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A natural monopoly in natural gas transmission

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Abstract

In this article, we test for subadditivity in the cost structure associated with transporting natural gas by Trans-Canada Pipelines Ltd. and measure for possible cost savings from increased competition that could be realized by removing the monopoly status granted by the National Energy Board. In measuring subadditivity, we apply both the Baumol et al. (Contestable Markets and the Theory of Industry Structure (1982)) and the Evans and Heckman (Am. Econ. Rev. 764 (1984) 613) procedures. Our results show evidence of subadditivity in the cost structure, and consequently, the possible benefits from increased competition resulting from splitting up the monopoly could be offset by the sacrifice of scale efficiencies.

JEL classifications: Q32; Q41

Keywords: Subadditivity; Natural monopoly; Natural gas transportation

1. Introduction

Over the past decades, numerous and significant changes have occurred within the natural gas industry, stemming largely from the deregulation of gas markets and pricing in both Canada and the US. In conjunction with enhanced competition in the marketplace, there comes an expectation to supply product to more distant markets as a means of supporting further growth in production capacity and profitability. As gas transmission costs represent a significant portion of the total price of natural gas in many markets, it is not surprising that there is pressure to reduce gas transmission tolls as part of the move towards a more competitive commodity marketplace.

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The increased focus on efficiency and cost issues with respect to gas has served to focus the regulatory debate surrounding the pipeline industry. In particular, persistent and strident demands for further deregulation have been levied by the shipping industry, which contends that a shift in the regulatory regime would markedly improve efficiency and reduce tolls. The critical question underlying the issue is whether scope or scale economies would be sacrificed upon the advent of competition, thereby resulting in substantive inefficiencies that more than offset the benefits resulting from increased competition. An inquiry into this question requires knowledge of the cost characteristics in gas transmission and specifically whether natural monopoly is the natural structure of the natural gas industry.

Subadditivity plays the dominant role in defining a natural monopoly. Subadditivity is realized if no combination of multiple firms can collectively produce industry output at lower cost than a monopolist (Berg and Tschirhart, 1988). In the single output case, the existence of economies of scale is a sufficient condition to ensure subadditivity. However, in the multiple output case the conditions for subadditivity are more elaborate requiring cost complementarities or product specific scale economies and economies of scope (Baumol, 1977; Baumol et al., 1982). The interest by applied economists in subadditivity is in measuring the benefits from splitting up a monopoly industry into a number of smaller firms. If subadditivity prevails, no cost benefits will be realized by increased competition. On the other hand, without subadditivity (or what is referred to as superadditivity) lower costs of production could be realized by splitting up a monopoly industry into a number of smaller firms.

Much of the applied work in testing for natural monopoly has been carried out for the telephone industry (Smith and Corbo, 1979; Fuss and Waverman, 1981; Evans, 1983; Evans and Heckman, 1984; Roller, 1992; Shin and Ying, 1992). In fact, some of this work was instrumental in the decision to break up the Bell telephone system in US (Shepherd, 1990). The natural gas pipeline industry is also an interesting candidate for natural monopoly testing but has received much less attention by applied economists (Aivazian et al., 1987; Ellig and Giberson, 1993). In Canada, Trans-Canada Pipelines Ltd (TCPL) has been granted by the National Energy Board (NEB) of Canada an effective monopoly in the transportation of natural gas from fields in Alberta to points in Eastern Canada and the US. In spite of the relative paucity of empirical studies on subadditivity in natural gas transmission, it seems reasonable, given the fundamental operating characteristics of the pipeline business, to speculate that subadditivity prevails in the cost structure of firms such as TCPL. In fact, Mansell and Church (1995) argue that in natural gas transmission both plant and firm level subadditivity is present.[1] The purpose and contribution of this article is to assess components of the natural gas transmission industry in Canada by empirically testing for subadditivity in the cost structure

[1] Sharkey (1982) distinguishes between factors that contribute to subadditivity at the plant level (single pipeline) and at the firm level (multi-pipeline or network). Where plant or firm level subadditivity exists, the ability to achieve economies will often be greatest in the case of a single firm, as significant transaction costs are often associated with achieving the optimal sequence and size of expansion, network management and network configuration through the use of contracts and market exchange.

associated with transporting natural gas by the carrier TCPL and to determine whether cost savings could be realized by removing the monopoly status granted by the NEB.

In a multiple output setting, Baumol et al. (1982) and Evans and Heckman (1984) provide alternative procedures for testing for natural monopoly. The former approaches the problem indirectly by testing the production structure for the necessary and sufficient conditions that would indicate subadditivity. The latter is a direct test of the cost structure. In Section 2, these testing procedures are reviewed. In Section 3, we provide a brief overview of the Canadian natural gas pipeline industry, discuss the data available for analysis and specify the cost function used in estimation. In Section 4, we evaluate the estimated cost function in terms of the regularity conditions and confirm that a 'proper' cost function has been identified. Following this, the alternative tests for natural monopoly are carried out and results presented. Section 5 concludes.

2. Methods

Subadditivity can be illustrated in a straightforward manner using a cost function representation of the technology. Let $C(Y)$ represent the cost function[2] for a single firm existing in the industry and let $C(y_i)$ represent the cost function for the ith firm in a multi-firm configuration of the industry. Subadditivity characterizes the cost structure if

$$C(Y) < \sum C(y_i) \tag{1}$$

where $\Sigma y_i = Y$. Changing the inequality to an equality implies additivity in the cost structure and a further change to greater than implies superadditivity, in which case, multiple firms can achieve lower total costs in producing industry output compared to the existence of only one firm.

Baumol et al. (1982) test for a form of local subadditivity.[3] The procedure is to evaluate the estimated cost structure at each data point for evidence of subadditivity. In the single output case, a test for economies of scale is sufficient evidence to ensure a natural monopoly. In the multiple output case, a sufficient condition is to find evidence of both economies of scale and transray convexity.

In the single output (y) case, a measure of scale economies is the ratio of average to marginal cost (C_y) or

$$S(y) = \frac{C(y)}{yC_y} \tag{2}$$

where $S(y) > 1$ implies increasing returns to scale and the opposite inequality implies

[2] Other arguments in the cost function are suppressed for ease of exposition.

[3] A test for global subadditivity requires cost information for firms of different size that could potentially produce industry output (Baumol et al., 1982, p. 171).

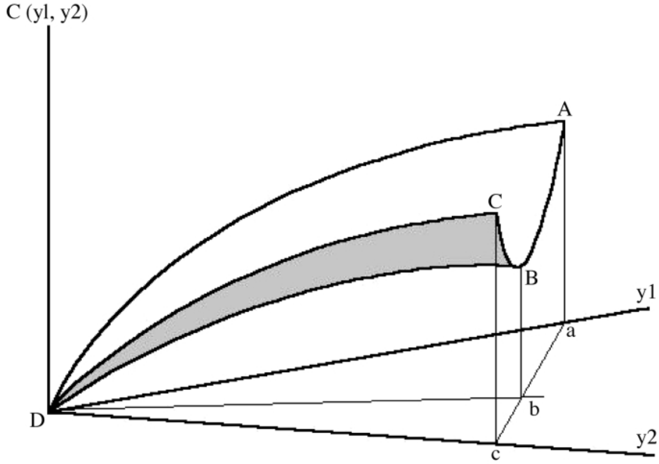

Fig. 1. Transray convexity.

decreasing returns to scale. Panzar (1989) extends this definition to the multiple output case or

$$S(Y) = \frac{C(Y)}{\sum y_j C_j(Y)} \tag{3}$$

where Y represents an aggregate measure of total output and $C_j(Y)$ represents the marginal cost of producing the jth output. Eq. (3) is defined for a ray from the origin where along the ray average costs are decreasing (Waterson, 1988). Hence, if output-weighted marginal cost is below total cost, then $S(Y) > 1$ and economies of scale are observed. Conversely, a less than inequality implies diseconomies of scale. In empirical analysis, this scale measure is evaluated at each data point.

Transray convexity, in the multiple output case, can be explained with reference to Fig. 1 (Evans and Heckman, 1984). In the figure, *ABCD* represents the cost surface of a two output (y_1, y_2) firm with a ray from the origin labeled *Db*. Another ray, a transray, intersects *Db* along *abc*. When the transray is extrapolated up to the cost hyperplane, it cross-sectionalizes the cost surface at *ABC*. A cost surface is said to be transray convex if the extrapolation of any transray up to the cost surface yields a convex cross-sectionalization.

Along the transray *abc*, let $C(\alpha)$ represent a point on the cost hyperplane between (a and c) and let $C(\beta)$ represent a point on the cost hyperplane between (b and c). Transray convexity implies that a line connecting $C(\alpha)$ and $C(\beta)$ must not lie below the cost surface at every point between α and β, or

$$C(k\alpha + (1-k)\beta) \leqslant kC(\alpha) + (1-k)C(\beta), \quad 0 < k < 1 \tag{4}$$

In other words, transray convexity implies that holding the aggregate output bundle fixed but allowing a change in the output mix will lower costs for a diverse rather than specialized output mix (Squires, 1988).

Observing transray convexity at one point in the data set does not imply convexity throughout the cost surface (Baumol et al., 1982). Squires (1988) suggests testing at each data point for pairwise transray convexity, where such pairwise evidence would imply that transray convexity holds overall. Pairwise transray convexity can be tested by calculating second-order partial derivatives or

$$\begin{aligned}&\text{(a)}\ \ Cy_iy_i \geqslant 0,\ \ Cy_jy_j \geqslant 0,\ \ Cy_iy_j = Cy_jy_i \leqslant 0;\\ &\text{(b)}\ \ Cy_cy_c\ \leqslant\ 0,\ \ Cy_jy_j \leqslant 0,\ \ Cy_iy_j = Cy_jy_i \leqslant 0,\ \ Cy_iy_j \leqslant -\sqrt{C\ y_iy_iCy_jy_j}\end{aligned} \tag{5}$$

where Cy_iy_i is the second-order partial of the cost function with respect to the ith output. $Cy_\mathrm{i}y_j \leqslant 0$ implies weak cost complementarities and $Cy_iy_i \leqslant 0$ represents product specific scale economies. From the last argument in Eq. (5), product specific scale economies are consistent with transray convexity only if cost complementarity is sufficiently strong (i.e. $Cy_iy_j \leqslant -\sqrt{(Cy_iy_iCy_jy_j)}$).

It is interesting to note that cost complementarity represents an alternative sufficient condition for subadditivity and, what is more, implies economies of scope, which also represents a necessary condition for subadditivity.[4] Empirically, the Squires procedure involves testing both for transray convexity and for cost complementarities.

Evans and Heckman (1984) suggest a direct test for subadditivity. Here subadditivity is defined for the two output case (y_1 and y_2) with n firms in the alternative configuration of the monopoly industry as

$$C(y_1,\ y_2) < \sum_i C(a_iy_i,b_iy_2),\quad a_i \geqslant 0,\ \ b_i \geqslant 0,\ \ i=1,\ldots n \tag{6}$$

If $\sum_{a_i} = \sum_{b_i} = 1$, the combined output of the individual firms equals the output of the monopolist (i.e. additivity). On the other hand, if the inequality in Eq. (6) is reversed, the cost function is characterized by superadditivity.

In measuring for subadditivity, it is necessary to compare the actual cost structure of the existing monopolist with the cost structure that would apply to an n-firm configuration of the industry. To accomplish this, Evans and Heckman place restrictions on the admissible output vectors used in testing. In general, they impose the restriction that the n-firm output vectors are within the range of output vectors actually observed in the data. Operationally, this implies that no firm in the alternative configuration of the industry is permitted to produce less of each output

[4] Cost complementarity ensures economies of scope, but large fixed costs common to the production of multiple outputs will also suffice. Economies of scope are available if the cost associated with producing, say, two products (y_1 and y_2) in joint production are strictly lower than the costs associated with producing these products separately or $C(y_1,\ y_2) < C(\ y_1,0) + C(0,\ y_2)$.

than the lowest observed output level of the monopolist. This imposes the restriction that testing can only be performed in a region where the output level of each product is at least twice that of the minimum observed production level of the monopolist. In addition, Evans and Heckman place a further restriction on the output mix for the *n*-firm configuration to be within a ratio observed in the data. This restricts any individual firm from having a more specialized output mix than the monopolist.

Imposing the Evans–Heckman restrictions, we rewrite Eq. (6) as

$$\mathrm{Sub} = \frac{C(y_1,\ y_2) - \sum_{i=1}^{n} C^i(y_1^R,\ y_2^R)}{C(y_1,\ y_2)} \tag{7}$$

where C^i represents the ith firm's cost function and y_j^R is the jth output greater than or equal to the minimum level of this output observed in the industry. If $\mathrm{Sub} < 0$, the data suggest subadditivity in the cost structure and, on the other hand, if $\mathrm{Sub} > 0$, the data suggest superadditivity.

3. Natural gas transmission

The NEB of Canada regulates the transmission of natural gas within Canada with respect to tolls, expansions, allowed rate of return and the right to transport. It is the latter certification that can bestow monopoly status in the natural gas transmission market. TCPL falls within the jurisdiction of the NEB and has been granted a certificate to transport natural gas from fields in Southern Alberta to delivery points in Canada and in the US. TCPL's main transmission line started operations in 1958. Prior to 1986, TCPL was engaged in both transporting and marketing natural gas. In 1986, the NEB deregulated the pricing of natural gas and withdrew the right of pipeline companies to engage in marketing and sales of natural gas. In 1986, TCPL formed Western Gas Marketing to carry out the marketing and sales of natural gas. Currently, TCPL has 13 687 km of pipe delivering some 55.8 billion cubic meters of natural gas annually.

Conditions within the natural gas transmission industry appear to reflect plant level subadditivity, or subadditivity that is associated with cost-efficiencies due to indivisibilities in production technology resulting in economies of scale and scope (Mansell and Church, 1995).[5] In the pipeline industry, volumetric returns to scale exist such that as the diameter of the pipe doubles, its volume increases by a factor of 4, while its surface area only increases by a factor of 2. Output is proportional to volume; however, the cost of construction is proportional to surface area. Economies of scope can arise if there are large common costs in the production of

[5] Economies of scale result from a reduction in the unit or average cost as production of a good or service expands. Economies of scope result from a reduction in costs when a single firm produces a group of products or services at a lesser cost than multiple firms, thereby giving rise to multi-product firms.

multiple outputs and cost complementarities (Sharkey, 1982). Certainly, in gas transmission, compressors and pipe are used in production of a number of transmission services and as long as capacity constraints are not binding cost complementarities should exist. Economies of 'rights-of-way' may also be important in this industry. 'Rights-of-way' allow pipeline companies the legal right to lay pipe without owning the land and can vary disproportionately with pipeline size.

It is also reasonable to assume that firm level subadditivity exists in the natural gas transmission industry as a result of network economies, where the transaction costs of organizing production within a single firm are less than those associated with using the market to organize production. For example, expansions within the pipeline industry are typically capital intensive, and as such, economies of fill exist where installation costs are minimized in cases where expansions are infrequent and large. In most cases, an optimal expansion path is more likely to be realized if a single firm dominates the industry.[6] In addition, network management economies are realized when a network is operated by a single firm, as a single operator is typically better positioned to manage the system effectively through re-routing, aggregating and transmission sharing activities. Consequently, with the possibility of observing cost complementarities and economies of scale and scope, it is possible that empirical evidence will support natural monopoly status in the cost structure for transporting natural gas.

In the case of the natural gas transmission industry in Canada, estimating the cost function to measure production parameters serves as a particularly attractive methodology. This is particularly true given that the level of output in the natural gas industry is more appropriately considered an exogenous rather than endogenous variable. In general, natural gas transmission entities are not able to select the level of transport that maximizes profits. Rather, such entities are required to supply sufficient shipping to meet demand at the given regulated tolls or prices. Thus, decision-making flexibility rests solely with the determination of the level of inputs utilized. In addition, given that the gas transmission industry competes with other industries in order to obtain such inputs, the specification of input prices as exogenous is also reasonable and appropriate.

The NEB requires TCPL to report on quarterly basis the cost and revenue information. In general, the data relate to total operating expenses, depreciation, income taxes, labour costs (expenditure and employment figures), rate base and volume or 'throughput' data disaggregated by delivery point; Canadian or US deliveries. A measure for the distance gas that is transported is not available. Rate base information is used to proxy a measure of capital in service. A standard measure of capital in service is net capital value of the plant. Over 90% of the rate base cost information is net capital value of the plant. As such, we consider the rate base proxy for capital in service to be reasonable. Two additional variables were

[6] Although it may be argued that the optimal expansion is obtainable through a consultative and cooperative interaction amongst several firms, whether regulated or not, the transaction costs of such efforts would undoubtedly be considerable, thereby negating the ability to derive the first best outcome.

collected from Statistics Canada.[7] An interest rate defined as the 3-month average of the 90-day prime corporate rate is used as a proxy price variable for capital, and a price for natural gas in cents per cubic meter based on total sales in Canada is used as the price measure of transporting natural gas through the pipeline.[8] The CPI deflates all nominal variables.

The NEB provided quarterly data on the information described for the period 1981–1995. However, observations are missing for 1988 and 1995.[9] Missing observations are filled with the mean value for each defined variable. In all, 48 quarterly observations are available.

The research strategy proposed in this article is to characterize the cost structure within a multi-output framework; deliveries within Canada and deliveries to the US. The two-output specification is based on the hypothesis that there exist cost differences between the two delivery points and following McCallum (1995) we suspect that there may be a boarder effect involved in US deliveries. The two-output cost function is estimated and tested for regularity conditions and subadditivity.

In application, we estimate a translog cost function to test for natural monopoly. This functional form is popular in the applied literature and has been used in other studies testing for natural monopoly (Smith and Corbo, 1979; Fuss and Waverman, 1981; Evans and Heckman, 1984; Shin and Ying, 1992; Ellig and Giberson, 1993).[10] As is well known, the cost function is derived from minimizing the cost of production subject to a given level of output. In general, the cost function is represented as

$$C(w;\ Y) \tag{8}$$

where w is a vector of input prices and Y is a vector of output quantities (Diewert, 1974). The translog functional form is used to represent Eq. (8) and to generate an estimable form of the cost function:

$$\begin{aligned}\ln C(w;\ Y) = {} & \alpha_0 + \sum_i \alpha_i \ln(w_i) + \sum_k \beta_k \ln(Y_k) + \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln(w_i)\ln(w_j) \\ & + \frac{1}{2}\sum_k \sum_l S_{kl} \ln(Y_k)\ln(Y_l) + \sum_i \sum_k \rho_{ik} \ln(w_i)\ln(Y_k)\end{aligned} \tag{9}$$

Eq. (9) must satisfy a number of regularity conditions in order that a 'proper' cost function is established (Roller, 1992). The regularity conditions require Eq. (9) to be concave in prices, to be homogeneous of degree one and non-decreasing

[7] Statistics Canada data are from CANSIM: price of natural gas from series E13450; interest rate from series B14017 and CPI from series P484000.

[8] Natural gas is used to power compressors to transport the volume of gas through the pipeline.

[9] No explanation for the missing observations is available either from NEB or from TCPL.

[10] There are some problems in using the translog in testing for product specific economies of scale and economies of scope (Braunstein and Pulley, 1992).

(monotonic) in input prices, and to be increasing in output. These conditions are evaluated on estimation.

Concavity implies that as an input price increases cost increases but at a decreasing rate as firms substitute away from the higher priced input. Homogeneity imposes the condition that a proportional increase in all prices causes a proportional increase in cost. Monotonicity shows that at the equilibrium an increase in an input price will cause cost to increase even though firms substitute away from the higher priced input. Increasing in output levels ensures that, for the single output case, marginal cost is positive. In the multiple output case, an additional assumption of free disposal for each output is required to ensure positive marginal cost. However, Shephard (1970) argues that this positive marginal cost in the multiple output case is unnecessary. Rather, what is required is that the multiple output cost function is increasing in output or, in other words, economies of scale must be positive.

In summing up, the translog cost function is defined over three input prices: the price of labour, capital and natural gas, with the output vector defined as the volume of gas transported within Canada or to the US.

As we are interested in measuring long run cost characteristics, no factors are held fixed in the cost function specification (Eq. (9)). Ellig and Giberson (1993) argue that for Eq. (9) to be a valid long run cost function TCPL must adjust capacity instantaneously and, in addition, depreciation values used in accounting must accurately measure economic depreciation. As the data at best only approximate these conditions with substantial fixed costs in terms of pipe in the ground, Ellig and Giberson suggest defining such a cost function as 'quasi-long run'.

4. Empirical results and testing

We follow standard procedures used to estimate the parameters of the cost function. The system of equations consisted of the cost function and two of the three share equations. A Zellner SUR iterative routine is used as the estimator. Our empirical strategy is to estimate the parameters and then evaluate and test for a 'proper cost function' in terms of the regularity conditions and elasticity characteristics of the data.

Our first test is to evaluate the joint condition of homogeneity and symmetry in the unrestricted estimated cost model. A χ^2-test procedure (the calculated χ^2 is 108.7 with 19 degrees of freedom compared to a critical value of 30.14) easily rejected the null hypothesis of homogeneity and symmetry, and in further estimation and testing these conditions are imposed on the cost function.

In Table 1, the estimated parameters and corresponding standard errors are reported for the translog cost model. In standard *t*-tests at the 10% level, most individual parameters (14 out of 22) are statistically important and, what is more, the Jarque–Bera test of the null hypothesis of normality in the estimated error terms cannot be rejected at the 95% confidence level. In other words, the estimated error terms approximate the normal distribution. In one other test, restrictions are imposed on the translog and we test for the nested Cobb–Douglas functional form. The null hypothesis is that the true form of the cost function is Cobb–Douglas and a

Table 1
Parameter estimates: two output cost model

Variable	Estimated coefficient	t-Ratio
Con[a]	19.15	356.1[a]
Dr	−0.11	−1.95[b]
Wage	0.08	24.89[b]
Wage^2	0.04	4.05[b]
Gas	0.53	22.32[b]
Gas^2	0.02	0.67
Interest	0.39	18.72[b]
Interest^2	0.01	0.09
Wage^{b}gas	−0.03	−2.89[b]
Interest^{b}gas	0.01	0.15
Wage^{b}interest	−0.01	−1.54[b]
Q_1	0.20	2.81[b]
Q_1^2	0.24	2.54[b]
Q_2	0.09	0.59
Q_2^2	2.26	1.32[b]
$Q_1{}^bQ_2$	−0.27	−1.52[b]
Wage^bQ_1	−0.01	−1.01
Interest^bQ_1	−0.01	−0.03
Gas^bQ_1	−0.48	−1.85[b]
Wage^bQ_2	0.01	1.01
Interest^bQ_2	0.01	0.03
Gas^bQ_2	0.48	1.85[b]
Log of likelihood	193.64	

Dr, regulation dummy; Q_1, US deliveries; Q_2, Canadian deliveries.
[a] Con, constant
[b] Significant at the 10% significance level.

likelihood ratio statistic is used in testing. The summary statistic generated a value of 1718. The statistic is distributed as χ^2 with 15 degrees of freedom and the null is easily rejected.

Further evaluation of the estimated model is obtained by testing for regularity conditions. We generate own price elasticities for the price of labour, capital and natural gas at each observation point. Testing of the individual elasticities supports non-zero inelastic values for all three summary statistics. (Labour has a mean estimated elasticity of −0.452, capital −0.584 and natural gas −0.435.) The elasticities are correct in sign and seem to be of a reasonable value.

The partial derivative of cost with respect to each input price is positive at each observation point in the data set and indicates that the empirical model satisfies monotonicity. Recall that this implies that the model is consistent with the condition that at the equilibrium an increase in an input price will cause cost to increase even though firms substitute away from the higher priced input.

Concavity is tested using the eigenvalues recovered from the Hessian matrix of the cost function. Concavity implies that as an input price increases cost increases but at a decreasing rate as firms substitute away from the higher priced input. All estimated eigenvalues are negative indicating that the model satisfies this condition.

Table 2
Transray convexity

	Mean	Minimum	Maximum
$\partial^2 C/\partial^2\mathrm{US}$[a]	9.97	0.698	31.3
$\partial^2 C/\partial^2\mathrm{CA}$	−1.77	2.67	−1.08
$\partial^2 C/\partial\mathrm{US}\partial\mathrm{CA}$	−2.79	−6.61	−0.931

[a] Second-order partial derivates of the cost function with respect to US (US) deliveries and Canadian (CA) deliveries.

On the basis of the above tests, we conclude that the estimated cost function appears to be well behaved and satisfies the conditions required for a proper and regular cost function. We proceed then with an evaluation of natural monopoly.

In the evaluation of natural monopoly, Panzar's (1989) measure for scale economies in multi-output production is calculated first (Eq. (3)). Economies of scale (i.e. $S>1$) will also indicate strictly decreasing ray average costs. Panzar's measure of scale economies is calculated at each data point and measures a mean value of 1.08 with a range from 1.05 to 1.18. Scale economies are measured to be greater than 1 for all observations and suggest that decreasing ray average costs are a characteristic of the cost structure for natural gas transmission, decreasing ray average cost being a necessary condition for subadditivity. Note that our measure of scale economies is within the upper limit of 2.07 argued in engineering studies (Aivazian et al., 1987).

With scale economies and decreasing ray average costs satisfied, we test for transray convexity by implementing Squires (1988) pairwise test for this characteristic. All second-order derivatives with respect to output are evaluated at each data point. Transray convexity requires second-order own derivatives to be positive and cross derivatives to be negative. The results are summarized in Table 2. As at least one second-order own derivative is negative at each observation point, transray convexity fails in the cost model. Recall that transray convexity is sufficient but not necessary for natural monopoly. On the other hand, we do observe evidence of cost complementarities (i.e. second-order cross partials being negative) at each observation point, which is a sufficient condition for natural monopoly. Consequently, Panzar's test provides evidence of both necessary and sufficient conditions for the existence of subadditivity in the cost structure for TCPL even though transray convexity fails.

We attempt to confirm these results by applying the subadditivity test suggested by Evans and Heckman (1984) (i.e. Eq. (7)). This test requires us to define an allowable production region for the alternative two-firm configuration of the industry. What is more, the combined output of the two-firm configuration must equal the production of the monopolist. A grid search pattern is used to examine the combination of outputs allowable for the two-firm configuration. In total, the results of this subadditivity test are too numerous to allow presentation here, but we summarize the results for the estimated model. Although this test is intensive, it is straightforward to obtain predictions and associated standard errors.

Table 3
Subadditivity results

Percentage of Canadian delivery by firm 1	Percentage of US delivery by firm 2				
	10	30	50	70	90
10	−1.028	−1.027	−1.026	−1.026	−1.026
30	−1.021	−1.020	−1.019	−1.019	−1.020
50	−1.018	−1.018	−1.018	−1.018	−1.018
70	−1.020	−1.019	−1.019	−1.020	−1.021
90	−1.026	−1.026	−1.026	−1.027	−1.028

The results for the Evans and Heckman test are shown in Table 3. The columns represent the percentage, from 10 to 90%, of Canadian deliveries produced by firm 1 and the rows represent the percentage, from 10 to 90%, of US deliveries produced by firm 2. For example, the element in row 1 column 1 (−1.028) is interpreted to represent the relative cost advantage of the two-firm configuration over the monopolist if firm 1 produces 10% of Canadian deliveries and 90% of US deliveries and firm 2 produces 90% of Canadian deliveries and 10% of US deliveries. As the matrix entries are all negative, this indicates that there exists no combination of outputs divided between the two firms that can produce the total output at lower cost than a monopolist.

In summing up, both the Baumol et al. (1982) and Evans and Heckman (1984) testing procedures provide statistical evidence for subadditivity in the cost structure of TCPL.

5. Concluding comments

In Canada, TCPL has a monopoly grant to transport natural gas from fields in Alberta to deliver points in Canada and the US. There is some interest by both private and public concerns in having the transportation of natural gas deregulated to allow for increased competition and presumably lower costs in transportation. The purpose of this article was to investigate whether cost savings could be achieved in transporting natural gas by allowing a multi-firm configuration of the industry. To this end we use both the Baumol et al. (1982) and Evans and Heckman (1984) procedures to test for subadditivity in the cost structure for TCPL. Using quarterly data for TCPL, statistical tests show evidence of multi-output scale economies, decreasing ray average costs and cost complementarities. Absent in the data set is evidence of transray convexity. Nevertheless, within the allowable output range, no combination of outputs divided between two firms can produce the total output at lower cost than a monopolist. These results lead to the conclusion that subadditivity is evident in the cost structure for transporting natural gas and that indeed TCPL is a natural monopoly.

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