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ORIGINAL ARTICLE

The role of excess capacity in determining market power in natural gas transportation markets

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Abstract The approval by FERC of a regulated natural gas pipeline's market-based rate application depends upon the availability of substitute pipelines with sufficient capacity to maintain the current transport price. But *how much* alternate capacity is enough? Clearly, the price will not increase when alternate pipelines have unsubscribed capacity equal to the capacity of the applicant pipeline, since the applicant's capacity is then perfectly substitutable. And indeed, FERC has approved market-based rates when this "complete-replacement" criterion has been met. However, complete-replacement is too stringent a condition and we determine precisely how much alternate capacity suffices to keep the price from rising.

Keywords Market-based rate application · Natural gas regulation

JEL Classifications D21 · D43 · L51 · L95

1 Introduction

Regulation of natural gas pipeline rates in US began with the Natural Gas Act of 1938. For almost five decades, pipelines offered a bundled service that combined the purchase and delivery of natural gas, principally to local distribution companies and

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large industrial buyers. The distortions created by government price controls in the gas industry are well-documented,[1] and since 1978 attempts have been made by Congress and the Federal Energy Regulatory Commission (FERC) to make gas prices and transportation rates more responsive to supply and demand conditions.

Despite dramatic changes in the structure of the US natural gas industry by the mid-1990s,[2] natural gas pipeline transportation rates continued to be regulated using traditional cost-of-service methods. Recognizing that additional pricing flexibility may be economically desirable, FERC requested comments on the possibility of allowing interstate natural gas pipelines to apply for market-based transportation rates.[3] In response, natural gas consumers, suppliers, and pipelines indicated that allowing pipelines enhanced flexibility in rates and service offerings could improve the efficiency of gas transportation services.

After a period of review, FERC issued, in (1996), a Policy Statement indicating that a natural gas pipeline would be permitted to charge market-based transportation rates if it could show that it lacked significant market power.[4] According to the Policy Statement,

> [FERC's] framework for evaluating requests for market-based rates addresses two principal purposes: (1) whether the applicant can withhold or restrict services and, as a result, increase price by a significant amount for a significant period of time, and (2) whether the applicant can discriminate unduly in price or terms and conditions. Undue discrimination is especially a concern when an applicant for market-based rates can deal with affiliates.[5]

The Policy Statement sets forth the criteria used by FERC to evaluate a proposal for market-based transportation rates. A critical criterion is the determination as to whether an alternate pipeline offers a "good alternative," defined as a service available soon enough, at price low enough, and at a quality high enough to permit customers to substitute the alternative for the applicant pipeline's service.[6] This criterion is critical because an alternate pipeline's service cannot be included in the product market unless it is determined to be a "good alternative."[7] FERC determines whether an alternate pipeline's service is available soon enough by comparing (1) the applicant's peak-day capacity and (2) the volume of unsubscribed capacity on alternate pipelines, especially on peak days.[8] The Policy Statement concludes: "only sales or capacity figures

[1] See, for example, MacAvoy and Pindyck (1975) and MacAvoy (2000).

[2] See, for example, Doane and Spulber (1994).

[3] Alternatives to Traditional Cost-of-Service Ratemaking for Natural Gas Pipelines, 70 FERC para. 61,139 (1995).

[4] Alternatives to Traditional Cost-of-Service Ratemaking for Natural Gas Pipelines, 74 FERC para. 61,076 (1996).

[5] Ibid at para. 61,230.

[6] Ibid at para. 61,232.

[7] Ibid.

[8] KN Interstate Gas Transmission Co., 76 FERC para. 61,134 (1996).

associated with good alternatives should be used in calculating the [Herfindahl-Hirschman Index (HHI)]."[9] Consequently, the HHI is directly affected by the volume of unsubscribed or excess capacity on alternate pipelines.[10]

The Policy Statement, like the U.S. Department of Justice and Federal Trade Commission *Horizontal Merger Guidelines*,[11] specifies the use of an HHI threshold to evaluate the competitive characteristics of a market. In particular, applications for market-based rates associated with an HHI above 1800 are subject to "closer scrutiny" than applications in less concentrated markets.[12] In practice, FERC's "closer scrutiny" includes considering whether "there is a sufficient amount of good alternatives available to make a price increase unprofitable."[13] For example, in approving part of KN Interstate's application to charge market-based transportation rates on a 100 mile segment of its system (called the "Buffalo Wallow System"), FERC placed "particular weight [on] the fact that the alternate systems have approximately five times the amount of unsubscribed peak-day capacity than [KN Interstate] can offer on the Buffalo Wallow System."[14]

By considering the total amount of unsubscribed capacity of alternative pipelines, FERC can assess whether a deregulated firm might have an incentive to increase its transport price by restricting output. For example, in the KN Interstate case, deregulation would not create an incentive to increase price because alternative pipelines have at least as much unsubscribed capacity as the applicant's peak-day capacity. When this "complete-replacement" condition holds, any reduction in output by the deregulated firm will be met by an equal increase in output by its (still regulated) rivals, who maximize profits by maximizing output sold at the regulated price.

Our central point is that FERC can ensure that deregulation does not lead to higher transport prices even when alternative pipelines do *not* have sufficient unsubscribed capacity to completely replace the applicant's peak-day capacity. That is, FERC need not adopt what we shall call the *complete-replacement criterion* to ensure that deregulated prices will not rise.

The intuition for this is as follows. Because competitors remain regulated, their outputs will exactly offset any reduction in a successful applicant's output until their capacities are reached. Consequently, an applicant's quantity reduction has no effect on the price until it is large enough that it equals the initial total unsubscribed capacity of his competitors. Because pipeline cost-of-service rates exceed marginal cost, this output reduction leads to a lump-sum loss in profits. Only additional reductions in the applicant's output over and above the competitors' unsubscribed capacity begin to have an upward affect on the price. However, if demand is sufficiently elastic, the price cannot increase enough to offset the lump-sum "loss-of-margin effect" and the

[9] Alternatives to Traditional Cost-of-Service Ratemaking for Natural Gas Pipelines, 74 FERC at para. 61,234.

[10] We use the terms "unsubscribed capacity" and "excess capacity" interchangeably.

[11] U.S. Department of Justice and Federal Trade Commission (1992).

[12] Alternatives to Traditional Cost-of-Service Ratemaking for Natural Gas Pipelines, 74 FERC at para. 61,235.

[13] KN Interstate Gas Transmission Co., 76 FERC at para. 61,726.

[14] Ibid at para. 61,719.

applicant will find it *unprofitable* to engage in any restriction of output whatsoever. Thus, even though the applicant's output may exceed the total unsubscribed capacity of its competitors, and hence even though it may be possible for the applicant to raise the price by reducing output, *he will not do so*. Our main results spell out precisely how elastic demand must be for this conclusion to hold.

Given the current record of market-based rate applications, it is not possible to determine with certainty whether or not FERC has, implicitly or explicitly, adopted the complete-replacement criterion as a necessary condition for approval. On the other hand, since FERC issued its 1996 Policy Statement, it has received four applications for market-based transportation rates: *KN Interstate Gas Transmission Company*,[15] *Gulf States Transmission Corporation*,[16] *CNG Transmission Corporation*,[17] and *Koch Gateway Pipeline Company*.[18] Of these, the only application to be approved (KN Interstate) was one in which the complete-replacement criterion was satisfied.[19] Unfortunately, the records do not permit us to discern whether or not the complete-replacement criterion was satisfied in the other three cases. Among these, the most complete record is that in the *Koch* case.[20] An Administrative Law Judge ruled in favor of Koch's request,[21] but FERC overturned that decision.[22] FERC concluded that Koch had not shown that it lacked market power. In particular, FERC disagreed with the Administrative Law Judge's finding that the presence of installed capacity owned by alternative pipelines was sufficient to demonstrate the availability of that capacity to shippers. As FERC stated: "Installed capacity does not indicate whether capacity is available. To determine available capacity, it is necessary to know whether there is unsubscribed capacity on the alleged alternatives."[23]

Clearly, FERC understands well that the ability to exercise market power is tied to the amount of unsubscribed capacity on alternative pipelines. Hence, to ensure that market power is not exercised, FERC quite correctly considers whether the amount of unsubscribed alternative capacity is sufficiently high. The central question from our perspective is: Exactly *how much* unsubscribed capacity on alternative pipelines is sufficient to preclude a deregulated pipeline from profitably exercising market power? Providing the answer will permit FERC to implement its objectives more precisely and more effectively. In particular, we will show quite generally that approving market-based rate applications only when the complete-replacement criterion is satisfied is *too restrictive*. Such a policy would reject market-based rate applications even when their

15 KN Interstate Gas Transmission Co., 76 FERC para. 61,134.

16 Gulf States Transmission Corp., 80 FERC para. 61,091 (1997).

17 CNG Transmission Corp., 80 FERC para. 61,137 (1997).

18 Koch Gateway Pipeline Co., 85 FERC para. 61,013 (1998).

19 Alternate pipeline unsubscribed capacity was about five times that of KN Interstate's production.

20 In *Gulf States*, FERC denied the application for market-based transportation rates because the applicant did not provide sufficient data. (Gulf States said that it could not afford to pay for the required economic analyses.) In *CNG*, FERC denied the application for market-based rates primarily because it rejected the applicant's claim that capacity release was a "good alternative."

21 Koch Gateway Pipeline Co., 80 FERC para. 63,008 (1997).

22 Koch Gateway Pipeline Co., 85 FERC para. 61,013.

23 Ibid at para. 61,042.

approval would not permit the deregulated firm to exercise market power profitably. In contrast, we shall provide a criterion that is exact. Our criterion is met precisely when market power cannot be profitably exercised.

To obtain our criterion, we determine the minimum excess capacity of an applicant's competitors that is both necessary and sufficient to guarantee that the applicant would be unable to profitably increase its price subsequent to the approval of market-based rates. In particular, under a large class of market demand functions it is shown that this critical level of the competitors' excess capacity is strictly less than the applicant's current supply whenever the elasticity of market demand for gas transportation is non-zero. And based upon this theoretical analysis, demand elasticity estimates permit us to be rather precise about the extent to which the complete-replacement criterion is too restrictive.

The long run elasticity of demand for natural gas by residential consumers has been estimated in the range of 0.30–0.80.[24] Consequently, the elasticity of demand for natural gas transportation seems unlikely to be much less than 0.1.[25] Indeed, according to the only estimate of which we are aware, natural gas transportation demand elasticity is about 0.12.[26] When we conservatively employ a demand elasticity of 0.1 together with reasonable values for remaining parameters, our results imply that a deregulated firm will have no incentive to increase price by reducing output even if its current supply is 2–3 times the excess capacity of alternative pipelines (see Sects. 2.1 and 2.2).

Thus, all else equal, employing the complete-replacement criterion would lead to too few successful market-based rate applications. By carefully taking into account demand elasticity, we offer here a more precise, and so also more effective, criterion for evaluating such applications.

But would firms apply for market-based rates when their applications are accepted only when it is not profitable to increase price by restricting output?[27] The answer is in the affirmative (e.g., recall the case of KN Interstate). Indeed, permission to charge market-based rates also provides incentives to innovate, to invest in additional capacity, etc. Consequently, a firm may reap substantial gains from market-based rates even though it cannot profitably raise its price given its current capacity, etc. Moreover, the subsequent changes and innovations that benefit deregulated firms may also be welfare enhancing. In short, even under our exact criterion, there may be both private and social gains from deregulation. Of course, the scope of our analysis is more modest. We focus only upon the conditions under which market power cannot be profitably exercised subsequent to deregulation.

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24 See, e.g., Maddala et al. (1997, 2001). We adopt the standard, but not universal, convention that elasticities are non-negative, being the absolute value of the percentage change in demand per percentage change in price.

25 Since shippers' demand for natural gas transportation is derived from their demand for natural gas, and because shippers will generally not pass on the full amount of an increase in transportation prices, one would expect the demand elasticity for natural gas transportation to be somewhat less than that for natural gas.

26 Policy for Selective Discounting by Natural Gas Pipelines, 113 FERC para. 61,173 at P 51 (2005).

27 We thank a referee for posing this question.

2 Model and notation

FERC sets maximum rates for transportation services offered by interstate natural gas pipelines. We shall investigate the effect of allowing a single pipeline to charge market-based rates while leaving the remaining pipelines subject to cost-of-service regulation.[28] Our central interest lies in establishing the conditions under which the deregulated pipeline will be unable to profitably increase its price. We assume throughout that all firms are profit maximizers.

Let us refer to the pipeline seeking to charge market-based rates as "firm 1." Let q_0 denote firm 1's current output (i.e., prior to deregulation), and let Q_0 denote current total industry output. Consequently, firm 1's current market share is $s_0 = q_0/Q_0$. Let us denote the current total excess capacity of the other firms by x_0, and the market demand function by $P(\cdot)$. Finally, let c denote firm 1's constant marginal cost.

A key observation concerns the manner in which the other firms react to a reduction in output by firm 1. Because the other firms continue to remain subject to cost-of-service regulation, they are unable to raise their price since, assuming that regulation is not redundant, the current price, $P(Q_0)$, is already equal to the prescribed maximum. Consequently, profit maximization will lead these firms to exactly match any output reduction by firm 1 with an equal increase in production up to their total excess capacity. Therefore, if firm 1's current output, q_0, is no greater than the others' combined current excess capacity, x_0, firm 1 cannot raise the price by restricting output because the other firms' reactions will ensure that total output remains equal to Q_0 and that the price remains equal to $P(Q_0)$, regardless of firm 1's output reduction.

Letting $z_0 = x_0/Q_0$, we may state this straightforward observation as follows.[29] *If*

$$z_0 \geq s_0, \tag{1}$$

then firm 1 cannot increase its profits by restricting output.

Note that (1) describes the complete-replacement criterion. Thus, as already mentioned briefly in the introduction, the complete-replacement criterion is sufficient to ensure that a pipeline allowed to charge market-based rates will not increase its price. However, while *sufficient* for this purpose, condition (1) is not necessary; it is very often *too restrictive*. That is, it can easily happen that allowing a pipeline to charge market-based rates will not lead to a price increase even though the complete-replacement criterion is not met, i.e., even though $z_0 < s_0$. We now explore these circumstances in detail.

Let $\Delta \geq 0$ denote the reduction in firm 1's output subsequent to permission to charge market-based rates.[30] Because the other firms will compensate for firm 1's output reduction up to their capacity, x_0, the only potentially profitable levels of Δ

[28] Similar results hold when more than one firm is permitted to charge market-based rates.

[29] Note that, in principle, z_0 need not be less than one, although in practice one would expect this to be the case.

[30] We need not consider an *increase* in firm 1's output since this would reduce the price. Any such price–quantity combination was feasible under regulation, but not chosen, and so cannot lead to higher profits.

are such that $x_0 < \Delta < q_0$. If firm 1 reduces its output by $\Delta \in (x_0, q_0)$, and the remaining firms increase their output up to capacity, x_0, the total reduction in output is $\Delta - x_0$ and so total output becomes $Q_0 - \Delta + x_0$. Firm 1's profits are then $(P(Q_0 - \Delta + x_0) - c)(q_0 - \Delta)$.

We wish to determine precisely those conditions under which firm 1 can increase its profits by reducing its output and increasing its price. That is, we wish to know when there exists $\Delta \in (x_0, q_0)$ such that $(P(Q_0 - \Delta + x_0) - c)(q_0 - \Delta) > (P(Q_0) - c)q_0$.

We will consider this question within two broad classes of demand functions. First, we provide the answer when demand is (weakly) concave. We then provide the answer under the even more general hypothesis that demand satisfies Marshall's second law. We begin with concave demand, which may be particularly relevant for natural gas transportation.

Before presenting the analysis, let us record a simple consequence of profit-maximization. Because regulation does not preclude any firm from increasing output and reducing the price, such price–quantity combinations cannot increase any firms' profits, including firm 1's. Consequently, we must have $(P(Q_0) - c)q_0 \geq (P(Q_0 + a) - c)(q_0 + a)$ for all $a \geq 0$. Therefore, the derivative of $(P(Q_0 + a) - c)(q_0 + a)$ with respect to a evaluated at $a = 0$ must be non-positive, or equivalently, $s_0 \geq \lambda_0 \varepsilon_0$, where ε_0 is the elasticity of demand at current total output, and λ_0 is $(P(Q_0) - c)/P(Q_0)$, the current markup. Because the product $\lambda_0 \varepsilon_0$ occurs frequently in the analysis below, let us denote it by η_0. Hence, throughout the remainder of the paper, the inequality, $s_0 \geq \eta_0$, will be assumed to hold because it follows from profit-maximization.

Finally, we shall refer to the function $P(Q) - c$ as the *net demand function*. Hence, because $\eta_0 = \lambda_0 \varepsilon_0 = -(P(Q_0) - c)/Q_0 P'(Q_0)$, η_0 is the *elasticity of net demand* at the quantity Q_0.[31]

2.1 Concave demand

In the context of natural gas transportation, it may be reasonable to suppose that demand is a concave function of price. This is because the demand for natural gas transportation is likely inelastic at low prices and might be expected to decrease rather sharply as the transport price rises, eventually leading the price of delivered natural gas to rise above the price of substitutes (e.g., oil). In the present section, therefore, we shall assume that demand is concave. That is, we assume:

$$P''(Q) \leq 0, \quad \text{for all} \quad Q \geq 0.$$

Let $p_0 = P(Q_0)$ denote the current price of natural gas transportation and recall that η_0 is the current elasticity of net demand, while ε_0 is the current elasticity of demand. We have the following result.

[31] In keeping with our convention, the elasticities ε_0 and η_0 are non-negative.

Theorem 1 *If demand is concave, then firm 1* cannot *increase its profits by restricting output and raising the market price so long as*

$$\sqrt{s_0} \leq \sqrt{z_0} + \sqrt{\eta_0}. \tag{2}$$

Moreover, this condition is the best possible. If (2) fails, there is a concave demand function consistent with the data that price and elasticity are p_0 and ε_0, respectively, when total output is Q_0, and such that firm 1 can *increase its profits by restricting output and raising the price.*

Evidently, (1) and (2) are equivalent only when the current elasticity of net demand, $\eta_0 = \lambda_0 \varepsilon_0$, equals zero. Consequently, when demand is concave, if price exceeds marginal cost (i.e., $\lambda_0 > 0$),[32] then the complete-replacement criterion, (1), is appropriate only when the market demand elasticity equals zero. But otherwise, when the demand elasticity is positive, the more permissive criterion (2) is the correct criterion to employ. In particular, whenever (2) holds and (1) fails, the complete-replacement criterion, (1), if employed by FERC, would inappropriately lead to a denial of an application for market-based rates. In such a case, if instead criterion (2) were employed, the application would be successful and, as desired, the firm would have no incentive to increase its price. Let us refer to (2) as the *square-root criterion*.

Note that (2) can be re-written as $z_0 \geq s_0 + \eta_0 - 2\sqrt{s_0 \eta_0}$. Thus, because $s_0 \geq \eta_0$ implies that $\eta_0 - 2\sqrt{s_0 \eta_0}$ is non positive, the actual value of z_0 at or above which price will not increase is never above s_0, the value given by the complete-replacement criterion.

To gain some practical feel for the square-root criterion, consider Fig. 1. There, we have plotted, for the fixed markup $\lambda_0 = 0.95$, three curves corresponding to each of three values of the elasticity of demand; $\varepsilon_0 = 0.1$, 0.2, and 0.3. Each curve provides the critical value of z_0 above which the firm would find it unprofitable to increase price by restricting output, as a function of the firm's current market share, s_0. Even when market demand at the current level of total output is quite inelastic (e.g., $\varepsilon_0 = 0.1$), the critical value of z_0 is significantly less than s_0 at all market shares.

For another comparison, consider the following example. Suppose that the markup is 0.95, that elasticity of demand is 0.1, and that the rival firms' combined excess capacity as a fraction of total industry output is 0.15. Then, according to the complete-replacement criterion, a pipeline's application for market-based rates would be denied if its market share exceeded 15%. However, according to the square-root criterion, the application should be denied only if the pipeline's market share exceeds approximately 48%, since only then will the firm have an incentive to increase the price.

[32] Price exceeds marginal cost in the interstate natural gas transport industry because FERC, targeting zero economic profits, uses a two-part price structure for firm service called the "straight fixed variable" rate design that recovers all fixed costs through a demand component and all variable costs through a commodity or usage component. Pipeline transportation rates generally have markups, i.e., (average price−commodity charge)/average price, of at least 0.90 even at a 100% load factor. (Markups are inversely related to load factors.) See, e.g., interstate gas pipeline tariffs available at http://www.ferc.gov/industries/gas/gen-info/fastr/htmlall/index.asp

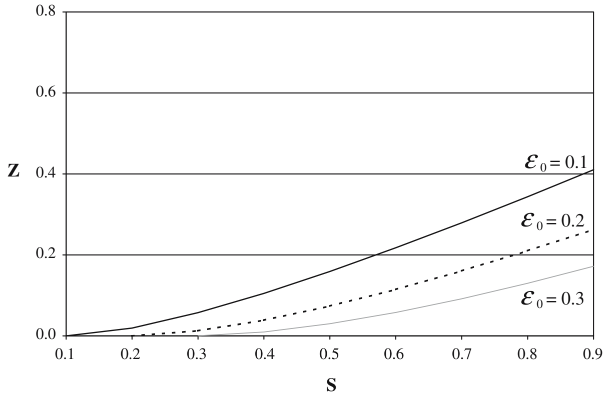

Fig. 1 Critical excess capacity given concave demand (the square-root criterion)

2.2 Marshall's second law

According to Marshall's second law of demand,[33]

Demand elasticity is non-increasing in quantity demanded.

Letting $\varepsilon(Q)$ denote the elasticity of demand at the quantity Q, Marshall's second law therefore states that $\varepsilon'(Q) \leq 0$.

Marshall's second law holds, for example, when the market demand function is not too convex at any point. In particular, it holds whenever demand is concave as in the previous section. Of course, it also holds when demand is of the constant elasticity form, in which case demand is a *convex* function.

Let $\eta(Q) = -(P(Q)-c)/QP'(Q)$ denote the elasticity of net demand at the quantity Q. Throughout the present section we shall assume only that net demand, $P(Q)-c$, satisfies Marshall's second law. That is, we assume that $\eta(Q)$ is non-increasing, or equivalently, that

$$\eta'(Q) \leq 0.$$

This is *weaker* than assuming that demand, $P(Q)$, satisfies Marshall's second law because $\eta(Q)$ is the product of the non-increasing function $(P(Q) - c)/P(Q)$ and the elasticity of demand. Consequently, if the elasticity of demand is non-increasing in quantity, so is the elasticity of net demand.

Therefore, by assuming only that the elasticity of net demand is non-increasing, we permit a strictly larger class of demand functions than in the previous section, including, in particular, all demand functions satisfying Marshall's second law. Accordingly, the criterion that we provide in this section will be *more* conservative than the square-root criterion, but still *less* conservative than the complete-replacement criterion. Once again, the complete-replacement criterion will be found to be too restrictive and valid only when the demand elasticity equals zero.

33 Marshall (1920), pp. 102–104.

Recalling that $\eta_0 = \eta(Q_0)$, $\varepsilon_0 = \varepsilon(Q_0)$, and $p_0 = P(Q_0)$, the main result of the present section is as follows.

Theorem 2 *If net demand satisfies Marshall's second law, then firm 1* cannot *increase its profits by restricting output and raising the market price so long as*

$$\left(\frac{s_0}{\eta_0}\right)^{\eta_0}\left(\frac{1-s_0+z_0}{1-\eta_0}\right)^{1-\eta_0} \geq 1. \tag{3}$$

Moreover, this condition is the best possible. If (3) fails, there is a demand function that is consistent with the data that price and elasticity are p_0 and ε_0, respectively, when total output is Q_0, and such that net demand satisfies Marshall's second law and firm 1 can *increase its profits by restricting output and raising the price.*

So, if demand is not concave, but net demand satisfies Marshall's second law, then (3) is the appropriate criterion to employ to ensure that the deregulated firm will have no incentive to increase its price. Let us refer to (3) as the *product criterion.*

The product criterion is more conservative than the square-root criterion. Indeed, according to Theorem 2, if (3) holds, then whenever net demand satisfies Marshall's second law, firm 1 cannot earn positive profits by restricting output and raising price. In particular, positive profits would not be possible for any concave demand function. Consequently, by the second part of Theorem 1, condition (2) must hold. Hence, condition (3) implies condition (2), which means that (3) is the more conservative condition—it holds on a strictly smaller set of parameters s_0, z_0, η_0.

On the other hand, the product criterion is less restrictive than the complete-replacement criterion. Perhaps the easiest way to see this is to rewrite (3) as

$$s_0 \leq z_0 + \left[1-(1-\eta_0)\left(\frac{\eta_0}{s_0}\right)^{\frac{\eta_0}{1-\eta_0}}\right],$$

and note that the term in square brackets is non-negative because, by profit-maximization, $s_0 \geq \eta_0$. Hence, (1) implies (3). Note also that, given Marshall's second law for net demand, the complete-replacement criterion is appropriate only when (1) and (3) are equivalent, which, assuming that price exceeds marginal cost, is the case only when $\varepsilon_0 = 0$, i.e., when the current elasticity of demand for natural gas transportation equals zero.[34]

To see more clearly the extent to which the complete-replacement criterion is too restrictive when demand satisfies Marshall's second law, consult Fig. 2. As in Fig. 1, for the fixed markup $\lambda_0 = 0.95$, each of the three curves plots, for a particular elasticity, ε_0, the critical value of z_0 at or above which the firm would find it unprofitable to increase price by restricting output, against the firm's current market share, s_0. The difference here is that, because net demand need only satisfy Marshall's second law, this critical value is given by the product criterion, not the square-root criterion. Nonetheless, it is evident that the critical value of z_0 is always well below the more conservative value, namely s_0, that is given by the complete-replacement criterion.

[34] The term in square brackets converges to zero as $\eta_0 \to 0$ and so also as $\varepsilon_0 \to 0$.

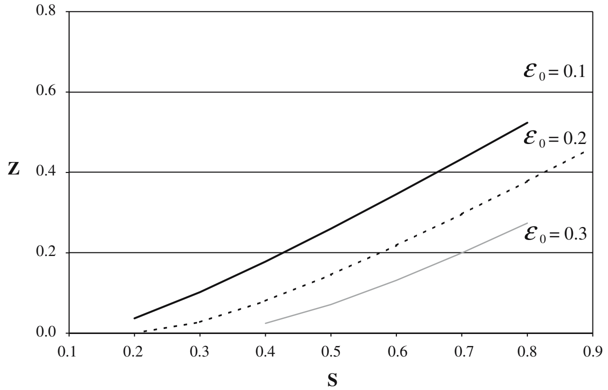

Fig. 2 Critical excess capacity given Marshall's second law (product criterion)

Finally, let us return to the previous subsection's example in which $\lambda_0 = 0.95$, $\varepsilon_0 = 0.1$, and $z_0 = 0.15$. When net demand is known only to satisfy Marshall's second law, the product criterion states that firm 1 cannot profit from restricting output unless it holds a market share of at least 36%. As expected, this is less than the market share that would lead the firm to increase price were demand known to be concave (i.e., 48%), but more than the market share given by the complete-replacement criterion (i.e., 15%).

3 Conclusion

In considering applications for market-based transportation rates, FERC has determined the availability of "good alternatives" by examining the relationship between (1) an applicant's peak-day capacity and (2) the volume of unsubscribed capacity on alternate pipelines. We have shown how to determine the minimum excess capacity of an applicant's competitors that is both necessary and sufficient to guarantee that an applicant would be unable to profitably increase its price subsequent to the approval of market-based rates. Our analysis shows that whenever the elasticity of market demand is non-zero, under a very broad class of market demand functions this critical level of excess capacity is strictly less than the applicant's current supply. We therefore conclude that, quite generally, excess capacity on rival pipelines need not be sufficient to replace all of an applicant's peak-day capacity in order to prevent the applicant from exercising market power subsequent to deregulation.

This conclusion has important implications. Indeed, permission to charge market-based rates provides a firm with incentives to innovate, to invest in additional capacity, etc. Such changes not only benefit the deregulated firm, but may also be welfare enhancing. In short, there may be both private and social gains from deregulation that would fail to be realized if the criterion proposed here is not employed.

Acknowledgements We thank Ashish Nayyar for valuable assistance, Michael Williams for a wealth of information on the history, development and regulation of the natural gas industry, and two referees and the editor for helpful comments.

Appendix: Proofs

Proof of Theorem 1 We first show that if $\sqrt{s_0} \leq \sqrt{z_0} + \sqrt{\eta_0}$, then the firm cannot increase its profits by restricting output. There are two cases to consider. The first case is $s_0 \leq z_0$. But, as we have already argued (see (1)), if $s_0 \leq z_0$ then the firm cannot increase its profits by restricting output.

Hence, we may assume that $s_0 > z_0$ and $s_0 \geq \eta_0$, where the second inequality follows from profit maximization. Let $P_0(Q)$ denote the linear demand function that is tangent to $P(\cdot)$ at $Q = Q_0$. Because $P(\cdot)$ is concave, $P_0(Q) \geq P(Q)$ for all $Q \geq 0$. Consequently, if firm 1 cannot earn positive profits by restricting output when demand is given by $P_0(\cdot)$, then it cannot increase profits by restricting output when demand is given by $P(\cdot)$.

So, suppose that demand is given by the linear demand function $P_0(Q)$. Then firm 1's gain from reducing output by $\Delta \in (x_0, q_0)$ is

$$\begin{aligned}\pi(\Delta) &= P_0(Q_0 - \Delta + x_0)(q_0 - \Delta) - P_0(Q_0)q_0 + c\Delta \\ &= \left[\frac{P_0(Q_0 - \Delta + x_0) - P_0(Q_0)}{\Delta - x_0}\right](\Delta - x_0)(q_0 - \Delta) - P_0(Q_0)\Delta + c\Delta.\end{aligned}$$

Consequently, because $P_0(\cdot)$ is linear with constant slope $P'(Q_0)$, and $P_0(Q_0) = P(Q_0)$, we have

$$\pi(\Delta) = -P'(Q_0)(\Delta - x_0)(q_0 - \Delta) - P(Q_0)\Delta + c\Delta. \tag{A.1}$$

The function of Δ in (A.1) is strictly concave and quadratic. Consequently, because its value is strictly negative when $\Delta = x_0$, it assumes a positive value for some $\Delta \in (x_0, q_0)$ if and only if its derivative at $\Delta = x_0$ is positive and its discriminant is positive. That is if and only if

(i) $-P'(Q_0)(q_0 - x_0) - P(Q_0) + c > 0$, and
(ii) $(-P'(Q_0)(q_0 + x_0) - P(Q_0) + c)^2 - 4[P'(Q_0)]^2 x_0 q_0 > 0$.

Dividing (ii) by $[-P'(Q_0)Q_0]^2$ yields $(s_0 + z_0 - \eta_0)^2 - 4z_0 s_0 > 0$, which is equivalent to,

$$0 < s_0 + z_0 - \eta_0 - 2\sqrt{z_0 s_0} = \left(\sqrt{s_0} - \sqrt{z_0}\right)^2 - \eta_0$$

because $\eta_0 \leq s_0 \leq s_0 + z_0$. Finally, because $s_0 > z_0$, we see that (ii) is equivalent to,

$$\sqrt{s_0} > \sqrt{z_0} + \sqrt{\eta_0}. \tag{A.2}$$

But (A.2) clearly implies $s_0 > z_0 + \eta_0$, which is equivalent to (i) after division by Q_0. Hence, (A.2) alone is equivalent to (i) and (ii). Consequently, (A.1) is strictly positive for some $\Delta \in (x_0, q_0)$ if and only if (A.2) holds.

But, according to the condition stated in the theorem, (A.2) fails. Hence, (A.1) is non-positive for $\Delta \in (x_0, q_0)$. Firm 1 therefore cannot increase its profits by restricting output against the true demand function $P(\cdot)$. This proves the first part of Theorem 1.

To prove the second part, merely note that if the condition stated in the theorem fails, then (A.2) holds. But then the linear demand function $P_0(\cdot)$ above yields price and elasticity p_0 and ε_0, respectively, at Q_0. Moreover, because (A.2) holds, firm 1 can increase its profits by reducing output by some $\Delta \in (x_0, q_0)$. □

Proof of Theorem 2 To prove the first part, let $P_0(Q) - c$ denote the CES net demand function with constant elasticity $\eta_0 = \eta(Q_0)$ and such that $P_0(Q_0) = p_0$. We first argue that,

$$P_0(Q) \geq P(Q), \text{ for all } Q \leq Q_0. \tag{A.3}$$

To see this, note that by Marshall's second law for net demand, for all $Q \leq Q_0$,

$$-\frac{P(Q) - c}{QP'(Q)} = \eta(Q) \geq \eta(Q_0) = \eta_0 = -\frac{P_0(Q) - c}{QP_0'(Q)},$$

so that,

$$\frac{P'(Q)}{P(Q) - c} \geq \frac{P_0'(Q)}{P_0(Q) - c}, \quad \text{for all } Q \leq Q_0.$$

Therefore, for all $Q \leq Q_0$,

$$\begin{aligned}
\ln(P(Q_0) - c) - \ln(P(Q) - c) &= \int_Q^{Q_0} \frac{P'(Q)}{P(Q) - c} \mathrm{d}Q \\
&\geq \int_Q^{Q_0} \frac{P_0'(Q)}{P_0(Q) - c} \mathrm{d}Q \\
&= \ln(P_0(Q_0) - c) - \ln(P_0(Q) - c),
\end{aligned}$$

which, because $P_0(Q_0) = p_0 = P(Q_0)$, implies (A.3).

By (A.3) it suffices to show that firm 1 cannot increase its profits by reducing output against the demand function $P_0(\cdot)$, since firm 1 can then not possibly increase its profits by reducing quantity against the true demand function.

By construction, $P_0(Q) = aQ^{-1/\eta_0} + c$, where a is a constant such that $P_0(Q_0) = p_0$. Given the demand function, $P_0(\cdot)$, firm 1's profits upon reducing output by $\Delta \in (x_0, q_0)$ are $a(Q_0 - \Delta + x_0)^{-1/\eta_0}(q_0 - \Delta)$. This expression must admit an interior maximum if such a reduction increases firm 1's profits. In particular, the first-order condition must hold with equality. It is straightforward to show that this implies

$$\Delta = \frac{q_0 - \eta_0(Q_0 + x_0)}{1 - \eta_0}. \tag{A.4}$$

Now, the reduction in quantity is profitable if and only if

$$a(Q_0 - \Delta + x_0)^{-1/\eta_0}(q_0 - \Delta) > aQ_0^{-1/\eta_0}q_0.$$

Substituting (A.4) into this inequality and dividing by Q_0 to obtain shares implies that the reduction is profitable if and only if

$$\left(\frac{s_0}{\eta_0}\right)^{\eta_0}\left(\frac{1 - s_0 + z_0}{1 - \eta_0}\right)^{1-\eta_0} < 1. \tag{A.5}$$

But this contradicts (3), the inequality stated in the theorem. Hence, reducing output cannot increase profits against the demand function $P_0(\cdot)$, and therefore it cannot increase profits against the true demand function either. This proves the first part of the theorem.

The second part now follows almost immediately. Simply notice that if (3) fails, then (A.5) holds and, given the demand function, $P_0(Q) = aQ^{-1/\eta_0} + c$ above, firm 1 can increase its profits by reducing output by Δ given by (A.4). Moreover, net demand, $P_0(Q_0) - c = aQ^{-1/\eta_0}$, being CES satisfies Marshall's second law. The only remaining detail is to ensure that Δ, given by (A.4), lies within the interval (x_0, q_0).

It is straightforward to show that Δ, given by (A.4) lies between x_0 and q_0 if and only if $s_0 > \eta_0 + z_0$. But this is equivalent to

$$\frac{1 - s_0 + z_0}{1 - \eta_0} < 1. \tag{A.6}$$

But observe that, because $s_0 \geq \eta_0$, the first-term in the product on the left-hand side of (A.5) is at least unity. Hence, (A.5) implies (A.6) and so Δ, given by (A.4), lies between x_0 and q_0. □

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