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Pipeline Access and Market Integration in the Natural Gas Industry: Evidence from Cointegration Tests

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Pipeline Access and Market Integration in the Natural Gas Industry: Evidence from Cointegration Tests*

*Arthur De Vany*** and W. David Walls****

This research seeks to determine the extent to which the Federal Energy Regulatory Commission's policy of "Open Access" to natural gas pipelines has created competition in natural gas markets. We argue that recently developed cointegration techniques are the natural way to evaluate competition between natural gas spot markets at dispersed points in the national transmission network. We test daily spot prices between 190 market-pairs located in 20 producing fields and pipeline interconnections and find that the price series are not stationary and that most field markets were not cointegrated during 1987. By 1991, more than 65% of the markets had become cointegrated. The increased cointegration of prices is evidence that open access has made gas markets more competitive.

INTRODUCTION

The relationship between commodity prices at geographically dispersed locations is evidence of market performance. If markets in different locations are integrated into one market, their prices will be linked and the "law of one price" will hold within the limits of transportation and arbitrage costs. By granting gas customers access to pipeline transportation, the Federal Energy Regulatory Commission has conducted a natural experiment that allows us to test

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the degree to which competition can discipline gas prices in markets that were regulated as natural monopolies. Convergence of gas prices under open access is evidence that competition has been effective in controlling prices and monopoly power. We examine the evidence from 190 market-pairs to see if open access has succeeded in bringing gas markets under the control of competition. We find that these market-pairs have become increasingly integrated as the network of pipelines has become more connected during the era of open access.

Our conclusion that prices converged and markets became integrated is both unremarkable and remarkable. It is unremarkable because economic theory teaches that arbitrage will cause prices to converge. It is remarkable because the experiment could have failed for so many reasons: bottleneck monopolies in the grid; poor coordination between gas purchases and transportation; risk averse buyers reluctant to rely on the spot market, creating a lack of depth and liquidity; excessively volatile prices; distributor city gates that are closed or difficult for buyers to get through; a lack of knowledge and experience on the part of gas producers and buyers long accustomed to regulated prices and long-term contracts; and questions about the incentives of regulated distributors to seek out lower cost gas. Most of all, there were no established market institutions for spot gas trading when open access began. Our conclusion tells us that markets overcame all these odds and that the *a priori* expectations of the theory of arbitrage are well-founded; the fears of monopoly and unreliable markets that support the case for regulation are not.

We have chosen cointegration techniques to examine natural gas prices because of its power in dealing with two key features of the gas market: it is a network of spot markets, and its prices vary over time. Because gas prices are volatile, it is difficult to determine if prices at different points in the network lie within the bounds that competition would imply. Competitive prices at points in the network must be free of arbitrage opportunities, but within these limits they are free to vary with respect to one another. Thus, the problem is to test two price series for arbitrage when they may be nonstationary and arbitrage only limits the range of volatility which they may exhibit with respect to one another. Cointegration provides a way to test for arbitrage-free pricing in time varying series. Two non-stationary series are cointegrated if they have a linear combination that is stationary.[1] When p_i and p_j are each integrated of order one and cointegrated, their linear combination $p_{j,t} - \alpha - \beta\ p_{i,t} = \mu_t$ is stationary. If two price series are within stable arbitrage limits, the "spread" between them will be stationary and they will be cointegrated. Cointegration, therefore, is the natural test for market integration of stochastically varying prices.

1. See Greene (1993, Chapter 19) for an introduction to stationarity, unit roots, and cointegration.

The time series methods that are based on cointegration, nonstationarity and unit root econometrics have been developed in the recent econometrics literature.[2] We use Engle-Granger cointegration techniques on time series of daily natural gas spot prices in 190 market-pairs located in 20 different gas markets to test for market integration.

GAS MARKET ORGANIZATION

In 1985, the Federal Energy Regulatory Commission (FERC) allowed interstate natural gas pipelines to carry gas for their customers as contract carriers. For over 40 years, pipelines had been required to operate as merchant carriers who owned the gas they transported and were prohibited from offering direct transportation services to their customers. This limitation on transportation and the regulatory requirement that pipelines had to buy and sell gas through long-term contracts prevented gas spot markets from existing. When the FERC permitted gas pipelines to become contract carriers under Order 436, the stage was set for the opening of markets and the competitive force of arbitrage was unleashed.[3]

Nearly all major natural gas pipelines have chosen to become open access carriers.[4] The move to open access reduced the concentration of transportation rights among market participants; firm transmission capacity was reallocated from a small number of pipelines to a large number of customers (primarily local distribution companies who held long-term contracts). There are now many suppliers of transportation and, within regulatory limits, they can exchange their firm transmission rights among themselves or transfer them to brokers and third parties. Trading of interruptible rights is largely unrestricted.[5]

2. See Engle and Granger (1987), Engle and Yoo (1987), Campbell and Shiller (1986), Granger (1986), Hendry (1986), and Johnston (1989, 1992).

3. See Smith, De Vany and Michaels (1987, Chapter 2; 1990) for a more detailed analysis of the gas pipeline industry under the merchant carriage regime. De Vany and Walls (1992a) show how the gas and transportation markets are coordinated under open access and show that gas prices are martingales with respect to past prices at almost all vertices in the graph structure of the pipeline network.

4. Most pipelines elected to become open access carriers as a way of abrogating their long-term purchase contracts. These contracts, signed in the late 1970's and early 1980's, contained high minimum purchase provisions and high prices. Providing pipelines the option to become contract carriers was the FERC's attempt to correct previous policies that led to the pipelines' contractual problems.

5. The FERC limited the transferability of firm transmission rights and limits the injection and withdrawal points. Most pipelines post on electronic bulletin boards the amount of interruptible transmission which they have available for sale.

Contract carriage gives pipeline customers direct access to transportation. By opening the transportation system to pipeline customers, open access made possible the creation of a connected pipeline grid.[6] Customers and brokers are able to exchange and combine transportation rights, and use this method to create connected network topologies over which they can effect arbitrage. A trading network can be constructed by combining transmission rights on several pipelines.

NETWORK ARBITRAGE

In contrast to the old system of merchant carriage, tradeable transportation rights permit gas buyers to reach through the grid of pipelines to transact at all directly or indirectly connected nodes. By acquiring transmission rights, gas producers can sell gas at any connected node and gas users can purchase gas at any connected node. Because open access allows these exchanges to be made, field markets previously separated by regulation can become more integrated.

Gas brokers can earn a fee for arranging transactions between producers and end users. They also contest markets by exercising the transportation rights of their customers. They buy and sell gas and hold a portfolio of gas contracts. They deliver it by aggregating transmission capacity from customers who hold firm transportation rights.[7]

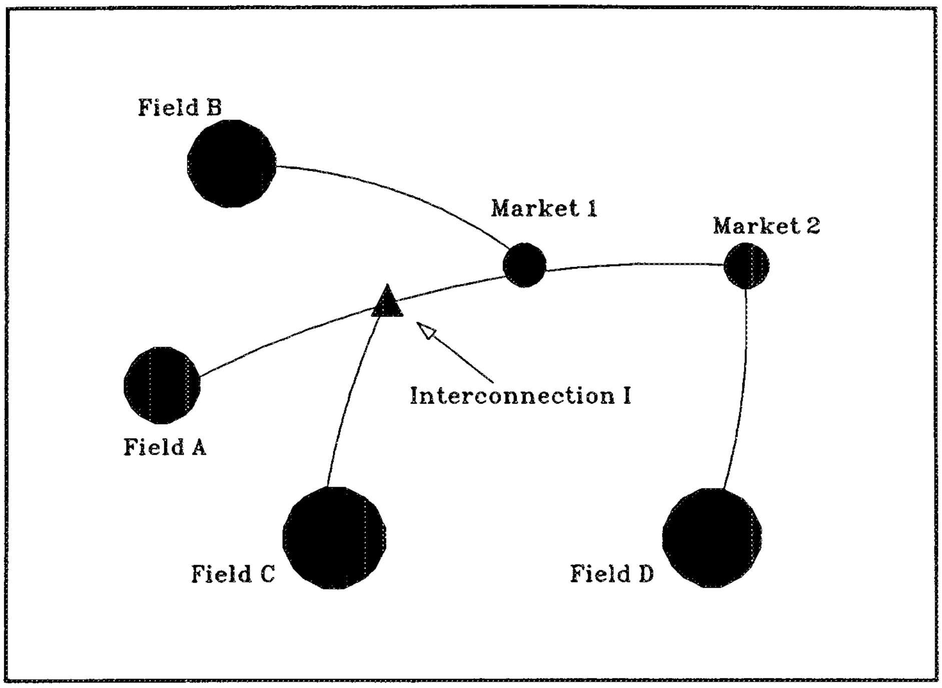
An arbitrageur in the network can exploit nonequilibrium price differences in several different ways; sometimes this will mean executing a transaction that is not physically possible, like selling gas to a customer who is upstream. The types of deals that traders can make are best explained by example.

Consider the pipeline network shown in Figure 1. There are four producing fields, *A* through *D*, two end user Markets, 1 and 2, and one interconnection node, *I*. Suppose initially that the markets in this network are in equilibrium, meaning that the differences between prices at different nodes are

6. Before open access, pipelines primarily served a producing basin and its city markets. There were few interconnections and gas markets were balkanized. See De Vany and Walls (1992a) and Walls (1992, Chapter 2) for a discussion of the disconnected markets that were created through regulatory policy.

7. Gas injections and withdrawals may take place at any number of locations. In the mid 1980's, pipeline companies began to organize their systems into a hub-and-spoke configuration. Once pipelines opened their systems to transportation, the demand for interconnections rose. Major hubs that interconnect pipelines have emerged. The hubs allow pipelines with different operating pressures to "wagon wheel" their customers' gas through the hub and over the network. See "Pipeline hub project sets up gas service for U.S. West Coast Markets." *Oil and Gas Journal*. August 6, 1990, 41-48.

Figure 1. Arbitrage Possibilities in the Transmission Network



less than or equal to the cost of transmission.[8] Now, let there be an exogenous increase in the demand for gas at Market 2. Initially its price will rise. Brokers, or the end users themselves, will raise their spot bids in Fields *A* through *D* for gas to send to Market 2. Buyers for Market 1 must raise their bids in the fields to meet the higher prices offered by Market 2. The prices in the fields will rise and producers will respond with new production levels. In the new equilibrium, the spread between prices in Market 1 and Market 2 will be restored, and the spreads between field prices will also be restored.

Now consider a more complex trade. Starting from equilibrium, suppose that the price in Market 1 increases. Trades will be made that have the effect of delivering gas destined for Market 2 to Market 1, in effect backhauling gas from Market 1 to 2. More gas from Field *D* would be sent to Market 2, releasing gas from Fields *A*, *B*, and *C* that was headed for Market 2 for sale in Market 1. In addition, gas from these fields that was destined for Market 2 could be diverted to Market 1. Price disparities in the producing fields could be exploited in a similar fashion. A broker could arbitrage price differences in, say,

8. Arbitrage leads to a set of equilibrium price vectors—rather than a unique price vector—by bounding variations in relative prices (cf. Huang and Litzenberger, 1988, pp. 106-109).

Fields A and B by buying gas at A, and shipping it to Market 2 in place of the gas he would buy at B. Or, he can simultaneously buy contracts at Field A and sell offsetting contracts in Field B and effect pure arbitrage. Even if there were no line from Market 1 to Market 2, so that they were not connected, it is possible to conduct limited arbitrage between those markets. For example, one could sell contracts delivering gas in Market 2 and buy contracts delivering gas to Market 1. Thus, even seemingly impossible transactions which involve selling gas against the flow of the pipeline or trading across points that are not physically connected can be executed when there is trading over all injection and withdrawal points.

In a pipeline network that links n markets, there are $(n^2-n)/2$ routes and transportation charges. Let $i \in [1,n]$ index the markets and let $t_{i,j}$ index the tariffs. For simplicity, assume the transmission charges are constant. An arbitrage-free equilibrium is one such that the absolute difference in prices is bounded by the transmission charge: $|p_j-p_i| \leq t_{i,j} \;\forall\; i \neq j$. Transitory breaks in the arbitrage inequality may occur when there are binding capacity constraints along some links in the system. In the absence of such constraints, competitive trading causes the price spreads to stay in line with transmission tariffs.

EMPIRICAL METHODOLOGY

Cointegration theory offers a statistically principled framework for evaluating market linkages across a transmission network when the data may be nonstationary. Even if the individual price series are nonstationary, their deviations from one another are limited by arbitrage constraints. If a stationary series may be obtained from a linear combination of two non-stationary series, they are *cointegrated* (Granger, 1986). The intuitive appeal of cointegration is that deviations from equilibrium are stationary, even though each series is nonstationary.

Unit Roots and Cointegration

Consider a time series of prices p_t and its autoregressive representation where μ_t is a Gaussian disturbance term, ρ is an autoregressive parameter, and t represents time:

$$p_t = \rho p_{t-1} + \mu_t \,. \tag{1}$$

This price series is stationary if the autoregressive parameter ρ is less than one in absolute value (Harvey, 1981). If $\rho=1$, then the series has a *unit root*, and it is *nonstationary* because its variance, $t\sigma^2$, becomes infinite with time.[9] If $\rho = 1$, Box and Jenkins (1976) define the autoregressive process generating p_t to be *integrated* of order one, *I(1)*. In general, a time series of data is said to be integrated of order d if it must be differenced d times to make the series stationary.

Now consider two series of prices, p_i and p_j. Each series itself is nonstationary and must be differenced d times and b times, respectively, to achieve stationarity. However, there may be a linear transformation of the two original series,

$$p_{j,t} - \alpha - \beta p_{i,t} = \mu_t \tag{2}$$

that results in a series μ_t that is integrated of order d-b. If such a linear transformation between p_i and p_j exists, they are said to be cointegrated of order (d,b) (Engle and Granger, 1987). The nonstationarity in one series effectively cancels out a portion of the nonstationarity in the other. The cointegrating parameter is given in the "cointegrating regression" shown above as equation (2). When p_i and p_j are each integrated of order 1, *I(1)*, and they are cointegrated, their linear combination μ_t will be stationary or *I(0)*. This case with $d = b = 1$ has been studied extensively in the literature and is the relevant case for the empirical work in this paper.[10]

Perfect market integration requires that the estimated cointegrating parameter $\hat{\beta}$ in the cointegrating regression be equal to one. Here, the cointegrating regression specifies the no-arbitrage equilibrium condition. The constant α reflects the cost of transmission between node i and node j. When the price at node i increases by one unit and the cost of transmission remains constant, the price at node j should rise by an equal amount for the equilibrium to be restored. Because $p_{i,t}$ and $p_{j,t}$ are nonstationary, standard statistical procedures do not allow reliable inference on the value of β. Engle and Granger show that the least squares estimator of the cointegrating parameter is consistent, but its estimated standard error is not consistent. Therefore, it is not possible

9. The variance of each individual price series is unbounded: Var[p_t] = $t\sigma^2$, where t = 1, 2, . . ., ∞ and σ^2 is the standard error of the white noise disturbance.

10. If the arbitrage bounds are nonstationary, the price series may be cointegrated of a higher order. For example, suppose that the arbitrage bounds were *I(2)*, that p_1 were *I(3)* and p_2 were *I(1)*. In this case the linear combination of p_1 and p_2 is not stationary even if the series are cointegrated; it would be *I(2)* if the pressure of arbitrage caused the prices not to diverge from one another. In general the difference in the order of integration of the two series must equal the order of integration of the arbitrage bounds.

within this framework to test directly the strength of market integration through inference on the cointegrating parameter.[11]

Testing for Unit Roots and Cointegration

Dickey and Fuller (1979) devised a statistical test for the presence of a unit root in a series of data. In their test, the first differences of the price series are regressed on a lagged value of the price level:

$$\Delta p_t = -\phi p_{t-1} + \epsilon_t \; . \tag{3}$$

Under the null hypothesis that the process generating prices is *I(1)*, the regression coefficient will be negative and significantly different from zero for a stationary series. Because the price series is nonstationary under the null hypothesis, the distribution theory which underlies this test is nonstandard, and the critical values must be generated using Monte Carlo techniques.

Engle and Granger (1987) suggest adding lagged values of the dependent variable as regressors in the Dickey-Fuller test to ensure that the residuals are white noise. This test for nonstationarity is called the Augmented Dickey-Fuller (ADF) test and it also relies on Monte Carlo generated critical values.

Engle and Granger (1987) propose a two-stage procedure for determining the cointegrating properties of a pair of nonstationary time series. In the first stage the parameters of the cointegrating regression are estimated. This regression equation specifies the long-run equilibrium condition between the two price series, and it can be estimated using ordinary least squares. The parameter estimates are then used to calculate estimates of the errors, $\hat{\mu}$:

$$\hat{\mu} = p_{i,t} - \hat{\alpha} - \hat{\beta} p_{j,t} \; . \tag{4}$$

The second stage is to test the estimated errors for nonstationarity. If the two nonstationary price series are of the same order and cointegrated, the residual from the cointegrating regression will be stationary.[12]

11. Johansen (1988, 1991) and Johansen and Juselius (1990) demonstrate a maximum likelihood based method used to make inference on the parameters of the cointegrating vector. Walls (1993) applied the likelihood based method to data from the natural gas industry and obtained results that are qualitatively similar to those obtained using the Engle-Granger cointegration tests.

12. We use the Dickey-Fuller and Augmented Dickey-Fuller type cointegration tests. Engle and Granger (1987) evaluate seven different cointegration tests and recommended tests that are similar to the Durbin-Watson test, the Dickey-Fuller test, and the Augmented Dickey-Fuller test because they all have high power. However, Engle and Yoo (1987, p. 158) find that the critical values for the Durbin-Watson type test are sensitive to the particular testing equation.

DATA AND EMPIRICAL RESULTS

The data were obtained from the *Gas Daily*. This industry periodical currently reports the spot price paid for natural gas at more than 60 locations. Our sample consists of 20 markets at which the *Gas Daily* continuously reported daily spot prices since July 1987. These markets are located within six geographic areas: West Texas-Waha, East Texas-Houston/Katy, South Texas-Corpus Christi, North Texas-Panhandle, Oklahoma-Beaver County, and South Louisiana-Onshore. Eleven major interstate pipelines are represented in the sample. Table 1 lists the markets where prices were obtained by geographic region and by pipeline company.

The daily spot prices are a volume-weighted average of each day's trades. These data are based on prices for injection into the pipeline at the location for which the price is listed (e.g., the price paid for natural gas injected into the Tennessee Gas Pipeline in Houston, Texas on a particular day). The prices are inclusive of transportation fees. The prices are on a dollar per million Btu basis for spot deals with a duration of 30 days or less.[13]

The data were segmented into four one-year samples to make comparisons between years possible. Our reasons for looking at different time periods are to see if the spread of open access pipelines and the development of new markets and pipeline connections over time succeeded in linking gas markets more tightly.[14] Each sample begins in July and ends the following June.[15] Each price series was tested for nonstationarity using the Dickey-Fuller test and the Augmented Dickey Fuller test with four lags.[16] By these tests, the null hypothesis of a unit root could not be rejected for any of the daily price series and the price series are not stationary.[17] Given the changes that were taking place in transportation and markets one would not expect the individual series to be stationary. Moreover, the hypothesis that the first difference of each

13. The prices account for the quality of the gas because they are quoted as dollars per unit of thermal energy ($ per MMBtu).

14. Open access and markets spread rapidly during the sample periods. In 1987 about 10 open access applications submitted to the FERC had been approved. By 1989 about 27 applications representing nearly all the major pipelines had been approved. During the same period the number of markets reporting spot prices doubled from about 24 to 50. See De Vany and Walls (1992a).

15. These sample sizes were possible because MacKinnon's Monte Carlo generated critical values were used for all of the unit root and cointegration tests. Earlier studies that used Dickey and Fuller's critical values or Engle and Granger's critical values were limited to sample sizes of 50, 100, or 200. MacKinnon has constructed a manifold of critical values for a continuum of sample sizes; these critical values are programmed into MicroTSP which was used for the estimation and testing.

16. Akaike's (1973) and Schwarz's (1978) lag selection criteria indicated that the number of significant lags was less than or equal to four for all of the price series.

17. Results of the unit root tests are reported in Appendix A of Walls (1992).

Table 1. Spot Market Locations and Pipelines

North Texas-Panhandle	South Texas-Corpus Christi
ANR Pipeline Company (ANR) Natural Gas Pipeline of America (NGPL) Northern Natural Gas Company (NORTH) Panhandle Eastern Pipe Line Company (PEPL)	Natural Gas Pipeline of America (NGPL) Tennessee Gas Pipeline Company (TENN)
East Texas-Houston/Katy	West Texas-Pecos/Waha
Natural Gas Pipeline of America (NGPL) Tennessee Gas Pipeline Company (TENN) Trunkline Gas Company (TRUNK)	El Paso Natural Gas Company (ELPASO) Transwestern Pipeline Company (TRANSW)
South Louisiana-Onshore	Oklahoma-Beaver County
Texas Gas Transmission (TEXGAS) ANR Pipeline Company (ANR) Columbia Gas Transmission (COL) Tennessee Gas Pipeline Company (TENN) Trunkline Gas Company (TRUNK) United Gas Pipe Line Company (UNITED)	ANR Pipeline Company (ANR) Natural Gas Pipeline of America (NGPL) Northern Natural Gas (NORTH)

price series is nonstationary was rejected; the first difference of each of the price series is stationary. That is, the price series are not integrated of an order greater than one. This means that gas prices in each individual market follow a random walk (e.g., equation (1) with $\rho = 1$).

Since we know each individual price series is nonstationary, we proceed to see if there is a linear combination of pairs of price series that is stationary. Even though the individual price series may diverge (have infinite variance), the prices should not diverge from one another if they constrained by arbitrage limits. We created a matrix of market-pairs from our sample of 20 price series. Every market was paired with every other market giving a matrix of 190 (20x19/2) unique market-pairs to test for cointegration. In those markets that are linked by arbitrage, the differences between their price series should be stationary, which means they must be cointegrated since each price series is *I(1)*.[18]

18. Johnston (1992) has shown that if more than two variables are considered and, "... if two or more cointegrating vectors exist, there is an infinite number of cointegrating vectors. There is then no connection between cointegrating vectors and any meaningful long term equilibrium. If the x vector contained just two variables and the eigenvalues were 1 and λ the cointegrating vector would be unique (up to a scale factor)." It is possible to test cointegrating relations in a multivariate setting, although it is not done here. Johansen (1991) has developed the likelihood-based methods for estimation and testing of cointegrating relations in a general Gaussian vector autoregressive model.

Cointegrating regressions were estimated by ordinary least squares for each of the 190 market-pairs for each of the four periods 1987-88, 1988-89, 1989-90, and 1990-91. The t-statistics for the cointegration tests and the Monte Carlo generated critical values are presented in Tables 2a, 2b, 2c, and 2d.[19]

In 1987-88, 87 (46%) of the 190 market pairs showed evidence of cointegration at a marginal significance level of 5%. In the following year, 103 (54%) of the market-pairs were cointegrated. This rose to 124 (65%) in 1989-90 and 126 (66%) in 1990-91. The increase in the number of market-pairs that are cointegrated is evidence that markets became more integrated over our sample period. An example of this is the West Texas region in the first column of Table 2a. Four market-pairs in the West Texas region served by El Paso and Transwestern pipelines were cointegrated in 1987-88. By 1989-90, the West Texas region was integrated with 32 other markets. By 1991, this high degree of integration lessened to a degree, primarily on the Transwestern pipeline. But, during the same period, South Texas, North Texas and Oklahoma became more integrated with other markets. The t-statistics for nearly all market-pairs drift upward over the entire sample period and this can be interpreted to indicate that most pairs became more strongly cointegrated. By the end of the sample in 1991, the degree of cointegration between distant market-pairs approaches the cointegration of near pairs.

Some markets are better integrated than others. As was noted earlier, transitory breaks in the arbitrage pricing inequality may occur due to binding capacity constraints along some pipelines. As more pipelines became open access, the number of routes and the transmission capacity between origin-destination pairs increased. Thus, the price series become more strongly cointegrated as open access expands through the network because the arbitrage-pricing inequality less frequently is violated by hitting capacity constraints. Moreover, open access expands the number of arbitrage paths, promoting a tighter arbitrage pricing inequality. One way to explore this connection between cointegration and the open access status of pipelines is to see how many other regions a region's price is cointegrated with relative to its open access date. Table 3 presents this information; it indicates for each pipeline and region how many other points that pipeline's price is cointegrated with. For example, the first two rows show that there are two spot prices in the West Texas region, one at the El Paso Pipeline injection point and the other at the Transwestern Gas Pipeline, and it indicates that spot prices at these points were cointegrated with

19. Results similar to those presented in Table 2 were obtained using the Augmented Dickey-Fuller test and are reported in Appendix B of Walls (1992). As suggested by Engle and Yoo (1987), a formal lag selection criterion was used to determine the number of lagged residuals to include in the testing equations. The lag selection criteria of Akaike (1973) and Schwarz (1978) each indicated lag lengths not greater than four, so four lagged residuals were included in the ADF testing equation. This lag length assured that the residuals from the testing equation were white noise.

Table 2a. Cointegration Test Results across Fields: July 1987 - June 1988

(Dickey-Fuller *t*-statistics)

	WTX-ELPASO	WTX-TRANSW	ETX-NGPL	ETX-TENN	ETX-TRUNK	NTX-ANR	NTX-NGPL
WTX-TRANSW	-5.701*						
ETX-NGPL	-3.243	-2.733					
ETX-TENN	-2.856	-2.633	-5.129*				
ETX-TRUNK	-3.900*	-3.285	-5.756*	-4.106*			
NTX-ANR	-2.725	-2.365	-2.773	-2.465	-2.421		
NTX-NGPL	-3.175	-2.634	-3.810*	-3.648*	-3.150	-2.506	
NTX-NORTH	-2.133	-1.720	-2.781	-3.542*	-3.022	-2.323	-4.474*
NTX-PEPL	-3.009	-2.688	-4.039*	-3.462*	-2.848	-2.169	-5.369*
STX-NGPL	-3.103	-2.426	-3.878*	-2.918	-2.951	-2.339	-2.375
STX-TENN	-2.248	-2.213	-3.045	-2.918	-2.504	-2.316	-2.225
LA-ANR	-3.538*	-2.843	-5.862*	-5.056*	-4.400*	-2.175	-4.826*
LA-COLUMB	-3.354	-2.769	-5.001*	-4.256*	-4.148*	-3.001	-3.568*
LA-TENN	-3.071	-2.736	-4.470*	-4.860*	-3.921*	-1.216	-3.891*
LA-TEXGAS	-3.745*	-3.239	-5.455*	-4.503*	-5.069*	-2.823	-4.869*
LA-TRUNK	-3.080	-2.712	-5.266*	-5.065*	-5.946*	-1.610	-2.994
LA-UNITED	-3.334	-2.847	-4.385*	-4.313*	-4.377*	-2.177	-3.830*
OK-ANR	-3.105	-2.712	-4.641*	-4.920*	-4.481*	-3.559*	-3.977*
OK-NGPL	-3.207	-2.991	-4.911*	-5.334*	-3.916*	-1.968	-4.977*
OK-NORTH	-3.007	-2.738	-4.108*	-3.677*	-3.273	-2.716	-5.028*

	NTX-NORTH	NTX-PEPL	STX-NGPL	STX-TENN	LA-ANR	LA-COLUMB
NTX-PEPL	-3.045					
STX-NGPL	-2.343	-3.292				
STX-TENN	-2.288	-2.638	-2.940			
LA-ANR	-3.776*	-3.881*	-4.229*	-2.311		
LA-COLUMB	-3.552*	-4.324*	-4.069*	-2.462	-5.413*	
LA-TENN	-1.772	-3.190	-3.360	-2.621	-5.310*	-3.656*
LA-TEXGAS	-2.426	-3.945*	-3.893*	-2.594	-5.858*	-6.307*
LA-TRUNK	-2.942	-2.791	-2.996	-1.869	-6.467*	-5.783*
LA-UNITED	-2.469	-3.669*	-4.627*	-2.865	-4.457*	-4.489*
OK-ANR	-3.025	-3.432*	-2.657	-3.023	-3.401*	-3.806*
OK-NGPL	-2.736	-3.825*	-3.169	-1.880	-3.492*	-3.086
OK-NORTH	-3.046	-3.678*	-2.276	-2.386	-3.108	-2.724

	LA-TENN	LA-TEXGAS	LA-TRUNK	LA-UNITED	OK-ANR	OK-NGPL
LA-TEXGAS	-4.818*					
LA-TRUNK	-5.992*	-4.218*				
LA-UNITED	-4.257*	-4.625*	-3.855*			
OK-ANR	-3.415*	-4.371*	-3.461*	-3.621*		
OK-NGPL	-3.395*	-4.026*	-5.482*	-3.414*	-3.876*	
OK-NORTH	-2.608	-3.325	-2.666	-2.682	-3.211	-4.289*

* Denotes that the null hypothesis of non-cointegration can be rejected at the 5% level.

MacKinnon Critical Values	H_o: Non-Cointegration
1% -3.960	Reject (87) 46%
5% -3.372	Not Reject (103) 54%
10% -3.069	

Table 2b. Cointegration Test Results across Fields: July 1988 - June 1989

(Dickey-Fuller *t*-statistics)

	WTX-ELPASO	WTX-TRANSW	ETX-NGPL	ETX-TENN	ETX-TRUNK	NTX-ANR	NTX-NGPL
WTX-TRANSW	-7.434*						
ETX-NGPL	-3.287	-3.331					
ETX-TENN	-3.367*	-3.649*	-4.363*				
ETX-TRUNK	-3.407*	-3.478*	-3.533*	-4.887*			
NTX-ANR	-3.588*	-3.705*	-1.687	-1.697	-2.509		
NTX-NGPL	-3.751*	-3.866*	-3.036	-2.767	-3.493*	-3.016	
NTX-NORTH	-4.095*	-4.234*	-2.041	-2.877	-2.393	-1.411	-4.454*
NTX-PEPL	-3.753*	-3.789*	-2.387	-2.611	-2.896	-3.480*	-4.626*
STX-NGPL	-3.593*	-3.736*	-6.006*	-3.610*	-4.273*	-2.423	-3.771*
STX-TENN	-3.464*	-3.733*	-4.218*	-3.779*	-5.801*	-2.621	-3.844*
LA-ANR	-3.482*	-3.633*	-3.767*	-3.138	-4.349*	-3.591*	-4.072*
LA-COLUMB	-3.417*	-3.605*	-3.390*	-3.356	-3.587*	-3.019	-4.120*
LA-TENN	-3.326	-3.476*	-3.097	-3.438*	-3.587*	-2.788	-3.599*
LA-TEXGAS	-3.490*	-3.628*	-3.731*	-3.856*	-4.744*	-4.737*	-4.088*
LA-TRUNK	-3.309	-3.491*	-3.936*	-3.238	-4.775*	-3.210	-3.785*
LA-UNITED	-3.239	-3.480*	-3.647*	-2.894	-3.984*	-1.894	-3.153
OK-ANR	-3.631*	-3.801*	-2.324	-2.136	-2.963	-10.330*	-4.058*
OK-NGPL	-3.864*	-3.863*	-2.936	-3.019	-3.628*	-3.053	-6.007*
OK-NORTH	-4.092*	-4.310*	-2.291	-2.815	-2.518	-3.027	-4.545*

	NTX-NORTH	NTX-PEPL	STX-NGPL	STX-TENN	LA-ANR	LA-COLUMB
NTX-PEPL	-3.495*					
STX-NGPL	-3.471*	-3.069				
STX-TENN	-3.562*	-3.356	-3.112			
LA-ANR	-3.913*	-4.429*	-2.502	-2.764		
LA-COLUMB	-3.876*	-4.197*	-1.978	-2.749	-3.031	
LA-TENN	-3.528*	-3.129	-2.232	-2.825	-3.746*	-4.256*
LA-TEXGAS	-4.066*	-5.200*	-2.835	-3.661*	-6.618*	-5.170*
LA-TRUNK	-3.460*	-3.766*	-3.351	-3.389*	-4.624*	-3.391*
LA-UNITED	-3.326	-2.547	-1.809	-2.503	-2.573	-2.537
OK-ANR	-3.673*	-4.505*	-1.513	-1.662	-2.856	-2.438
OK-NGPL	-4.174*	-3.833*	-2.588	-2.779	-2.882	-2.801
OK-NORTH	-5.824*	-4.888*	-1.500	-2.435	-2.583	-2.613

	LA-TENN	LA-TEXGAS	LA-TRUNK	LA-UNITED	OK-ANR	OK-NGPL
LA-TEXGAS	-4.914*					
LA-TRUNK	-4.144*	-5.752*				
LA-UNITED	-3.306	-3.124	-3.089			
OK-ANR	-2.535	-4.174*	-2.897	-1.243		
OK-NGPL	-2.717	-2.929	-3.038	-1.998	-2.621	
OK-NORTH	-2.878	-3.464*	-2.603	-2.179	-2.154	-3.257

* Denotes that the null hypothesis of non-cointegration can be rejected at the 5% level.

MacKinnon Critical Values	H_o: Non-Cointegration
1% -3.944	Reject (103) 54%
5% -3.363	Not Reject (87) 46%
10% -3.064	

Table 2c. Cointegration Test Results across Fields: July 1989 - June 1990

(Dickey-Fuller *t*-statistics)

	WTX-ELPASO	WTX-TRANSW	ETX-NGPL	ETX-TENN	ETX-TRUNK	NTX-ANR	NTX-NGPL
WTX-TRANSW	-5.083*						
ETX-NGPL	-4.139*	-4.292*					
ETX-TENN	-2.964	-3.067	-4.030*				
ETX-TRUNK	-3.665*	-3.707*	-3.267	-4.848*			
NTX-ANR	-2.488	-2.731	-3.247	-2.413	-3.995*		
NTX-NGPL	-3.255	-3.684*	-3.254	-2.602	-4.273*	-3.456*	
NTX-NORTH	-5.363*	-6.168*	-4.787*	-2.501	-4.569*	-2.602	-3.767*
NTX-PEPL	-3.767*	-4.043*	-3.652*	-2.782	-4.302*	-4.197*	-4.094*
STX-NGPL	-3.637*	-3.970*	-4.915*	-3.345	-5.558*	-2.507	-1.488
STX-TENN	-3.025	-3.173	-3.568*	-3.396*	-3.881*	-3.133	-3.113
LA-ANR	-5.228*	-4.897*	-4.678*	-4.409*	-4.614*	-4.033*	-4.814*
LA-COLUMB	-3.590*	-3.337	-2.380	-4.859*	-1.962	-4.728*	-4.910*
LA-TENN	-3.044	-3.076	-3.499*	-4.060*	-4.247*	-3.889*	-3.406*
LA-TEXGAS	-3.917*	-3.710*	-4.064*	-4.073*	-4.093*	-3.579*	-4.215*
LA-TRUNK	-3.899*	-4.057*	-2.967	-4.114*	-2.989	-4.542*	-5.657*
LA-UNITED	-3.192	-3.048	-2.994	-4.569*	-3.060	-4.134*	-4.254*
OK-ANR	-2.373	-2.605	-3.002	-2.265	-3.631*	-5.862*	-2.624
OK-NGPL	-3.285	-3.859*	-3.419*	-3.158	-4.873*	-4.206*	-2.438
OK-NORTH	-5.283*	-5.342*	-4.559*	-2.539	-4.522*	-2.659	-4.045*

	NTX-NORTH	NTX-PEPL	STX-NGPL	STX-TENN	LA-ANR	LA-COLUMB
NTX-PEPL	-4.225*					
STX-NGPL	-3.557*	-2.658				
STX-TENN	-2.698	-3.031	-3.313			
LA-ANR	-5.306*	-4.120*	-5.053*	-3.934*		
LA-COLUMB	-4.463*	-4.695*	-4.225*	-3.810*	-4.127*	
LA-TENN	-2.930	-3.039	-2.793	-3.492*	-3.918*	-5.630*
LA-TEXGAS	-3.278	-3.347	-3.839*	-3.541*	-4.789*	-5.071*
LA-TRUNK	-5.179*	-4.896*	-4.437*	-3.845*	-3.888*	-2.423
LA-UNITED	-4.302*	-4.173*	-4.796*	-3.935*	-4.048*	-2.335
OK-ANR	-2.608	-3.836*	-1.820	-3.083	-3.859*	-4.491*
OK-NGPL	-3.931*	-4.378*	-1.719	-3.306	-4.697*	-4.743*
OK-NORTH	-3.163	-4.666*	-3.476*	-2.845	-5.158*	-4.562*

	LA-TENN	LA-TEXGAS	LA-TRUNK	LA-UNITED	OK-ANR	OK-NGPL
LA-TEXGAS	-3.754*					
LA-TRUNK	-4.139*	-3.618*				
LA-UNITED	-4.001*	-3.985*	-2.744			
OK-ANR	-3.216	-3.287	-4.280*	-3.888*		
OK-NGPL	-3.550*	-3.955*	-6.057*	-4.805*	-3.155	
OK-NORTH	-2.947	-3.155	-5.291*	-4.191*	-2.702	-4.229*

* Denotes that the null hypothesis of non-cointegration can be rejected at the 5% level.

MacKinnon Critical Values	H_o: Non-Cointegration
1% -3.936	Reject (124) 65%
5% -3.360	Not Reject (66) 35%
10% -3.061	

Table 2d. Cointegration Test Results across Fields: July 1990 - June 1991

(Dickey-Fuller t-statistics)

	WTX-ELPASO	WTX-TRANSW	ETX-NGPL	ETX-TENN	ETX-TRUNK	NTX-ANR	NTX-NGPL
WTX-TRANSW	-3.714*						
ETX-NGPL	-4.422*	-3.098					
ETX-TENN	-4.311*	-4.009*	-3.950*				
ETX-TRUNK	-3.621*	-3.650*	-3.756*	-3.877*			
NTX-ANR	-2.958	-2.640	-2.627	-2.524	-2.567		
NTX-NGPL	-3.957*	-3.491*	-4.796*	-4.385*	-4.134*	-3.107	
NTX-NORTH	-4.842*	-3.910*	-3.879*	-3.702*	-3.531*	-2.851	-3.435*
NTX-PEPL	-3.711*	-3.602*	-2.881	-4.426*	-4.422*	-3.197	-4.087*
STX-NGPL	-4.298*	-3.870*	-2.921	-4.113*	-4.130*	-2.896	-5.159*
STX-TENN	-4.499*	-3.891*	-4.520*	-4.597*	-3.664*	-2.424	-4.661*
LA-ANR	-3.413*	-3.856*	-3.083	-2.466	-2.997	-2.692	-3.427*
LA-COLUMB	-3.657*	-3.789*	-3.419*	-3.971*	-2.647	-2.561	-3.574*
LA-TENN	-3.978*	-3.885*	-3.737*	-3.560*	-3.351	-2.626	-4.064*
LA-TEXGAS	-3.656*	-3.735*	-3.718*	-3.925*	-2.995	-2.958	-4.568*
LA-TRUNK	-3.484*	-3.518*	-3.694*	-3.804*	-2.858	-2.933	-4.681*
LA-UNITED	-3.630*	-3.977*	-3.984*	-3.379*	-4.554*	-2.786	-3.929*
OK-ANR	-2.949	-2.728	-2.570	-2.508	-2.543	-4.319*	-3.128
OK-NGPL	-3.674*	-3.602*	-4.577*	-4.206*	-3.625*	-2.563	-3.606*
OK-NORTH	-4.325*	-2.840	-3.064	-3.407*	-3.084	-2.426	-3.385*

	NTX-NORTH	NTX-PEPL	STX-NGPL	STX-TENN	LA-ANR	LA-COLUMB
NTX-PEPL	-3.745*					
STX-NGPL	-3.749*	-3.174				
STX-TENN	-3.842*	-3.578*	-4.423*			
LA-ANR	-3.658*	-5.975*	-3.749*	-2.433		
LA-COLUMB	-3.845*	-3.937*	-3.510*	-3.388*	-3.373*	
LA-TENN	-4.014*	-4.897*	-3.836*	-3.761*	-2.424	-4.034*
LA-TEXGAS	-3.654*	-5.478*	-3.925*	-3.552*	-3.761*	-3.903*
LA-TRUNK	-3.658*	-4.544*	-4.050*	-3.622*	-3.048	-2.854
LA-UNITED	-3.562*	-5.153*	-4.420*	-3.178	-3.402*	-3.146
OK-ANR	-2.818	-3.072	-2.712	-2.232	-2.728	-2.485
OK-NGPL	-3.100	-3.779*	-5.003*	-4.363*	-2.870	-2.653
OK-NORTH	-7.792*	-2.653	-2.925	-3.160	-3.393*	-3.361*

	LA-TENN	LA-TEXGAS	LA-TRUNK	LA-UNITED	OK-ANR	OK-NGPL
LA-TEXGAS	-3.787*					
LA-TRUNK	-3.517*	-4.163*				
LA-UNITED	-2.987	-4.315*	-3.944*			
OK-ANR	-2.604	-2.832	-2.800	-2.747		
OK-NGPL	-3.571*	-3.594*	-3.516*	-3.725*	-2.545	
OK-NORTH	-3.702*	-3.220	-3.168	-3.127	-2.389	-2.775

* Denotes that the null hypothesis of non-cointegration can be rejected at the 5% level.

MacKinnon Critical Values	H_o: Non-Cointegration
1% -3.937	Reject (126) 66%
5% -3.360	Not Reject (64) 34%
10% -3.062	

Table 3. Number of Other Regional Prices Found to Move with a Particular Regional Price

Region	Cointegrated 1987-88	Cointegrated 1990-91	Application Date	Approval Date
WTX-El PASO	4	17	6/88	11/88
WTX-TRANSW	1	15	12/87	3/88
ETX-NGPL	14	12	6/86	5/87
ETX-TENN	14	16	12/86	6/87
ETX-TRUNK	11	11	6/86	4/87
ETX-PEPL	10	13	6/86	11/87
NTX-ANR	1	1	6/88	7/88
NTX-NGPL	12	17	6/86	5/87
NTX-NORTH	4	16	6/86	1/88
STX-NGPL	5	14	6/86	5/87
STX-TENN	0	14	12/86	6/87
LA-ANR	15	10	6/88	7/88
LA-COLUMB	13	13	12/85	2/86
LA-TENN	11	14	12/86	6/87
LA-TEXGAS	14	15	8/88	9/88
LA-TRUNK	10	13	6/86	4/87
LA-UNITED	13	13	10/87	1/88
OK-ANR	13	1	6/88	7/88
OK-NGPL	12	13	6/86	5/87
OK-NORTH	5	7	6/86	1/88

four and one other points in 1986-87 and 17 and 15 points in 1990-91 for El Paso and Transwestern, respectively.[20]

The first fact that stands out in this table is that open access came unevenly over the regions, beginning with applications dated as early as 12/85 and as late as 6/88. Approvals began to be granted by the FERC as early as 2/86 and ending as late as 11/88. By late 1988, all the regions in the sample were connected *via* an open access pipeline. Even before applications for open access were approved, all the pipelines had interim transportation programs that supported limited spot market trading. The reliability of these spot markets was not assured until the open access application was approved and until trading grew to a level that would give the market the depth required to assure it as a reliable source of gas. Wider participation and widening access to points in the network went hand in hand in the development of the spot market.

20. We are indebted to a referee for suggesting this way of looking at market integration. We have added the open access application and FERC approval dates to the table to clarify when the opportunity for integration occurred. Doane and Spulber (1992) compiled the dates from EIA Report.

By the last sample period, all the supply regions are connected to more than one open access pipeline: West Texas-2, East Texas-4, North Texas-3, South Texas-2, Louisiana-6, Oklahoma-3. The degree of cointegration of a region with other regions is not related to the number of pipelines connecting the region to the national market. For example, West Texas has but two pipelines and yet WTX-El Paso and WTX-TRANSW prices are cointegrated with 17 and 15 of the 19 other markets with which they could be cointegrated. With the exception of one pipeline, ANR, every pipeline-regional price is cointegrated with at least as many other regions in 1991 as it was in 1987. When the level of integration is high in the 1986-87 sample, that region's open access date occurs during that time period. When the level of integration increased from 1986-87 to 1990-91, the open access date of the region is after 1986-87 and before 1990-91. Thus, the increase in the number of cointegrated regions from 1987 to 1990 coincided with the opening of access in those regions during that time period.

The ANR pipeline is the interesting exception to the increasing integration that has taken place in the market. The three supply basins where gas is injected into the ANR pipeline are: North Texas, Louisiana, and Oklahoma. ANR operates two pipelines. One is from Oklahoma and North Texas to Chicago and Wisconsin, with a loop over to Grand Rapids. The other is from the Louisiana Gulf area to Detroit. Of these injection points, the Louisiana point is cointegrated with 10 other markets, and this is less than the 15 it was integrated with earlier. The Oklahoma point had been integrated with 13 regions and this declined to only one by 1991. And the North Texas injection point into the ANR is cointegrated with only one other region in both periods. The other pipelines operating in these supply basins are cointegrated with far more regions than ANR. There are no clear explanations for ANR's lack of cointegration with other regions. It is one of the later pipelines to adopt open access; ANR's petition was made in 6/88 and approved in 7/88, one month later. The late adoption may have slowed the integration of its regions. But, the other pipelines that serve the same regions are far more integrated than ANR. It may be that the distributors connected to ANR have been slower to seize the opportunities in the spot market, but other evidence casts doubt on this as an explanation.[21] ANR meets more international competition than many pipelines since Canadian gas is available in the Chicago, Detroit and northern Wisconsin and Michigan areas that it serves. The evidence suggests this will not account for the low level of integration of ANR injection points either. ANR's implementation of open access appears to be less effective than the other pipelines.

21. In De Vany and Walls (1992b) we show that the Chicago city gate price is well integrated in the national market. Our study of city gate prices also shows that Canadian border zone prices are highly integrated with field and pooling area prices in the United States.

CONCLUSIONS

Cointegration is the natural method for testing market integration. The appeal of cointegration techniques for testing integration in gas markets is the natural way it handles time varying prices spread out over points in a network. If arbitrage is working in a market with these characteristics, then deviations from equilibrium will be stationary even though each price series is nonstationary. Open access set the stage for the opening of spot markets and provided the links for arbitrage. Direct dealing between buyers and sellers replaced intermediation by the pipeline. Open access made it possible to connect the grid of pipelines and link the regional supply basins that they serve. In this connected network, arbitrage can take sophisticated forms. Opening the grid increased the depth of the gas market because every point became a source of supply to every point in the grid. If open access permits virtually every demand point to draw gas from every field, then these supply fields form a common pool.

Our empirical examination of natural gas spot prices in twenty spatially separated markets leads us to conclude that gas markets became more strongly integrated from 1987 to 1991. We tested each daily price series for 190 market-pairs representing arbitrage points in the national pipeline network. The price series were non-stationary and follow a random walk. Early in the sample, soon after open access became an effective policy, only 46% of the market-pairs were cointegrated. By 1991, 66% of the market pairs were cointegrated and the degree of cointegration became independent of the distance between the pairs. The spread of open access through the grid was not uniform and the pattern of cointegration shows discontinuities that match the opening of key pipelines. Open access has provided the basis for integrating separate and even distant gas markets into one market. Policy should aim at removing the remaining barriers to pipeline integration.

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