**Title**

# Competition and Prices in the Deregulated Gas Pipeline Network: A Multivariate Cointegration Analysis



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# Competition and Prices in the Deregulated Gas Pipeline Network: A Multivariate Cointegration Analysis


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**Abstract**

This research uses multivariate cointegration analysis to assess the degree of competition in the U.S. natural gas industry following the move to open access pipeline transportation. The testing methodology allows multiple nodes in the pipeline network to be analyzed simultaneously and is based on recent advances by Johansen (1988, 1991) and Johansen and Juselius (1990) on estimation and hypothesis testing in multivariate cointegrated systems. Daily price data across the North American natural gas transmission grid are analyzed and the results indicate that the pattern of prices between production areas is consistent with allocative efficiency.

# 1 Introduction

Natural gas pipeline deregulation occurred *de facto* in 1985 when pipelines were allowed to become *open access* transporters. Prior to open access, natural gas pipelines functioned as merchant carriers that were required to bundle together gas and its transportation.[1] Under the new system of open access, pipelines carry gas for their customers as contract carriers.[2] Contract carriage gave pipeline customers direct access to transportation and created a connected pipeline grid. Open access enabled pipeline customers and natural gas brokers to exchange and combine transportation rights. By exchanging and combining transmission rights on several connecting pipelines, gas buyers and sellers were able to create connected topologies over which they could trade natural gas.

The open access pipeline network connects numerous natural gas spot markets where exchanges are made on a daily basis. The magnitude and time varying properties of spatial price differentials are an important indicator of market performance. This is especially apparent in the gas pipeline industry, where a dense and highly interconnected transmission network connects a large number of spot markets. Within such a transmission network, the persistence of price differentials in excess of transmission and transaction costs indicates the failure of potential arbitrage to discipline prices. When this occurs, the price signals received by demanders and suppliers of the commodity are distorted and resources are misallocated; moreover, price distortions are likely to result in inefficient shipments or "crosshauling." Alternatively, when potential and actual arbitrage are successful in enforcing the "law of one price" across the transmission network, up to transmission and transaction costs, then the correct price signals will propagate and allocative efficiency will be obtained.

In the gas pipeline network, daily price observations are generated at

[1] See Cramer (1991) and Energy Information Administration (1989) for an overview of how availability of open access transportation changed dramatically the relative volumes of gas shipped under the new and the old systems.

[2] See De Vany and Walls (1992) and Walls (1992, chapter 2) for a detailed description of the institutions coordinating the gas and the transportation markets. Smith *et al.* (1988, 1990) contains an analysis of the system of merchant carriage and the original proposal for open access applied to natural gas pipelines.

each node in the network. However, standard statistical methods are unable to properly analyze this type of data for price disparities between locations. The empirical technique required to analyze such data must explicitly allow for multiple time series of data that may be nonstationary.[3] The theory of cointegration as developed by Granger (1986) and Engle and Granger (1987) has been used successfully to test for price disparities in financial and geographic product markets when the data are nonstationary.[4] The basic idea of these studies is that even though certain economic variables fluctuate in the short run, deviations from an economic equilibrium must vanish in the long run. For example, gas prices in two areas may fluctuate stochastically relative to past prices, but the difference between the two prices must be stable. In this case, the economic equilibrium condition can be written as $| P_i - P_j | \leq T_{i,j}$ where $P_i$ and $P_j$ denote distinct geographic prices and $T_{i,j}$ is the transportation cost between location $i$ and location $j$. If the inequality were violated, gas traders could effect spatial arbitrage between the two markets causing the price disparity to vanish.

Previous studies of spatial commodity prices generally consider prices on a pairwise basis only.[5] This treats the remaining markets as if they were not affected by the price changes in the two markets under study. This may not be appropriate when the markets at each location operate simultaneously, as is the case for the natural gas spot market. In general there may be $N$ nodes in a transmission network where each node represents a distinct geographic market. The entire set of $N$ markets must be analyzed simultaneously to accurately make inference on the process through which prices are determined. Søren Johansen's (1988, 1991) method of cointegration analysis allows data

[3]See Greene (1993, Chapter 19) for an accessible introduction to nonstationarity, unit roots, and cointegration.

[4]Ardeni (1989) tests the law of one price; Goodwin and Schroder (1991) evaluate spatial market linkages in cattle markets; Bessler and Covey (1991) quantify the relationship between cash and futures prices for cattle; Chowdhury (1991) tests futures market efficiency on the London Metal Exchange; De Vany and Walls (1993) evaluate regulatory changes on natural gas spot markets; Bentzen and Engsted (1993) use Johansen's cointegration analysis to estimate elasticities of energy demand.

[5]De Vany and Walls (1993), Doane and Spulber (1992), and Walls (1993) use cointegration analysis to quantify the degree of market integration between pairs of natural gas spot markets. However, De Vany and Walls (1992a,1992b) have used multivariate time series methods to quantify the strength of market integration between production fields and city gates.

from the full set of markets to be analyzed simultaneously and his method is used in this paper to analyze natural gas prices in the deregulated pipeline network.

The paper continues as follows: A simple model of competition in the gas pipeline network is developed in section 2. The cointegration analysis is explained in section 3 and the empirical results are presented in section 4. Conclusions are made in section 5.

## 2 Competition in the Gas Transmission Network

Pipeline deregulation unbundled natural gas from its transportation and made it possible for gas buyers and sellers to transact directly in the spot market. Gas users in each downstream market can purchase from all the fields to which they are directly or indirectly connected and they will demand transportation connections to gain access to fields with low prices. Gas producers will demand transportation connections to customers in downstream markets with high prices. Under the system of open access, there are many suppliers of pipeline transportation and the holders of transmission capacity can exchange their transmission rights among themselves or transfer them to brokers and third parties.[6] Pipeline users can ship gas from an injection node to a withdrawal node by purchasing the transmission rights which connect them. There may be many alternative pipeline routes between a given origin-destination pair. Moreover, pipeline users can combine the transmission rights of two or more pipelines; such inter-pipeline interchanges make it possible to combine a set of nodes spanning several individual pipeline systems.

One way to characterize allocative efficiency within the transmission network is the absence or presence of unexploited profit opportunities. Within the deregulated pipeline network an unexploited profit opportunity would occur when the price differential between two locations exceeded the transmission cost; this would be indicative of allocative inefficiency because the

[6] Trading of transmission rights is largely unrestricted; however the Federal Energy Regulatory Commission has not permitted transportation to become a fully transferable property right. For example, the FERC continues to limit the allowable injection and withdrawal points.

marginal value of gas across locations would differ by more than transmission costs. However, when all profitable opportunities have been exploited the marginal value of gas would be equalized across locations up to the cost of transmission.

Consider a pipeline network in which there are four nodes: Two production nodes and two consumption nodes (see figure 1). For simplicity and without loss of generality, refer to the nodes using a numerical subscript ranging from one to four. Let $P_i$ refer to the price at node $i$, where $i = 1,2,3,4$, and let $T_{i,j}$ denote the price of transmission between node $i$ and node $j$. Competition within the network implies that all profitable exchanges have been made. This implication yields six inequalities for the four node network which can be written briefly as $\mid P_i - P_j \mid \leq T_{i,j} \;\; \forall\, i \leq j$. However, three of the six inequalities are redundant and can be duplicated by substituting the remaining three inequalities into one another. With four nodes in the network, the full set of prices is determined once the price at an arbitrary node and the transmission charges are set. Thus, there are only three price spreads, $P_i - P_j$, that are relevant at any time. More generally, in a network with $N$ nodes there are $N - 1$ non-trivial price spreads.

To quantify the degree of competition in the network, the number of binding price spreads could be estimated empirically. Each price spread could be modeled as a linear relationship

$$P_{i,t} = \beta_0 + \beta_1 \, P_{j,t} + \mu_t \quad \forall\, i \neq j \tag{1}$$

where $\mu_t$ is a random disturbance term with zero mean and finite variance. Each of the six equations could be estimated by least-squares regression. However, this method has two major problems: First, if the price series are nonstationary, it is not appropriate to make statistical inference based on least-squares regression; nonstationarity invalidates the asymptotic statistical theory that underlies standard inferential procedures. Second, the bivariate regression equations do not account for the simultaneous interaction between all of the price series.

The following section introduces and explains the concepts of nonstationarity, unit roots, and cointegration. It is shown how multivariate cointegration analysis can be used to make inference on the number of binding price inequalities in the gas transmission network.

# 3 Empirical Method

A time series is integrated of order $d$ if the series is stationary after being differenced a minimum of $d$ times; such a series is denoted $I(d)$. By definition an $I(0)$ series is stationary. An $I(1)$ series is nonstationary and is said to have a unit root; such a series must be differenced one time to obtain a stationarity. In general, linear combinations of two $I(1)$ series would result in another $I(1)$ series. For example, a linear combination of the variables $x$ and $y$:

$$\mu_t = y_t - \beta_0 - \beta_1 x_t \tag{2}$$

would generally also be an $I(1)$ series. However, if there exist $\beta_0$ and $\beta_1$ such that $\mu_t$ is stationary, then $y$ and $x$ are defined to be cointegrated. The cointegrating or equilibrium relationship between $y$ and $x$

$$y_t - \beta_0 - \beta_1 x_t = 0 \tag{3}$$

represents the long-run equilibrium deviation between the two series. When the price inequality between two points in the gas pipeline network is binding, prices will be cointegrated and transmission cost will be the equilibrium deviation between the two prices. Furthermore, when $N$ prices are under consideration we should find that there are $N-1$ cointegrating relations; each cointegrating relation reflects one of the binding price constraints.

## 3.1 Testing the Order of Integration

The time series properties of the individual price series are quantified using the augmented Dickey-Fuller (1979) unit root test. The augmented Dickey-Fuller test for each time series is given by the $t$-statistic for $\phi$ in the regression equation

$$\triangle x_t = \phi x_{t-1} + \sum_{i=1}^{\rho} \beta_i \triangle x_{t-i} + \mu_t. \tag{4}$$

A total of $\rho$ lags of $\triangle x_{t-i}$ are included in order to assure that the residuals are serially uncorrelated. If $\phi$ is not found to be negative and significant, then the null hypothesis that $x_t$ is an $I(1)$ variable cannot be rejected. The $t$-statistic does not follow standard distributions because $x_t$ is a nonstationary series under the null hypothesis. Therefore, Monte Carlo generated critical values such as those reported by MacKinnon (1990) must be used. If the series are found to be nonstationary, it is appropriate to model them using cointegration analysis.

### 3.2 Cointegration Analysis

When the data are nonstationary, the method of cointegration allows us to estimate and make inference on long-run equilibrium relationships in the presence of short-run fluctuations. The general method of cointegration analysis is most clearly illustrated by the Engle-Granger cointegration test.

The Engle-Granger cointegration test for an equilibrium relationship between $y$ and $x$ consists of two steps: first estimate the cointegrating regression that specifies the long-run equilibrium between the two variables

$$y_t = \beta_0 + \beta_1 x_t + \mu_t; \tag{5}$$

second, test the residuals from the cointegrating regression for stationarity using the unit root test. If the residuals are found to be stationary, the null hypothesis of no cointegrating relationship between $x$ and $y$ is rejected.

The Engle-Granger test answers the question: Is there a cointegrating relationship between $x$ and $y$? In fact, the variable $x$ could be replaced by a vector of variables. Then the Engle-Granger test could be used to test for the presence of a cointegrating relationship between a large number of variables. However, the test would only tell us if there is *at least* one cointegrating relationship between the variables. It does not allow us to make inference on the number of cointegrating relationships between the variables. However, the multivariate cointegration analysis developed by Johansen does allow inference to be made on the number of cointegrating relationships. Thus, Johansen's method will allow us to determine the number of binding price inequalities within the gas transmission network.

Johansen's method tests for cointegration within a general vector autoregressive (VAR) model that incorporates the relationships between the system of economic variables. The VAR model describes the variation in the data without restriction. Johansen has shown that the test for the number of cointegrating relationships between a set of variables can be expressed as a test of reduced rank of a regression coefficient matrix. The regression coefficient matrix can be estimated consistently using linear regression techniques and the rank of the coefficient matrix is the number of cointegrating relationships between the variables. The *trace test* statistic for the number of cointegrating relations can be computed from the solution to an eigenvalue problem. The Appendix contains the computational details of the estimation and hypothesis testing procedures.

## 4 Empirical Results

Natural gas spot market prices at 39 nodes throughout the U.S. gas pipeline network were analyzed for 1991.[7] Of the 39 nodes, 37 are located in or near production areas and 2 are located at city gates far from the production areas. The production area nodes are located within seven geographic regions: West Texas, East Texas, South Texas, North Texas, Oklahoma, South Louisiana, and the San Juan basin of New Mexico. The two city gate markets are located at the California Border and at Chicago. Sixteen major interstate pipelines are represented in the sample and table 1 lists the markets where prices were obtained by geographic region and by pipeline company. The data consist of daily observations on the spot price and were obtained from the *Gas Daily*, an industry periodical. The data are based on prices for injection into the pipeline at the location for which the price is listed. The prices are reported on a dollar per million Btu basis for spot deals with a duration of 30 days or less, and they account for the quality of the gas because they are quoted as dollars per unit of thermal energy ($/MMBtu).

Augmented Dickey-Fuller test statistics were computed for each price series and the results of the unit root analysis are displayed in table 1. The null hypothesis of a unit root could not be rejected for any of the price series. The augmented Dickey-Fuller test was also performed with a time trend and this did not alter the results.[8] In addition, the Dickey-Fuller test

[7]The computations were performed using MicroTSP and RATS. Søren Johansen kindly provided the RATS procedures used to perform the cointegration analysis.

[8]The Phillips-Perron unit root test (Phillips, 1987; Phillips and Perron, 1988) and the Bayesian odds ratio unit root test (Sims, 1988) gave the same qualitative results as the Dickey-Fuller test.

was performed on the first differences of the price series; the results indicated that the first differences of the price series are stationary. From these test results it is reasonable to conclude that all of the natural gas price series analyzed are $I(1)$.

The cointegration analysis was performed for several pipeline networks with varying characteristics; the constructed networks are listed in table 2. Networks were selected to include nodes within the same geographic region, nodes across different regions but on the same company's pipeline system, and nodes across different regions and on different pipeline systems. Also, some of the networks included nodes located at city gates. For each of the networks, Johansen's cointegration analysis was used to test for the number of binding price inequalities (*i.e.* the number of cointegrating relations between the prices).

Network 1 consisted of spot markets located on NGPL's pipeline system in five geographic areas. The null hypothesis that the number of cointegrating relations or binding price inequalities was less than or equal to four could not be rejected. However, we could reject that the number of binding price inequalities was less than or equal to three. This provides evidence that prices in this network are related in the way that competition implies.

The second network tests for the number of binding price inequalities across five separate pipelines all located in the Louisiana region. Again, the hypothesis that there are four or more binding price constraints could not be rejected and the hypothesis of three or less binding price constraints could be rejected. Network 3 extended network 2 to include all of the pipeline nodes located in Louisiana. The results for network 3 indicate that there are seven binding price constraints between the eight pipeline nodes. This is consistent with competition across the eight Louisiana injection nodes.

Network 5 includes one spot market node from each of the seven production areas. At the 5% marginal significance level we conclude that there are six binding price constraints. However, it should be noted that in this large network we reject by only a small margin the hypothesis that there are five or less binding price constraints (the test statistic is 17.99 with a critical value of 17.84). Thus, it appears that the competitive pressure is reduced as the number of spot markets under consideration increases.[9]

The remaining networks test for the number of binding price constraints across networks that include production and city gate markets. Network 5 included the California city gate and three field markets in close proximity. It was found that there were three binding price constraints which is consistent with a high degree of competition. However, the degree of competition declined as the network was expanded to include field markets more distant from the California city gate. Network 6 extended network 5 to include spot markets in the North Texas and Oklahoma production areas. For this network of six nodes, the cointegration tests indicated that there were only four binding price constraints instead of the five implied by a high degree of competition. This indicates that while the California city gate market is highly integrated with the field markets in close proximity, it is not linked strongly to the more distant production field markets.

The results for network 7 show that the degree of competition is high between the Chicago city gate and production field markets in Louisiana, Oklahoma, and North, South and East Texas: in this network of six nodes there are five binding price constraints. However the degree of competition appears to be less when this network is expanded to include nodes in the West Texas and San Juan production areas. In this network of eight nodes, the evidence shows that there only six binding price constraints instead of the seven implied by competition.

## 5 Conclusions

This research has applied multivariate cointegration analysis to data from the natural gas industry to quantify the degree of competition in the open access pipeline network. The analysis explicitly accounts for the network structure of the natural gas industry and for the time series properties of the data. The empirical results indicate that within and between production markets there is a high degree of competition. This high degree of price competition across the transmission network implies allocative efficiency across

[9] It was not possible to estimate the number of binding price constraints in a network with more than eight nodes. In each such network formed, the cointegration analysis became incomputable due to singularities in the data matrix.

production field markets. City gate markets appear to be integrated well with nearby production fields and less well with more distant production areas. It is clear that pipeline deregulation successfully linked together numerous geographically dispersed spot markets and that open access transportation satisfied the conditions necessary for gas traders to exploit price differentials across the pipeline network. This has led to an efficient allocation of gas across the production markets. Policy should aim to remove the remaining restrictions on open access transportation, especially in the city gate markets.

# Appendix

## Description of Multivariate Cointegration Analysis

The vector autoregression model of the price series can be written in the error correction form as

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Gamma_k P_{t-1} + \gamma + \mu_t$$

where $\Delta$ is the difference operator. Johansen (1988, 1990) has shown that the coefficient matrix $\Gamma_k$ contains sufficient information to determine the cointegrating relationships between the variables. Maximum likelihood estimation of the cointegrating vectors from the above equation consists of the following procedure.

First estimate each of the following two regression equations

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu_{1t}$$

$$P_{t-k} = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \mu_{2t}.$$

Define the product moment matrices of the regression residuals to be $S_{ij} = \sum_{t=1}^{T} \hat{\mu}_{it}\hat{\mu}'_{jt} \ \forall \ i,j = 1,2$. The likelihood function, concentrated with respect to $\Gamma_1, \ldots, \Gamma_{k-1}$, can be expressed in terms of $\Gamma_k$ and the $S_{ij}$ matrices. Johansen has shown that the likelihood ratio test statistic for the null hypothesis of at most $r$ cointegrating relationships can be written as

$$-2\ln Q(r) = -T \sum_{i=r+1}^{n} \ln(1-\lambda_i)$$

where $\lambda_1 > \ldots > \lambda_n$ are the eigenvalues that solve the equation

$$|\lambda S_{22} - S_{21}S_{11}^{-1}S_{12}| = 0.$$

Computationally, it is easier to find the eigenvalues by solving the characteristic equation

$$|\lambda I - S_{22}^{-1/2}S_{21}S_{11}^{-1}S_{12}S_{22}^{-1/2}| = 0.$$

The likelihood ratio statistic $-2\ln Q(r)$ converges in distribution to $(n-r)$-dimensional Brownian motion. This distribution is nonstandard and must be generated through simulation. Johansen and Julius (1990) and Osterwald-Lenum (1992) tabulate the quantiles of the distribution for $n-r = 1, \ldots, 5$ and $n-r = 1, \ldots, 10$, respectively.

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Table 1: Unit Root Tests on Natural Gas Spot Prices, 1991

| Node | Augmented Dickey-Fuller $t$-statistics $\rho = 0$ | $\rho = 4$ |
|---|---|---|
| West Texas—Waha | | |
| El Paso | −1.375 | −1.523 |
| Transwestern | −1.223 | −1.514 |
| East Texas—Houston/Katy | | |
| Florida Gas | −1.682 | −1.714 |
| NGPL | −1.450 | −1.428 |
| Tennessee | −1.439 | −1.522 |
| Texas Eastern | −1.401 | −1.414 |
| Transco | −1.336 | −1.297 |
| Trunkline | −1.071 | −1.160 |
| North Texas—Panhandle | | |
| ANR | −0.596 | −0.630 |
| NGPL | −0.456 | −0.082 |
| Northern | −1.161 | −1.058 |
| Panhandle Eastern | −0.496 | −0.432 |
| Transwestern | −1.064 | −1.050 |
| South Texas—Corpus Christi | | |
| Florida Gas | −1.607 | −1.633 |
| NGPL | −1.316 | −1.331 |
| Tennessee | −1.467 | −1.550 |
| Texas Eastern | −1.342 | −1.356 |
| Transco | −1.339 | −1.309 |
| Trunkline | −0.943 | −1.040 |
| United | −1.164 | −1.174 |

*continued—Unit Root Tests*

| Node | Augmented Dickey-Fuller $t$-statistics $\rho = 0$ | $\rho = 4$ |
|---|---|---|
| Louisiana—Onshore South | | |
| ANR | −1.621 | −1.606 |
| Columbia | −1.567 | −1.591 |
| NGPL | −1.316 | −1.360 |
| Tennessee | −1.365 | −1.452 |
| Texas Gas | −1.270 | −1.341 |
| Transco | −1.372 | −1.441 |
| Trunkline | −1.239 | −1.149 |
| United | −1.296 | −1.335 |
| Oklahoma | | |
| ANR | −0.558 | −0.317 |
| Arkla | −1.138 | −0.993 |
| El Paso | −1.236 | −1.187 |
| NGPL | −0.297 | −0.266 |
| Northern | −1.129 | −1.073 |
| Oklahoma Gas | −0.802 | −0.827 |
| Panhandle Eastern | −0.526 | −0.463 |
| Transwestern | −0.765 | −0.763 |
| New Mexico—San Juan Basin | | |
| El Paso | −1.418 | −1.400 |
| Citygates | | |
| California Border | −2.217 | −2.282 |
| Chicago, Illinois | −1.297 | −1.495 |

MacKinnon Critical Values for the $t$-statistics:
For $\rho = 0$, −3.450 (1%); −2.871 (5%); −2.572 (10%).
For $\rho = 4$, −3.453 (1%); −2.872 (5%); −2.572 (10%).

Table 2: Test Results to Determine Number of Cointegrating Relations

$H_o$ : # of Cointegrating Relations $\leq r$

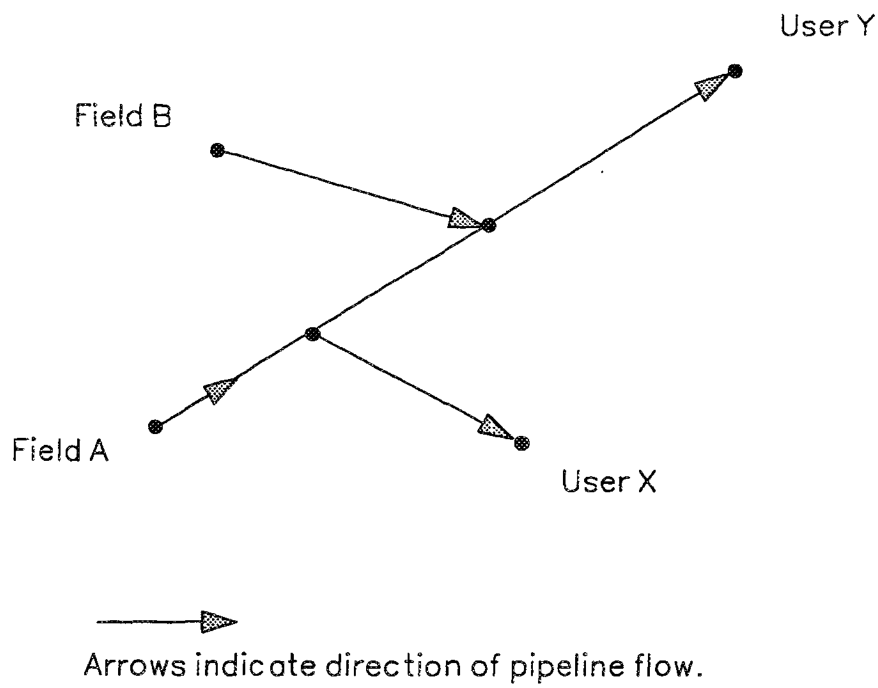
| Pipeline | Region | $r$ | Trace Test Statistic | 5% Critical Value |
|---|---|---|---|---|
| **Network 1** | | | | |
| NGPL | East Texas | | | |
| NGPL | North Texas | 4 | 2.56 | 8.08 |
| NGPL | South Texas | 3 | 18.77 | 17.84 |
| NGPL | Louisiana | 2 | 56.53 | 31.27 |
| NGPL | Oklahoma | | | |
| **Network 2** | | | | |
| ANR | Louisiana | | | |
| Tennessee | Louisiana | 4 | 1.87 | 8.08 |
| Texas Gas | Louisiana | 3 | 21.09 | 17.84 |
| Transco | Louisiana | 2 | 54.50 | 31.27 |
| Trunkline | Louisiana | | | |
| **Network 3** | | | | |
| ANR | Louisiana | | | |
| Columbia | Louisiana | | | |
| NGPL | Louisiana | 7 | 6.91 | 8.08 |
| Tennessee | Louisiana | 6 | 19.56 | 17.84 |
| Texas Gas | Louisiana | 5 | 42.23 | 31.27 |
| Transco | Louisiana | | | |
| Trunkline | Louisiana | | | |
| United | Louisiana | | | |
| **Network 4** | | | | |
| El Paso | West Texas | | | |
| El Paso | San Juan | | | |
| Trunkline | East Texas | 6 | 6.46 | 8.08 |
| Panhandle | North Texas | 5 | 17.99 | 17.84 |
| NGPL | South Texas | 4 | 38.02 | 31.27 |
| Tennessee | Louisiana | | | |
| Northern | Oklahoma | | | |

*continued* — Cointegration Tests

| Pipeline | Region | $r$ | Trace Test Statistic | 5% Critical Value |
|---|---|---|---|---|
| **Network 5** | | | | |
| California CG | Topock, AZ | | | |
| El Paso | West Texas | 3 | 6.94 | 8.08 |
| Transwestern | West Texas | 2 | 18.52 | 17.84 |
| El Paso | San Juan | 1 | 38.17 | 31.27 |
| **Network 6** | | | | |
| California CG | Topock, AZ | | | |
| El Paso | West Texas | 5 | 4.58 | 8.08 |
| Transwestern | West Texas | 4 | 16.41 | 17.84 |
| El Paso | San Juan | 3 | 42.29 | 31.27 |
| Panhandle | North Texas | | | |
| Northern | Oklahoma | | | |
| **Network 7** | | | | |
| Chicago CG | Illinois | | | |
| Arkla | Oklahoma | 5 | 2.93 | 8.08 |
| Trunkline | East Texas | 4 | 26.52 | 17.84 |
| Transwestern | North Texas | 3 | 59.30 | 31.27 |
| NGPL | South Texas | | | |
| Tennessee | Louisiana | | | |
| **Network 8** | | | | |
| Chicago CG | Illinois | | | |
| El Paso | West Texas | | | |
| Transwestern | San Juan | 7 | 2.21 | 8.08 |
| Arkla | Oklahoma | 6 | 14.97 | 17.84 |
| Trunkline | East Texas | 5 | 36.72 | 31.27 |
| ANR | North Texas | | | |
| NGPL | South Texas | | | |
| Tennessee | Louisiana | | | |

The number of cointegrating relations represents the number of binding price constraints in the pipeline network. In a network with $n$ nodes, competition implies $n-1$ binding price constraints. A lower number of binding price constraints indicates a lesser degree of competition and a less efficient allocation of gas.

Figure 1: A Simple Pipeline Network




In a simple four-node network, prices are determined through the transmission tariffs and by fixing the price at an arbitrary base node. Alternatively, there will be three relevant price spreads once the transmission charges are set.