible transportation service ("ITS"). When a shipper contracts with a pipeline for FTS, the pipeline commits to transport the contracted amount of the shipper's natural gas. ITS differs from FTS in that a pipeline supplies ITS only after that pipeline's FTS obligations have been fulfilled. In general, FTS is more reliable than ITS since ITS can be interrupted depending on the demand for FTS.

The U.S. Federal Energy Regulatory Commission ("FERC") currently regulates the prices that interstate natural gas pipelines can charge for FTS and ITS. In its 1996 Statement of Policy and Request for Comments[1] ("Policy Statement"), the FERC outlined criteria it would use to evaluate proposals by interstate pipelines to charge market-based rates for services such as FTS and ITS. According to the Policy Statement, a pipeline seeking permission to charge market-based rates must demonstrate a lack of market power in the relevant market. The Policy Statement uses the well-known Herfindahl–Hirschman Index ("HHI") as a screening device for evaluating a pipeline's market power.[2]

The HHI is calculated by summing the squared market shares of all firms in a market. The rationale for using the HHI is provided by the widely used Cournot model of oligopoly.[3] Under the assumptions of the Cournot model, the HHI is proportional to the price–cost margin, which is the proportion of price that is a mark-up over marginal cost. Market power is the ability to maintain prices above a competitive level profitably for a significant period of time.[4] Thus, if the assumptions underlying the Cournot model are satisfied, a higher HHI implies a higher price–cost margin and, therefore, greater market power, all else equal.[5]

The set of sellers available to consumers of natural gas transportation consists of pipelines and shippers holding FTS capacity on pipelines, since shippers holding FTS capacity can use the FERC's capacity release rules to compete with pipelines' FTS and ITS offerings in the secondary market for natural gas transportation. Thus, an HHI for the secondary market for natural gas transportation could be calculated by summing the squared market shares of the pipelines and shippers holding FTS capacity in the relevant geographic market. However, as we demonstrate below, the price–cost margin, and hence the market power, implied by this HHI is too high because this calculation of the HHI does not account for the effect of the pipeline's residual rights with respect to FTS capacity contracted for but not used by shippers. That is, shippers' attempts to exercise market power in the secondary market for natural gas transportation by withholding FTS capacity may be hindered, and in some cases defeated, because the pipeline will find it profitable to resell some or all of the FTS capacity contracted for but not used by shippers as ITS.

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[1] Federal Energy Regulatory Commission, *Alternatives to Traditional Cost-of-Service Ratemaking for Natural Gas Pipelines*, 74 FERC 61,076 (1996).

[2] See, Policy Statement at 34–36.

[3] See, e.g., Jeffery Church and Roger Ware, Industrial Organization, A Strategic Approach, Irwin McGraw-Hill (2000), pp. 231–256.

[4] See, e.g., U.S. Department of Justice and Federal Trade Commission, Horizontal Merger Guidelines, Revised April 8, 1997, at 0.1.

[5] Note that, in practice, violations of the assumptions underlying the Cournot model make the HHI an imperfect indicator of market power. See, e.g., R. Preston McAfee, Joseph J. Simons, and Michael A. Williams, *Horizontal Mergers in Spatially Differentiated Noncooperative Markets*, Journal of Industrial Economics, vol. 40, no. 4 (1992), pp. 349–358.

In Section 2, we discuss a pipeline's residual rights in the secondary market for natural gas transportation. Our model of the secondary market for natural gas transportation, as well as our main results, are presented in Section 3. Our conclusions are presented in Section 4. All derivations are contained in the Appendix.

2. Capacity release and a pipeline's residual rights

FERC Order No. 636, released in 1992, spurred the development of a secondary market for unbundled transportation capacity by allowing shippers holding interstate pipeline FTS contracts to "release" all or part of their contracted capacity for resale on either a permanent or temporary basis.[6] The released capacity is allocated to the "replacement shipper" offering the highest rate (not exceeding the pipeline's regulated maximum rate).[7] Thus, shippers who have contracted for FTS with interstate pipelines can resell their capacity at a price not exceeding the pipeline's regulated maximum rate. In practice, shippers post the capacity they wish to release on electronic bulletin boards provided by the pipeline, with the released capacity allocated to the highest bidder.[8]

An interesting feature of the secondary market for gas transportation is the ability of the pipeline to sell any FTS capacity contracted for but not utilized by shippers as ITS. The pipeline is required to offer all unused capacity as ITS at its regulated maximum rate (i.e., a pipeline with available capacity cannot refuse service to shippers offering to pay the pipeline's regulated maximum rate). In addition, the pipeline may choose to offer unused capacity as ITS at prices below its maximum rate (i.e., a pipeline may price its service below its regulated maximum rate if it so desires). The pipeline, thus, has residual rights with respect to any FTS capacity contracted for but not utilized by shippers. The main contribution of this paper is to demonstrate that these residual rights may have a significant effect on the competitiveness of secondary markets for natural gas transportation.

3. The secondary market for natural gas transportation

The amount of transportation capacity each shipper can sell in the secondary market cannot exceed the shipper's contracted FTS capacity. The pipeline can sell an amount of transportation capacity not exceeding the sum of (1) any capacity not contracted for by FTS shippers and (2) any FTS capacity contracted for but not used by shippers.

Suppose that, in addition to the pipeline, there are n firms in the market (each firm is a shipper holding FTS capacity on the pipeline), each with capacity k_i, $i=1,\ldots, n$. We assume that shippers purchase FTS capacity from the pipeline (based on their expected demands) prior to the realization of their own demand for FTS.[9] Shippers thus choose the amount of capacity to resell

[6] See, *Pipeline Service Obligations and Revisions to Regulations Governing Self-Implementing Transportation Under Part 284 of the Commission's Regulations, and Regulation of Natural Gas After Partial Wellhead Decontrol,* FERC Order No. 636 (April 8, 1992) (hereinafter "Order No. 636).

[7] In Order No. 637, the FERC removed the price ceiling on short-term (less than one year) capacity release transactions for a two-year period ending September 30, 2002. See, *Regulation of Short Term Natural Gas Transportation Services and Regulation of Interstate Natural Gas Transportation Services*, FERC Order No. 637 (February 9, 2000). The FERC allowed the waiver on the price ceiling for short-term capacity release transactions to expire in 2002.

[8] However, if the shipper releasing capacity directly arranged for a replacement shipper, then that replacement shipper has the right to match the highest bid. See, Order No. 636 at 256–258.

[9] Since FTS contracts are often long-term (i.e., greater than one year in length), this is a reasonable assumption.

following the realization of their own demand for FTS. Let the pipeline be indexed by 0 with capacity k_0. The timing in the secondary market, following the realization of the shippers' demand for FTS, is as follows:

Stage 1. First, shippers choose their sales of capacity,[10] $q_i \leq k_i$.
Stage 2. Next, after observing q_i, the pipeline chooses its sales of capacity,[11] $q_0 \leq k_0 + \sum_{i=1}^{n} k_i - q_i$ where k_0 is the amount of pipeline capacity not contracted for by shippers.
Stage 3. Finally, the price of capacity in the secondary market, $p(Q), Q = \sum_{i=0}^{n} q_i$, is realized.

Since shippers are required to post the amount of capacity they wish to resell on the pipeline's electronic bulletin board, and since available capacity is allocated to the highest bidder, the assumptions regarding the timing in the market appear reasonable, given the static model employed.

Since the price of transportation capacity may not exceed the price ceiling set by the FERC, there are two states of the world to examine. Either the price ceiling is binding or it is not. If the price ceiling is binding, then firms will not withhold any capacity.[12] A binding price ceiling corresponds to the "high" and "intermediate" demand cases discussed below. The price ceiling not binding corresponds to the "low" demand case discussed below. We first solve the model without explicitly specifying the price ceiling, and then interpret the results depending on whether or not the price ceiling binds.

3.1. The secondary market without pipeline residual rights

In the absence of pipeline residual rights, the secondary market for natural gas transportation may be modeled as a standard Cournot game. Each shipper can resell an amount of capacity not exceeding that shipper's FTS capacity, k_i. The pipeline can sell an amount of capacity not exceeding the pipeline's unsubscribed capacity, k_0.

Each firm chooses q_i (i = 0, 1, 2, …, n) to maximize its profits, $(p(Q) - c)\, q_i$, where c represents a constant marginal cost, implying the following first-order condition:

$$0 = p'(Q) q_i + p(Q) - c$$

Then, the first-order condition may be rewritten as:

$$q_i = -\frac{p(Q) - c}{p'(Q)} \tag{1}$$

[10] The demand for natural gas transportation is derived from the demand for natural gas at the destination (i.e., delivered natural gas). Thus, shippers are really consumers of natural gas transportation. They consider withholding natural gas transportation to increase the value of the gas they do deliver. Thus, their choice in Stage 1 is to use or sell capacity up to their contracted FTS capacity.

[11] Although we do not make a formal distinction between FTS and ITS in our model in order to simplify the presentation, our main conclusion, i.e., the existence of pipeline residual rights increases the competitiveness of the secondary market for natural gas transportation, should continue be true in a model that explicitly accounts for the differentiated nature of FTS and ITS. In addition, as noted by the FERC in the Policy Statement, if there is sufficient unsubscribed capacity available during peak periods, then ITS is a "good alternative" (i.e., perfect substitute) for FTS. See, Policy Statement, at 28.

[12] Firms withhold capacity to increase the price. If increasing the price is not possible, as is the case when the price ceiling binds, then firms will sell all their capacity as long as the price exceeds the marginal cost.

Eq. (1) defines each firm's *best-response* or *reaction* function, i.e., Eq. (1) determines each firm's profit-maximizing level of sales, given the anticipated sales by its rivals. With capacity constraints, each firm produces $q_i = \min\left\{-\frac{p(Q)-c}{p'(Q)}, k_i\right\}$, for i=0, 1, 2, …, n.

A unique solution to the Cournot game is guaranteed if the reaction function for each firm, $-\frac{p(Q)-c}{p'(Q)}$, is a decreasing function of Q, for all Q such that $p(Q)>c$. A sufficient condition for decreasing reaction functions is that Log($p(Q)$) is concave in Q.[13] Since the concavity of p implies that Log(p) is concave, this condition is automatically met when p is concave.

It is useful to introduce the following notation:

$$\phi = \frac{d}{dQ}\frac{p(Q)-c}{p'(Q)} = 1 - \frac{(p(Q)-c)}{(p'(Q))^2}p''(Q) \tag{1a}$$

Note that the second order condition for a firm's optimization, when evaluated at a firm's optimal point, requires $-p''(Q)\left(\frac{p(Q)-c}{p'(Q)}\right) + 2p'(Q) \leq 0$, and hence $\phi \geq -1$. The assumption that Log (p) is concave implies that $\phi > 0$. Also note that, for linear demand, since $p''(Q)=0$, $\phi=1$.

3.2. The secondary market with pipeline residual rights

In the presence of pipeline residual rights, the secondary market for natural gas transportation may be modeled as a Stackelberg game with multiple leaders and a single follower.[14] As above, each shipper can sell an amount of capacity not exceeding that shipper's FTS capacity, k_i. The pipeline can sell an amount of capacity not exceeding the sum of (1) the amount of pipeline capacity not contracted for FTS by shippers, k_0, and (2) the amount of pipeline capacity contracted for but not utilized by shippers.

In Stage 2, the pipeline chooses q_0 to maximize its profits, $(p(Q)-c)\,q_0$, which implies the following first-order condition:

$$0 = p'(Q)q_0 + p(Q) - c$$

As above, the first-order condition for the pipeline may be rewritten as:

$$q_0 = -\frac{p(Q)-c}{p'(Q)} \tag{2}$$

[13] For a discussion of the existence and uniqueness of equilibrium in the Cournot model, see, e.g., Xavier Vives (1999), Oligopoly Pricing: Old Ideas and New Tools, MIT Press, ch. 4 as well as the references contained therein.

[14] The original formulation of the Stackelberg model, which assumes a single leader and a single follower, has been previously generalized to allow for a succession of leaders and followers (see, e.g., Arthur J. Robson, *Stackelberg and Marshall*, American Economic Review, vol. 80, no. 1, pp. 69–82 (1990)), a single leader and multiple followers (see, e.g., Hanif D. Sherali, Allen L. Soyster, Frederic H. Murphy, *Stackelberg–Nash–Cournot Equilibria: Characterizations and Computations*, Operations Research, vol. 31, no. 2, pp. 253–276 (1983)), and multiple leaders and multiple followers (see, e.g., Hanif D. Sherali, *A Multiple Leader Stackelberg Model and Analysis*, Operations Research, vol. 32, no. 2, pp. 390–404 (1984) and Nick Feltovich, *Mergers, Welfare, and Concentration: Results from a Model of Stackelberg–Cournot Oligopoly*, Atlantic Economic Journal, vol. 29, no. 4, pp. 378–392 (2001)). However, we are not aware of any prior research utilizing a Stackelberg model with multiple leaders and a single follower. In particular, we are not aware of any prior research addressing the main theoretical contribution of this paper: that even a single follower can have a large effect in the Cournot–Stackelberg model.

Note that Eq. (2) has the same form as Eq. (1). However, the constraint on the pipeline has weakened thanks to recapture, and the pipeline now produces $\min\left\{-\frac{p(Q)-c}{p'(Q)}, k_0+\sum_{i=1}^{n} k_i - q_i\right\}$. If market conditions were such that the pipeline would sell all the capacity available to it, then shippers will sell all of their capacity since the alternative is to have the same price but with the pipeline selling the balance. Thus, the only interesting case is when the pipeline restricts sales below capacity, with $q_0=-\frac{p(Q)-c}{p'(Q)}$.

Also as above, Eq. (2) is the reaction function of the pipeline, given the anticipated sales by shippers in the secondary market. Let $Q_{-0}=\sum_{i=1}^{n} q_i$ represent shippers' sales. Then, differentiating Eq. (2) with respect to Q_{-0} yields the pipeline's response to a change in sales by shippers:

$$\frac{dq_0}{dQ_{-0}}=-\frac{\phi}{1+\phi} \tag{3}$$

Note that since $\phi \geq -1$, $\frac{dq0}{dQ_{-0}}<0$ is equivalent to $\phi>0$. As discussed above, $\phi>0$ follows from the assumption that guaranteed the existence and uniqueness of equilibrium in the Cournot model (i.e., Log(p) is concave). Note, however, that although $\phi>0$ follows from standard assumptions used in textbook expositions of the Cournot game, perverse cases of $\phi<0$ are possible, whereby an increase in sales by the shippers increases the pipeline's sales.[15]

In Stage 1, given the anticipated reaction of the pipeline, each shipper chooses q_i ($i=1,2,\ldots,n$) to maximize its profits, $(p(Q)-c)\,q_i$, implying the following first-order condition:

$$0=p'(Q)q_i\left(1+\frac{dq_0}{dQ_{-0}}\right)+p(Q)-c$$

Once again, the first-order condition may be rewritten to obtain the shipper's reaction function:

$$q_i=-\frac{p(Q)-c}{p'(Q)\left(1+\frac{dq_0}{dQ_{-0}}\right)}=-\frac{p(Q)-c}{p'(Q)}(1+\phi) \tag{4}$$

A comparison of Eq. (4) with Eq. (1) reveals that the secondary market for natural gas transportation with pipeline residual rights is at least as competitive as the secondary market for natural gas transportation without pipeline residual rights if $\frac{dq0}{dQ_{-0}}<0$ (i.e., $\phi>0$), which is true if Log(p) is concave. Note, however, that concavity of Log(p) is a sufficient condition but not a necessary condition for this result.

Thus, if $\phi>0$, then

(a) Cournot reactions functions slope down,
(b) the pipeline reduces sales in response to an increase in sales by shippers, and
(c) the pipeline's residual rights increase the total output.

Thus, a pipeline's residual rights make the secondary market for natural gas transportation more competitive for concave, linear, and some convex inverse demand functions. We note that a

[15] This may occur, for example, if demand is of the constant elasticity form.

concave function for the demand for natural gas transportation appears reasonable because demand is likely inelastic at low prices, but may decrease sharply as the price of transportation rises, when the price of delivered natural gas exceeds the price of substitutes like oil.[16]

To summarize the implications of the foregoing discussion, note that we can identify three cases corresponding to high demand, intermediate demand, and low demand.

(a) High demand: If demand is sufficiently high, then shippers contract for all available pipeline capacity and, in addition, the shippers use all of their contracted capacity. In this case, no market power is exercised, and hence the secondary market for natural gas transportation is competitive.
(b) Intermediate demand: If demand is at an intermediate level, in the absence of the pipeline's residual rights, the shippers would have withheld some capacity from the secondary market so as to exercise market power. However, the existence of the pipeline's residual rights forces the shippers to sell all of their capacity. That is, it might be that some firms would find it profitable to withhold capacity; however, in this case, the pipeline would choose to resell all withheld capacity, and hence all firms, including those who would have preferred to withhold capacity, sell all of their capacity. Once again, since no capacity is withheld, no market power is exercised, and the secondary market for natural gas transportation is competitive.
(c) Low demand: If demand is sufficiently low, then the pipeline along with the shippers would choose to withhold capacity. However, relative to the case where the pipeline does not have any residual rights, the secondary market for natural gas transportation is more competitive if $\phi > 0$ (i.e., for concave, linear, and some convex inverse demand functions).

Finally, with regard to the FERC imposed price ceiling, note that if the price ceiling is binding, then the pipeline and the shippers will sell all of their capacity. This corresponds to the high demand and intermediate demand cases described above. In both the high and intermediate demand cases, since no capacity is withheld from the market, the secondary market for natural gas transportation is competitive. If the price ceiling is not binding, then shippers and the pipeline withhold some capacity. This corresponds to the low demand case described above. In this case, the secondary market is more competitive than it would be in the absence of the pipeline's residual rights if $\phi > 0$.

[16] We are not aware of prior empirical research on the functional form of the demand for natural gas transportation. Although there is considerable prior research on the demand for natural gas, in general, it is not possible to make inferences about the functional form of the demand for natural gas transportation from the functional form of the demand for natural gas despite the fact that the demand for natural gas transportation is derived from the demand for delivered natural gas. In particular, the price of natural gas transportation is regulated while the wellhead price of natural gas has been completely unregulated in the United States since 1993 (as per the Wellhead Decontrol Act of 1989). Thus, according to the Energy Information Administration, from January 1996 through March 2006, the value of natural gas transportation (as measured by the difference between the city gate price and wellhead price of natural gas) has ranged from 6.5% to 41.9% of the city gate price of natural gas (see, http://tonto.eia.doe.gov/dnav/ng/ng_pri_sum_dcu_nus_m.htm, website last visited on June 26, 2006). Given this wide variance of the share of transportation in the price of delivered natural gas (as measured by the city gate price), drawing conclusions about the functional form of the demand for natural gas transportation based on the functional form of the demand for natural gas appears unwarranted. (We note that a number of functional forms have been employed to estimate the demand for natural gas (and energy demand generally) including the linear, log linear, and other more flexible (e.g., Translog) specifications. See, e.g., Carol Dahl, *A Survey of Energy Demand Elasticities in Support of the Development of the NEMS*, prepared for the United States Department of Energy (1993) and the references contained therein).

3.3. How misleading is the HHI?

As demonstrated above, the secondary market for natural gas transportation is more competitive in the presence of the pipeline's residual rights than it would be otherwise if $\phi > 0$. However, how misleading is the HHI as a measure of the price–cost margin in the secondary market for natural gas transportation?

One way to consider this question is to note that Eq. (4) implies that a pipeline's residual rights causes unconstrained shippers to ship approximately ϕ more than they would have otherwise. That is, if there were m unconstrained firms producing q, then these firms would produce approximately ϕq more when the pipeline has residual rights. However, the pipeline reduces output when shippers increase output at the rate $\frac{dq_0}{dQ_{-0}} = \frac{\varphi}{1+\varphi}$, and hence $\frac{dQ}{dQ_{-0}} = \frac{d(Q_{-0}+q_0)}{dQ_{-0}} = 1 + \frac{dq_0}{dQ_{-0}} = \frac{1}{1+\phi}$.

Thus, the direct effect of a pipeline's residual rights is for shippers' output, $Q_{-0} \approx \frac{n}{n+1}Q$ to rise by approximately $\frac{m\varphi}{n+1}$ beyond the level it would have been in the absence of the pipeline's residual rights, but for reductions in output by the pipeline to reduce that to $\frac{m\varphi}{(n+1)(1+\varphi)}$. For linear demand, $\phi = 1$, and this represents a proportional increase of $\frac{m}{2(n+1)}$ over the Cournot quantity.

As an illustration of this effect, we compute the Stackelberg equilibrium for three hypothetical inverse demand functions — one linear, one concave, and one convex. Table 1 presents the equilibrium price, output, elasticity of demand, HHI, and price–cost margin for these three hypothetical inverse demand functions. For simplicity, we assume that there are three firms in the market, although results with more firms should be qualitatively similar. We note that the case with few firms and a high HHI is also the most interesting case, since this is when regulation of natural gas transportation is most likely to continue.

Table 1
Comparison of Stackelberg and Cournot models

	Functional form of inverse demand		
	Concave	Linear	Convex
Assumed inverse demand function	$5-0.1Q^2$	$10-Q$	$10Q^{-1}$
Assumed marginal cost	1	1	1
Stackelberg model (firms 1 and 2 leaders, firm 3 follower)			
q_1 (firm 1's equilibrium quantity)	2.20	3.00	2.81
q_2 (firm 2's equilibrium quantity)	2.20	3.00	2.81
q_3 (firm 3's equilibrium quantity)	1.01	1.50	1.88
Q (equilibrium market quantity)	5.40	7.50	7.50
P (equilibrium market price)	2.09	2.50	1.33
HHI	3658	3600	3437
E (equilibrium elasticity of demand)	0.36	0.33	1.00
$(P-c)/P$ (equilibrium price–cost margin)	0.52	0.60	0.25
Comparison with Cournot model			
Price–cost margin implied by the Stackelberg HHI and elasticity of demand under the Cournot model	1.02	1.08	0.34
Percentage by which the Cournot model overestimates the price–cost margin that prevails under the Stackelberg model	96.54%	80.00%	37.50%
HHI required under the Cournot model to achieve the price–cost margin that prevails under the Stackelberg model	1861	2000	2500

For each of the three assumed inverse demand functions, Table 1 also presents three statistics that allow a comparison of the Stackelberg and Cournot models. In order to compute these statistics, we utilize the equilibrium relationship between the price–cost margin, the HHI, and the elasticity of demand under the Cournot model[17]:

$$\frac{p-c}{p} = \frac{\text{HHI}}{\varepsilon} \tag{5}$$

The first statistic is the price–cost margin implied by the Stackelberg HHI under the Cournot model. To compute this statistic, we use the equilibrium HHI and elasticity of demand prevailing under the Stackelberg model in Eq. (5) to compute the implied price–cost margin that would prevail under the Cournot model. As seen in Table 1, the price–cost margin that would prevail under the Cournot model exceeds the price–cost margin that prevails in the secondary market for natural gas transportation under the Stackelberg model for all three assumed inverse demand functions.

The second statistic is the percentage by which the Cournot model overestimates the price–cost margin that prevails under the Stackelberg model. This is computed directly by comparing the equilibrium price–cost margin under the Stackelberg model with the price–cost margin that would prevail under the Cournot model, which was the first statistic calculated above. As seen in Table 1, the Cournot model overestimates the price–cost margin that prevails in the secondary market for natural gas transportation under the Stackelberg model by approximately 97%, 80%, and 38% for the assumed concave, linear, and convex inverse demand functions, respectively.

The third statistic is the HHI that would be required under the Cournot model to achieve the price–cost margin that prevails under the Stackelberg model. To compute this statistic, we use the equilibrium price–cost margin and elasticity of demand prevailing under the Stackelberg model in Eq. (5). As seen in Table 1, the HHI required under the Cournot model to achieve the price–cost margin that prevails in the secondary market for natural gas transportation under the Stackelberg model is considerably lower than the HHI in the secondary market for natural gas transportation for all three assumed inverse demand functions.

Table 1 demonstrates that the HHI is indeed a misleading measure of the price–cost margin that prevails in the secondary market for natural gas transportation. In particular, the price–cost margin that prevails in the secondary market for natural gas transportation is significantly lower than that implied by the prevailing HHI under the Cournot model. For the cases examined, the HHI is most misleading when the inverse demand function is concave and least misleading when the inverse demand function is convex. However, even when the inverse demand function is convex, the HHI may significantly overestimate the prevailing price–cost margin, as seen in Table 1.

4. Conclusion

The HHI is used as a screening device by the FERC in evaluating the ability of a natural gas pipeline to exercise market power. The use of the HHI in antitrust analysis is justified by the Cournot model of competition, which predicts that the competitiveness of the market, as measured by the price–cost margin, is proportional to the HHI. The contribution of this paper is to demonstrate that a pipeline's residual rights with respect to FTS capacity contracted for but not

[17] For a derivation of this relationship, see, e.g., Jeffery Church and Roger Ware, Industrial Organization, A Strategic Approach, Irwin McGraw-Hill (2000), pp. 238–239.

utilized by shippers can make the secondary market for natural gas transportation significantly more competitive than indicated by the HHI.

Appendix A. Derivations

Derivation of Eq. (1)

Each firm chooses q_i (i=0, 1, 2, …, n) to maximize its profits, $(p(Q)-c)\,q_i$. The first-order condition for profit-maximization is:

$$\begin{aligned}&0 = p'(Q)q_i + p(Q) - c\\ \Rightarrow\quad &q_i = -\frac{p(Q)-c}{p'(Q)}.\end{aligned}$$

Derivation of Eq. (1a) and the properties of ϕ

Differentiating a firm's reaction function with respect to Q, we obtain:

$$\begin{aligned}&\phi = \frac{d}{dQ}\frac{p(Q)-c}{p'(Q)}\\ &\Rightarrow\phi = \frac{p'(Q)}{p'(Q)} + \frac{(p(Q)-c)(-p''(Q))}{(p'(Q))^2}\\ &\Rightarrow\phi = 1-\frac{(p(Q)-c)}{(p'(Q))^2}p''(Q)\end{aligned}$$

The second order condition for a firm's optimization is:

$$-p''(Q)q_i + p'(Q) + p'(Q) \leq 0$$

Substituting for q_i from Eq. (1), we obtain:

$$-p''(Q)\left(\frac{p(Q)-c}{p'(Q)}\right) + 2p'(Q) \leq 0.$$

Thus, $\phi \geq -1$.

Note that Log(p) is concave if and only if

$$\begin{aligned}&\frac{d^2\,\mathrm{Log}\,(p(Q))}{dQ} < 0\\ &\Rightarrow p(Q)p''(Q)-(p'(Q))^2 < 0.\end{aligned}$$

Now,

$$\begin{aligned}&\phi > 0 \Rightarrow 1-\frac{(p(Q)-c)}{(p'(Q))^2}p''(Q) > 0\\ &\Rightarrow (p(Q)-c)p''(Q)-(p'(Q))^2 < 0\end{aligned}.$$

Since $c \geq 0$, it follows that $(p(Q)-c)p''(Q)-(p'(Q))^2 \leq p(Q)p''(Q)-(p'(Q))^2 < 0$. Hence, if Log ($p$) is concave, then $\varphi > 0$.

Derivation of Eq. (2)

In Stage 2, the pipeline chooses q_0 to maximize its profits, $(p(Q)-c)\ q_0$. The first-order condition for profit-maximization is:

$$0 = p'(Q)q_0 + p(Q) - c$$
$$\Rightarrow \quad q_0 = -\frac{p(Q)-c}{p'(Q)}.$$

Derivation of Eq. (3)

From Eq. (2) we have:

$$q_0 = -\frac{p(Q)-c}{p'(Q)}$$

Let $Q_{-0} = \sum_{i=1}^{n} q_i$ represent shippers' sales. Then, differentiating Eq. (2) with respect to Q_{-0} yields:

$$\Rightarrow \frac{dq_0}{dQ_{-0}} = -\frac{(p'(Q_{-0}+q_0))^2\left(1+\frac{dq_0}{dQ_{-0}}\right) - p''(Q_{-0}+q_0)\left(1+\frac{dq_0}{dQ_{-0}}\right)(p(Q)-c)}{(p'(Q))^2}$$
$$\Rightarrow \frac{dq_0}{dQ_{-0}} = -\left(\frac{(p'(Q))^2 - p''(Q)(p(Q)-c)}{(p'(Q))^2}\right)\left(1+\frac{dq_0}{dQ_{-0}}\right)$$
$$\Rightarrow \frac{dq_0}{dQ_{-0}} = -\left(1+\frac{p''(Q)}{p'(Q)}q_0\right)\left(1+\frac{dq_0}{dQ_{-0}}\right) \text{ [since, from Eq. (2), } q_0 = -\frac{p(Q)-c}{p'(Q)}\text{]}$$
$$\Rightarrow \frac{dq_0}{dQ_{-0}}\left(1+1+\frac{p''(Q)}{p'(Q)}q_0\right) = -\left(1+\frac{p''(Q)}{p'(Q)}q_0\right)$$
$$\Rightarrow \frac{dq_0}{dQ_{-0}} = -\frac{1+\frac{p''(Q)}{p'(Q)}q_0}{2+\frac{p''(Q)}{p'(Q)}q_0} = -1 + \frac{1}{2+\frac{p''(Q)}{p'(Q)}q_0} = -1 + \frac{1}{2-\left(\frac{p(Q)-c}{p'(Q)}\right)\frac{p''(Q)}{p'(Q)}} = -1 + \frac{1}{1+\phi}$$
$$\Rightarrow \frac{dq_0}{dQ_{-0}} = \frac{\phi}{1+\phi} \text{ [since from Eq. (2), } q_0 = -\frac{p(Q)-c}{p'(Q)}\text{]}.$$

Derivation of Eq. (4)

In Stage 1, given the anticipated reaction of the pipeline, each shipper chooses q_i $(i=1, 2, \ldots, n)$ to maximize its profits, $(p(Q)-c)\ q_i$. The first-order condition is:

Either $q_i=0$

Or $q_i>0$ and $0 = p'(Q)q_i\left(1+\frac{dq_0}{dQ_{-0}}\right) + p(Q) - c$.

If $q_i>0$, then:

$$q_i = -\frac{(p(Q)-c)}{p'(Q)}\frac{1}{\left(1+\frac{dq_0}{dQ_{-0}}\right)}$$
$$\Rightarrow \quad q_i = -\frac{(p(Q)-c)}{p'(Q)}(1+\phi)$$

[since from Eq. (3), $\frac{dq_0}{dQ_{-0}} = -\frac{\phi}{1+\phi}$].