BARNETT AND HAYNESVILLE SHALE PLAYS AND THEIR IMPACT ON THE SOUTHEWEST NATURAL GAS TRANSPORTATION CORRIDOR AND BEYOND

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ABSTRACT

This paper focuses on the Barnett and Haynesville shale plays and their impacts on midstream market linkages along the Southwest transportation corridor and beyond. Using the Bai-Perron test for structural breaks, we identify the relevant dates for the Barnett and Haynesville boom to be October 2007 and September 2007, respectively. Our subsequent cointegration analyses reveal market linkages remain after the break date, although a change in the short-run dynamics moving into the long-run equilibrium is perceptible. We observe a general slowdown in the speed of adjustment towards the long-run equilibrium, perhaps suggesting midstream infrastructure bottlenecks. **JEL Classification:** C1, L95

INTRODUCTION

The outlook of the U.S. natural gas markets has evolved considerably since the boom in shale gas production. Estimates from the U.S. Energy Information Administration (EIA) in 2017 indicate 60% of U.S. total production was from shale resources, up from 23.1% in 2010, and from only 1.6 % a decade earlier. This extraordinary growth in production can be attributed to the convergence of previously sustained high natural gas prices encouraging investments in the industry, market structure, pipeline infrastructure, government policy, and most notable, innovations in exploration and drilling activities (i.e., hydraulic fracturing technology and horizontal drilling) fueled by government research and development (R&D) programs (Wand and Krupnick, 2013). Advancements in exploration and drilling technologies have made it profitable to produce large quantities of shale gas. This dramatic increase in supply has since caused downward pressure on natural gas prices. Hausman and Kellogg (2015) estimate that wholesale prices lowered by $3.45 per mcf due to the natural gas supply expansion from 2007 to 2013. However, the extent of the price drop is not uniformly experienced across all segments of the market. Thus, how this new supply source impacts the domestic natural gas market is of interest to stakeholders.

The overall objective of our study is to investigate the effect of the significant increase in shale gas production on the market integration of the domestic natural gas market. We focus on two major shale plays— Barnett (Texas) and Haynesville (Louisiana and Texas). The Barnett shale in north-central Texas has been a source of large-scale natural gas production since 2000 and has since provided the technology template for developing other shale plays in the U.S. By 2005, the Barnett shale was producing almost half a trillion cubic feet (tcf) of natural gas per year. The profitability of producing natural gas in the Barnett shale has given producers the confidence to develop other shale formations. Barnett's and Haynesville's geologic and geographic location provide a unique opportunity to examine their direct impact on a major natural gas transportation corridor—the Southwest (SW). The transportation network includes intra and interstate pipelines, processing plants, and local distribution companies (LDCs)—transporting natural gas from production areas to consumers. The SW transportation corridor, which includes the states of Arkansas (AR), Louisiana (LA), New Mexico (NM), Oklahoma (OK), and Texas (TX), is mainly categorized as a production corridor, exporting natural gas to other parts of the country. As such, we likewise investigate if the impact extends to the overall aggregated U.S. natural gas market. According to the EIA, this area of the country currently exports about 45% of its production which is 47% of natural gas consumption elsewhere in the U.S.

The literature investigating the cointegration of various segments of the U.S. natural gas industry before the shale boom in the early to mid-2000 generally find market integration (DeVany and Walls, 1993; Walls, 1994; King and Milan, 1996; Leitzinger and Collette, 2002; Cuddington and Wang, 2006; Arano and Velikova, 2009 & 2010). However, the development of these shale plays has brought a massive supply shock on the SW transportation corridor and beyond and has likely altered the linkages across submarkets. To investigate the impact of such supply shock, we break down our study into two parts: (1) statistically identify when the actual structural break/s in the production data occurred to allow us to control for these shock/s in our analyses; and then (2) use the results from the structural break tests to investigate the market integration of midstream natural gas prices (citygate) within the SW transportation corridor before and after the shale boom. We use the price-based approach to market integration as it reflects both demand and supply conditions and can help ascertain if the 'law of one price' (LOP) holds among the segmented domestic natural gas markets. LOP dictates that natural gas prices in different segments of the industry will tend to move together since they are drawn from the same overall market integrated by a network of pipeline, transmission, and spot markets. Stigler and Sherwin (1985) suggest the price-based approach is preferable for testing market integration. Aruga (2016) uses U.S. natural gas marketed production to capture the shale boom and investigates price integration of U.S., Japanese, and European natural gas markets. We utilize shale gas production in the appropriate shale plays to capture the supply shock directly. This allows for a more precise measure of the supply shock as we can utilize actual shale gas production as opposed to total production, and even more specific to only two major shale plays in the Southwest transportation corridor. We also utilize the most current data to date—from 2000 when the initial activities in shale production became more active, and to the most current data available in 2018. With the increased production from shale gas in these shale plays, exporting natural gas to other segments of the domestic market is likely. However, there could be potential barriers to the movement of natural gas across market segments and may impact previously established integrated segments in the domestic market. Indeed, EIA (2016) reported that the spread between Henry Hub (used as a benchmark national price) and Marcellus natural gas prices (one of the most active shale plays located in the Northeast region) have narrowed as pipeline capacity grew.

Most studies investigating the impact of the shale boom have examined the issue on a more aggregated basis, be it U.S. markets vs international markets or natural gas markets vs oil markets. Wakamatsu and Aruga (2013) find that the shale production revolution in 2005 caused a change in the relationship between the U.S. and Japanese natural gas markets—the two markets used to be interlinked but the U.S. market shifted to a more independent one after the boom. In a similar study, Aruga (2016) finds price linkages among U.S., Japanese and European markets before the boom (structural break identified as 2006:8) but the relationship disappeared after the break date. Geng, et al investigate both the impact of the shale revolution on U.S. gas prices as well as European prices and the relationship of North American natural gas prices and crude oil prices. They find evidence of gas price movement from "slightly upward" to "slightly downward" for U.S. prices but European price movement was not impacted as much. They also find evidence that before the shale gas revolution, natural gas prices and crude oil prices in North America maintained a long-term equilibrium relationship but have decoupled since the period of the shale revolution. The long-run relationship between natural gas and oil prices has also been investigated by Asche, et al (2012). Although they find a long-run relationship between the two markets, they argue that using historic prices cannot necessarily be used to forecast the development of future relative prices. In a study investigating a similar issue but utilizing more current data (1997-2013), Caporin and Fontini (2017) conclude that although they show gas quantities become relevant in natural gas prices formation after the beginning of shale gas boom and the impact of oil prices on gas prices doubles, it is not possible to indisputably assess whether a new long-run relationship between the two markets has been established.

In terms of studies that have been done to examine a specific shale play in the U.S., Potts and Yerger (2016) find a structural break in the impact of Pennsylvania's (PA) natural gas production from the Marcellus boom on prices in early 2009. They show that post-boom, an increase in PA's production leads to a lower average national price of natural gas whereas PA's impact on the national market was minimal before the boom. Arano, et al (2018) find evidence of cointegration of natural gas prices from upstream, midstream, to downstream segments of the market in Ohio (OH), New York (NY), PA, and West Virginia (WV) post-Marcellus boom but a change in the short-run dynamics are evident. The speed of adjustment slowed down post-boom suggesting potential infrastructure bottlenecks in the Northeast region.

To maintain market integration, production must move efficiently from production fields to end-users. For the full benefits of the boom in production to be realized, complementary changes in processing and pipeline infrastructure are necessary to accommodate increased capacity. Indeed, previous studies have recognized the importance of pipeline capacity constraints in market integration (Marmer, et al., 2007; Brown and Yucel, 2008). Using data from 2006-2010 which captures the boom in U.S. shale production, Avalos, et al (2016) find support of integrated regional markets but also find evidence that pipeline congestion in Florida (FL) increased realized citygate prices by at least 11% and by 6% in Southern California. These findings highlight the value of studying the impact of a significant supply shock from the shale revolution on specific transportation corridor segments of natural gas in the U.S. Potential bottlenecks can be uncovered providing meaningful information to policymakers as well as both upstream and midstream producers.

DATA AND EMPIRICAL TESTS

Data

Our empirical analyses focus on the SW natural gas transportation corridor which includes the states of AR, LA, OK, NM and TX and we use monthly data from 2000:1 – 2018:6 available from the U.S. Energy Information Administration (EIA). The specific area of study and observation period allows us to explicitly capture the impact of the shale gas revolution from two major shale plays—Barnett (TX) and Hayneville (TX and LA). We examine the following variables: dry shale gas production from Barnett and Haynesville (bcf/day), citygate prices in AR, LA, OK, NM, and TX ($/ thousand cubic ft.), U.S. average citygate prices ($/thousand cubic ft), and Henry Hub spot price ($/million Btu). We use dry shale gas production to capture the supply shock and identify the structural break/s in the series. We then utilize the price series variables to test for cointegration, accounting for structural break/s brought about by the shale boom in the specified region. The use of citygate prices within the SW corridor captures the impact of the boom midstream (including pipeline and transportation infrastructure) within the same market segment where the supply shock has taken place. To further examine the trickle effect beyond the SW transportation corridor, we also investigate the link to U.S. average citygate prices and the Henry Hub prices. The Henry hub prices, which serve as the benchmark for U.S. natural gas prices, allow us to approximate the impact of the shale boom across the national market.

Figure 1 displays production in the Barnett and Haynesville shale plays from 2000 – 2018 based on data from the EIA. It shows rapid growth in the Barnett shale around 2007, peaking around 2012 but has since rebounded around 2017. Haynesville production shows a sharp increase around 2009, also peaking around 2012, and has since trended downwards. In the next section, we discuss the use of the Bai-Perron (BP) method (Bai and Perron, 1998) to statistically identify the structural break/s in the production data initially visually revealed in Figure 1.

Structural Break Tests

The literature on the U.S. shale boom has ascertained various dates on when the boom occurred, mostly around the mid to late 2000s (Wakamatsu and Aruga, 2013; Aruga, 2016; Geng et al, 2016; Potts and Yerger, 2016; and Caporin and Fontini, 2017). Similar to these studies, we utilize structural break tests to determine when and whether there is a significant change in natural gas prices in the SW transportation corridor brought about by the shale gas boom from the Barnett and Haynesville shale plays. Since the number of breaks and breakpoints are unknown, we use the BP method (Bai and Perron, 1998) to statistically identify the boom and other break point/s in the production data from the Barnett and Haynesville shale plays, respectively. We estimate the following multiple linear regression with m breaks (m+1 regimes):

$$y_t = z_t'\delta_j + u_t \quad (t = T_{j-1}, \dots, T_j, j = 1, m+1) \qquad (1)$$

Here, y_t is the observed dependent variable, shale gas production data at time t; z_t ($q \times 1$) is the vector of covariates, and δ_j (j=1, m+1) is the corresponding vector of coefficients; u_t is the disturbance at time t. The indices ($T_1, \dots, T_m$), or the breakpoints, are explicitly treated as unknown (we use the convention that T_0= 0 and T_{m+1} = T). The purpose is to estimate the unknown regression coefficients together with the breakpoints when T observations on (Y_t,z_t) are available. The method of estimation is based on the least-squares principles (Bai and Perron, 2003). Since we wish to allow for serial correlation in the errors, we specify a quadratic spectral kernel-based HAC covariance estimation using prewhitened residuals. The kernel bandwidth is determined automatically using the Andrews AR (1) method (Andrews, 1993). The test allows for a maximum of 5 breaks, employs a trimming percentage of 15 percent, and uses a 0.05 significance level for the sequential testing. We also allow for error distribution to differ across breaks; therefore, we allow error heterogeneity. Since there are multiple selection and specification procedures in choosing the number of breaks, we employ a sequential procedure, a strategy suggested by Bai and Perron (2003) by first using the UD max and/or WD max tests to see if at least a break is present (Bai-Perron tests of 1 to M globally determined breaks, i.e., global L breaks vs none) and then utilizing the L+1 vs L globally determined breaks in deciding the number of breaks.

Given the swings in production data as shown in Figure 1, we expect the BP test to identify multiple breaks. We first identify the main break associated with the shale boom by cross-checking with Figure 1 and corroborating with dates identified by previous studies and then using this date to split the sample into before and after the boom to carry out the cointegration analyses. If we find other breaks, we create exogenous dummy variables based on these breakpoints and incorporate the effects in the cointegration tests.

Cointegration Tests

We utilize the Johansen cointegration method (Johansen and Juselius, 1990) to test the midstream (i.e., citygate) market linkages on the SW transportation corridor and beyond and carry out the cointegration tests for the price pairs between gas originating from the Barnett (TX) and Haynesville (LA, TX) shale plays, respectively, to states within the SW transportation corridor, and further out to overall U.S. market as captured by U.S. average citygate and Henry Hub prices. The list of price pairs tested is in Table 1.

The cointegration tests are carried out by splitting the data into before and after the shale boom dates (i.e., the main break in the data) as identified by the BP tests. We then incorporate other identified structural break/s by including them as exogenous dummy variables in the cointegration models and take on the value of 1 after the break date/s and 0 before the break date/s (Joyeux, 2001). As a benchmark, we also perform all the tests for the full time period.

We perform stationary tests using the augmented Dickey-Fuller (ADF) unit root test for all price pairs and time periods studied (Dickey and Fuller, 1979) before proceeding with the cointegration tests. The econometric model for the Johansen procedure (1988) estimates a fully specified error-correction model (ECM) by maximum likelihood (ML) and is specified as:

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-1} + \Pi P_{t-1} + \Phi D_t + \varepsilon_t \qquad (2)$$

where P_t denotes a p$\times$1 vector of natural gas prices; Γ_i with i = 1, …, k-1 the short-run coefficients; Π is the long-run impact matrix summarizing all the long-run information in the P_t process; D_t is the exogenous dummy variables: and ε_t is an independently and identically distributed n-dimensional vector with zero mean and variance matrix Σ_ε. The rank of a matrix denotes the number of distinct cointegrating vectors in the system. Using E-Views, we obtain estimates of Π and its characteristic roots. The test for the number of characteristic roots can be conducted using the following two test statistics as outlined in Enders (2004):

$$\lambda_{trace}(r) = -T \sum_{i=r+1}^{p} \ln(1-\hat{\lambda}_i) \qquad (3)$$

$$\lambda_{\max}(r, r+1) = -T \sum_{i=r+1}^{p} \ln(1-\hat{\lambda}_{r+1}) \qquad (4)$$

where $\hat{\lambda}_i$ = the estimated values of the characteristic roots (also called eigenvalues) obtained from the estimated Π matrix and T = the number of usable observations. Equation (3) tests the null hypothesis that the number of distinct cointegrating vectors is less than or equal to r against a general alternative while equation (4) tests the null that the number of cointegrating vectors is r against the alternative of r+1 cointegrating vectors. The results of this study are based on $\lambda_{\max}$ statistic[1].

RESULTS

Structural Breaks

The results of the sequential BP tests reveal 4 breakpoints for both Barnett and Haynesville. These are listed in Table 2 and are the basis for the before and after boom dates along with the relevant exogenous dummy variables utilized in the succeeding cointegration tests.

We identify 2007:10 and 2007:9 as the relevant dates for the shale boom in Barnett and Haynesville, respectively. These coincide closely with the steep increase in production. We consider the break identified before the boom is from the initial increase in production activities at the start of the shale revolution. The dates identified after the boom may have picked up on the boom/bust cycle showing the swings in production as affected by market conditions. This is typical of industries that capitalize on non-renewable resources (Howley, 2012). These dates simply identify significant changes in the price data for the time period under consideration. The next step is to examine how these structural breaks potentially altered the long-run equilibrium and the short-run dynamics that lead to the long-run equilibrium.

COINTEGRATION RESULTS

Detailed results of the unit root tests for all the time periods and price series tested are available in the appendix section. The ADF tests for non-stationarity confirm all have unit roots and are integrated of the same order one[2]. This allows us to proceed to the Johansen cointegration tests for market linkages and is presented in Tables 3a-3d[3]. These results reveal that all the price pairs, for the three time periods considered, in both Barnett and Hayneville, are cointegrated. There is a long-run relationship between citygate prices in the SW transportation corridor indicating regional market linkages. Indeed, the market linkages extend to the national market as the results show citygate prices from Barnett (TX) and Haynesville (LA & TX) are cointegrated to U.S. average citygate prices and the Henry Hub spot prices. The supply shock from the shale boom coming from the Barnett and Haynesville shale plays has not altered the previously established cointegrated regional and national natural gas markets. Moreover, the benefits from the boom in production in the SW transportation corridor were not limited to this region but seemed to have trickled to the national market.

Even if markets remain linked after the massive supply shock, it would be interesting to further examine the short-run dynamics as the markets move towards the long-run equilibrium. These can be gleaned from the speed of adjustment parameters shown in column 5 of Tables 3a-3f. For brevity, we only present the estimates flowing from Barnett (TX) and Hayneville (TX & LA) to states within the SW transportation corridor and to the national market as we are mainly focused on the impact of the shale boom. The larger these coefficients are, the greater is the response of the previous period's deviation from long-run equilibrium (Enders, 2004). More specifically, these parameters are interpreted as how fast the disequilibrium is corrected each month by changes in citygate prices originating from the Barnett and Haynesville shale plays.

Before the boom in the Barnett shale (Tables 3a), changes in TX citygate prices "correct" the disequilibrium each month across all the price-pairs within the SW transportation corridor (first four price-pairs) by an average of 19%. However, it would seem the adjustment towards the long-run equilibrium has slowed down after the boom in shale production indicating a change in short-run dynamics. For example, before the boom, changes in TX citygate prices correct for the disequilibrium with LA citygate prices by 23% but this drops to only 3% after the boom. A similar pattern is exhibited between TX citygate prices and U.S. average citygate and Henry Hub spot prices. At the national level using average U.S. citygate prices, about 44% of the disequilibrium is "corrected" each month by changes in citygate prices in TX before the boom and slows down to 37% after the boom. A slowing down in long-run adjustment is likewise evident in the Haynesville shale play encompassing both TX and LA (Tables 3d & 3e). All of these may allude to potential gridlock in the pipeline and overall infrastructure capacity from large-scale increases in production volume. These results are mostly consistent with the findings of Arano, et al (2018) in the Marcellus shale play in the Northeast (NE) region and the EIA report that lack of available takeaway pipeline capacity to move shale production from the Marcellus and Utica basins in the NE has constrained the ability to move it to new markets (EIA, 2018). The same EIA report indicates that the NE region is slated for record natural gas pipeline capacity buildout in 2018 to help keep pace with production. The expansion in production from Barnett and Haynesville has not been as massive as the Marcellus but a similar pipeline capacity constraint is likely. There are currently multiple natural gas pipeline projects and expansions in the TX and LA region slated to be completed within the next 2-3 years which will help improve the movement of natural gas produced in the region to other parts of the country and beyond[4].

CONCLUSIONS AND POLICY RECOMMENDATIONS

In this paper, we set out to detect structural breaks in the U.S. natural gas markets brought about by the massive supply shock from the shale gas boom, with a specific focus on the Barnett and Haynesville shale plays. We account for these structural breaks in testing for the market linkages within the SW natural gas transportation corridor and beyond, i.e., the national aggregated U.S. natural gas market. We find the relevant dates for the Barnett and Haynesville boom to be 2007:10 and 2007:9, respectively. We also identified several other breaks alluding to the boom/bust nature of natural gas shale production. We are able to identify specific dates that likely produced structural breaks in production data from these shale plays ultimately impacting linkages of various segments of the U.S. natural gas market.

The overall U.S. natural gas market is comprised of multiple segments—from production, gathering, and processing (upstream), to transmission (midstream), and distribution (midstream). Natural gas prices across segments of the industry might exhibit short-run variations but will move towards a long-run equilibrium if they are cointegrated since they have been drawn from the same overall natural gas market. Integrated markets across different locations will be differentiated only by transportation and arbitrage costs (DeVany and Walls, 1993 and King and Milan, 1996). It has been established in the literature that the combination of wellhead deregulation, open access, and a comprehensive and integrated natural gas transportation and pipeline infrastructure has effectively linked natural gas markets across the U.S. Our results suggest that the market linkages in the SW transportation corridor and beyond remain after the break date relevant to the shale gas boom. However, there is a noticeable change in the short-run dynamics moving into the long-run equilibrium. Although markets remain cointegrated, the speed of adjustments towards the long-run equilibrium has slowed down after the boom, perhaps suggesting midstream infrastructure bottlenecks. For example, our results show in general that the slow-down in the movement towards the long-run equilibrium between where the shale boom is (TX for Barnett shale and LA and TX for Haynesville shale) and to the overall national market (i.e., average U.S. citygate prices) was slightly more noticeable compared to the slow-down in the adjustment in prices between states within the transportation corridor closest to where the shale boom is (SW transportation corridor). Perhaps the infrastructure to move these new supplies from shale gas to other markets has not kept up with the increased production. Overall, however, although the adjustment towards the long-run equilibrium has slowed down with the boom, the potential infrastructure bottlenecks have not been significant enough to cause a breakdown in market linkages. Our findings should be helpful to midstream producers by recognizing opportunities to pipeline companies for expansion. Regulators could also use these results to guide their decision-making towards awarding certificates for pipeline projects. All of these could reduce investment risks and help with overall natural gas supply security. Ultimately, demand and supply shocks will impact the market equilibrium. However, it is important to examine the short-run dynamics to identify potential barriers as the industry moves to a new long-run equilibrium.

An important implication of our results is that as pipeline projects are completed and exports increase not only from producing regions of the U.S. (like the SW transportation corridor) to other parts of the U.S. but to international markets as well, how this will affect the global linkages of natural gas markets. Indeed, Aruga (2016) found that the linkage between the U.S. natural gas market and international gas markets became weaker after the shale gas revolution perhaps an indication of infrastructure constraints. In terms of the Barnett and Haynesville shale plays, the closest potential international market linkage is Mexico. In fact, new U.S. border-crossing pipelines, mostly in Texas, have brought more shale gas to Mexico with exports standing at 7.3 billion cubic ft per day in 2016 and continue to expand in 2018 with the commissioning of new pipelines in Mexico (EIA, 2016 and 2018). The large quantities of shale gas in the U.S. market are likely to be exported globally and may help gas prices in the U.S. rebound. After all, the decline in shale gas production activities in the last few years has been partly attributed to depressed prices. Additionally, there may likewise be untapped natural gas reserves in other international markets, which, if discovered, could potentially alter the short-run dynamics and the long-run equilibrium trajectory within these markets, and ultimately the global market for natural gas. Integrated domestic and international gas markets, where there is efficient movement of natural gas through various segments of the industry both locally and globally, send a security signal to all stakeholders including energy investment companies and consumers. This allows for the benefits of the new natural gas supply source to trickle down to all segments of the market and stakeholders as well.

END NOTES

[1]The results of λ_{trace} and λ_{max} tests can conflict, however λ_{max} has the sharper alternative hypothesis and is usually preferred to determine the number of cointegrating vectors. End notes go here. Please use the following format. Endnotes are discouraged so use them sparingly.

[2]Except for NM and OK citygate prices in the Barnett shale boom period (Appendix Table 1b) and NM citygate prices in the Hayneville shale boom period (Appendix Table 1d). For these price series, we cannot perform the cointegration tests.

[3]The cointegration results for the full time period are available in the Appendix section (Appendix Table 2a and 2b). Results indicate all price pairs are cointegrated.

4EIA Natural Gas Pipelines.

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FIGURE 1. BARNETT AND HAYNESVILLE PRODUCTION

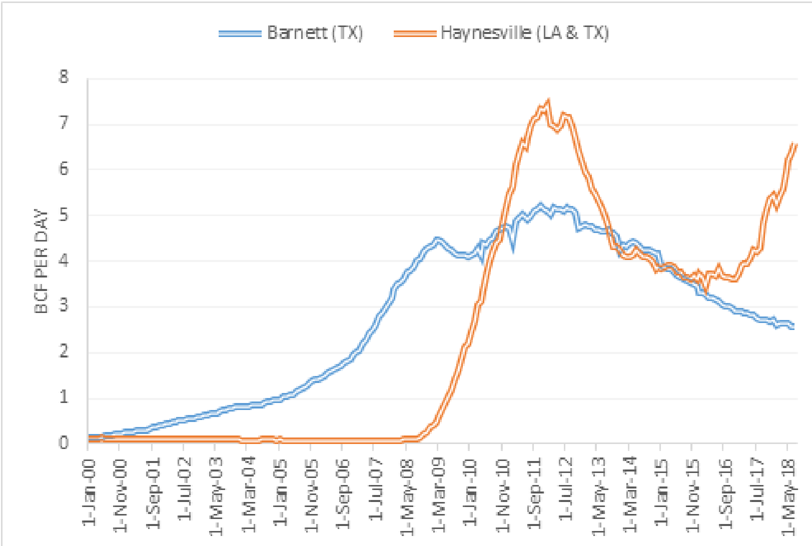

TABLE 1. PRICE-PAIRS TESTED

Shale Plays	Price Pairs (Direction of Flow)
Barnett (TX)	CP_TX to CP_AR
Haynesville (LA and TX)	CP_TX to CP_LA
	CP_TX to CP_NM
	CP_TX to CP_OK
	CP_LA to CP_TX
	CP_LA to CP_AR
	CP_LA to CP_NM
	CP_ LA to CP_OK
	CP_TX to US Citygate
	CP_LA to US Citygate
	CP_TX to Henry Hub
	CP_LA to Henry Hub

Notes: CP = citygate price

TABLE 2. BAI-PERRON TEST OF L+1 VS L GLOBALLY DETERMINED BREAKS

Barnett Shale (TX)	Haynesville (LA & TX)
January 2005 (2005:1)	June 2003 (2003:6)
October 2007 (2007:10)[a]	September 2007 (2007:9)[a]
July 2010 (2010:7)	June 2010 (2010:6)
February 2015 (2015:2)	June 2013 (2013:6)

Notes: [a]Identified as shale boom dates

TABLE 3A. JOHANSEN COINTEGRATION TEST RESULTS FOR PRE BARNETT SHALE GAS BOOM (2000:01 - 2007:10)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	26.54250* 0.038155	26.50434* 0.038155	-0.114244 (0.08130)
CP_TX & CP_LA	r=0 r<=1	17.33883* 0.066388	17.27245* 0.066388	-0.229859 (0.24000)
CP_TX & CP_NM	r=0 r<=1	19.39962* 0.116868	19.28275* 0.116868	-0.301813 (0.20243)
CP_TX & CP_OK	r=0 r<=1	17.97222* 0.013698	17.95852* 0.013698	-0.094353 (0.17124)
CP_TX & CP_USA	r=0 r<=1	18.41756* 0.007357	18.41020* 0.007357	-0.443308 (0.32128)
CP_TX & Henry Hub	r=0 r<=1	12.27643 0.000156	12.27627* 0.000156	-0.102909 (0.11923)

Notes: *denote significance at 5%

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TABLE 3B: JOHANSEN COINTEGRATION TEST RESULTS FOR BARNETT SHALE GAS BOOM (2007:11 – 2018:06)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	34.66043* 2.184714	32.47572* 2.184714	-0.126683 (0.05345)
CP_TX & CP_LA	r=0 r<=1	16.04703* 2.626108	13.42092* 2.626108	-0.031368 (0.13610)
CP_TX & CP_USA	r=0 r<=1	22.93713* 4.049251	18.88788* 4.049251	-0.368361 (0.10981)
CP_TX & Henry Hub	r=0 r<=1	19.91641* 2.958078	16.95833* 2.958078	-0.095950 (0.07134)

Notes: *denote significance at 5%

TABLE 3C: JOHANSEN COINTERATION TEST RESULTS FOR PRE HAYNESVILLE SHLAE GAS BOOM (2000:01 – 2007:09)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	27.42593* 0.172842	27.25308* 0.172842	-0.100805 (0.08024)
CP_TX & CP_LA	r=0 r<=1	18.34640* 0.263255	18.08314* 0.263255	-0.256424 (0.23365)
CP_TX & CP_NM	r=0 r<=1	29.19493* 0.289225	28.90571* 0.289225	-0.370508 (0.21842)
CP_TX & CP_OK	r=0 r<=1	18.88961* 0.177566	18.71205* 0.177566	-0.083779 (0.17355)
CP_LA & CP_TX	r=0 r<=1	18.34640* 0.263255	18.08314* 0.263255	-0.487941 (0.28340)
CP_LA & CP_AR	r=0 r<=1	25.79473* 0.404721	25.39001* 0.404721	-0.123219 (0.09264)
CP_LA & CP_NM	r=0 r<=1	24.80297* 0.539412	24.26356* 0.539412	-0.347031 (0.23105)
CP_LA & CP_OK	r=0 r<=1	21.08678* 0.287216	20.79956* 0.287216	-0.174709 (0.17588)
CP_TX & CP_USA	r=0 r<=1	20.24101* 0.056679	20.18434* 0.056679	-0.487100 (0.33036)
CP_LA & CP_USA	r=0 r<=1	23.31160* 0.066061	23.24554* 0.066061	-0.351439 (0.26396)
CP_TX & Henry Hub	r=0 r<=1	12.65773* 0.267828	12.38990* 0.267828	-0.104065 (0.12132)
CP_LA & Henry Hub	r=0 r<=1	15.21623* 0.847660	14.36587* 0.847660	-0.183962 (0.17549)

Notes: *denote significance at 5%

TABLE 3D. JOHANSEN COINTEGRATION TEST RESULTS FOR HAYNESVILLE GAS BOOM (2007:10 – 2018:06)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	38.13458* 2.948223	35.18635* 2.948223	-0.134133 (0.05591)
CP_TX & CP_LA	r=0 r<=1	21.55775* 5.001145*	16.55661* 5.001145*	-0.114922 (0.15111)
CP_TX & CP_OK	r=0 r<=1	23.90578* 2.804558	21.10123* 2.804558	-0.184380 (0.07092)
CP_LA & CP_TX	r=0 r<=1	21.55775* 5.001145*	16.55661* 5.001145*	-0.369230 (0.13414)
CP_LA & CP_AR	r=0 r<=1	39.52942* 4.152214*	35.37720* 4.152214*	-0.142767 (0.05463)
CP_LA & CP_OK	r=0 r<=1	26.40254* 3.285303	23.11724* 3.285303	-0.202591 (0.05671)
CP_TX & CP_USA	r=0 r<=1	23.44733* 3.202465	20.24487* 3.202465	-0.384589 (0.10889)
CP_LA & CP_USA	r=0 r<=1	21.40042* 2.947610	18.45281* 2.947610	-0.312019 (0.07886)
CP_TX & Henry Hub	r=0 r<=1	16.06887* 3.351574	12.71729* 3.351574	-0.110173 (0.07629)
CP_LA & Henry Hub	r=0 r<=1	18.18996* 5.793813*	12.39614* 5.793813*	-0.174421 (0.07307)

Notes: *denote significance at 5%

APPENDIX

TABLE 1A: UNIT ROOT TEST PRE BARNETT SHALE GAS BOOM (2000:01 - 2007:10)

Series	Lags (selected by AIC)	Estimated a_1	t-statistic	Prob-value
CP_TX	0	-0.113303	-2.438949	0.1340
CP_AR	3	-0.168596	-2.120825	0.2371
CP_LA	0	-0.142607	-2.789523	0.0636
CP_NM	0	-0.075172	-1.959094	0.3043
CP_OK	1	-0.098112	-2.039326	0.2698
US City Gate	3	-0.090285	-2.211870	0.2036
Henry Hub	0	-0.129812	-2.629187	0.0908

Notes: Null Hypothesis: Series has a unit root
ADF test statistic: -3.460173 at 1%; -2.874556 at 5%; -2.573784 at 10%

TABLE 1B: UNIT ROOT TEST BARNETT SHALE GAS BOOM (2007:11 - 2018:06)

Series	Lags (selected by AIC)	Estimated a_1	t-statistic	Prob-value
CP_TX	0	-0.061241	-2.262259	0.1859
CP_AR	8	-0.117712	-2.447757	0.1311
CP_LA	3	-0.072288	-3.037778	0.0342
CP_NM	6	-0.188456	-4.444595	0.0004
CP_OK	8	-0.179604	-4.700688	0.0002
US City Gate	1	-0.052075	-2.386010	0.1477
Henry Hub	0	-0.050947	-1.998019	0.2875

Notes: Null Hypothesis: Series has a unit root
ADF test statistic: -3.460173 at 1%; -2.874556 at 5%; -2.573784 at 10%

TABLE 1C: UNIT ROOT TEST PRE HAYNESVILLE SHALE GAS BOM (2000:01 – 2007:9)

Series	Lags (selected by AIC)	Estimated a_1	t-statistic	Prob-value
CP_TX	0	-0.115550	-2.482316	0.1231
CP_AR	3	-0.172271	-2.113112	0.2401
CP_LA	0	-0.141911	-2.762849	0.0677
CP_NM	0	-0.076473	-2.030828	0.2734
CP_OK	1	-0.099223	-2.047228	0.2665
US City Gate	3	-0.092433	-2.253769	0.1893
Henry Hub	0	-0.130452	-2.633004	0.0901

Notes: Null Hypothesis: Series has a unit root
ADF test statistic: -3.460173 at 1%; -2.874556 at 5%; -2.573784 at 10%

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TABLE 1D: UNIT ROOT TEST HAYNESVILLE SHALE GAS BOOM (2007:10-2018:06)

Series	Lags (selected by AIC)	Estimated a_1	t-statistic	Prob-value
CP_TX	0	-0.054248	-1.978416	0.2960
CP_AR	8	-0.101434	-2.149512	0.2260
CP_LA	3	-0.065725	-2.732361	0.0714
CP_NM	7	-0.194113	-4.401060	0.0005
CP_OK	8	-0.131426	-3.357765	0.0147
US City Gate	3	-0.044125	-1.958167	0.3050
Henry Hub	0	-0.047950	-1.895789	0.3334

Notes: Null Hypothesis: Series has a unit root
ADF test statistic: -3.460173 at 1%; -2.874556 at 5%; -2.573784 at 10%

TABLE 1E. UNIT ROOT TEST FULL PERIOD (2000:01 - 2018:06)

Series	Lags (selected by AIC)	Estimated a_1	t-statistic	Prob-value
CP_TX	0	-0.078849	-3.089113	0.0288
CP_AR	10	-0.093435	-1.836096	0.3623
CP_LA	12	-0.049533	-1.659603	0.4503
CP_NM	0	-0.073859	-2.935668	0.0429
CP_OK	1	-0.083696	-2.892540	0.0478
US City Gate	1	-0.059845	-2.826179	0.0562
Henry Hub	9	-0.059045	-2.000998	0.2864

Notes: Null Hypothesis: Series has a unit root
ADF test statistic: -3.460173 at 1%; -2.874556 at 5%; -2.573784 at 10%

TABLE 2A. JOHANSEN COINTERATION TEST RESULTS FOR BARNETT SHALE GAS FULL TIME PERIOD (2000:01 - 2018:06)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	49.78227* 0.886893	48.89537* 0.886893	-0.149021 (0.05048)
CP_TX & CP_LA	r=0 r<=1	26.11793* 1.898666	24.21927* 1.898666	-0.022402 (0.13601)
CP_TX & CP_NM	r=0 r<=1	25.47582* 1.492946	23.98287* 1.492946	-0.260459(0.10811)
CP_TX & CP_OK	r=0 r<=1	32.80579* 0.614041	32.19175* 0.614041	-0.205847 (0.07635)
CP_TX & CP_USA	r=0 r<=1	54.28147* 20.83885*	33.44262* 20.83885*	-0.238923 (0.15149)
CP_TX & Henry Hub	r=0 r<=1	30.3290* 0.970269	29.35363* 0.970269	-0.185244 (0.08872)

Notes: *denote significance at 5%

TABLE 2B. JOHANSEN COINTEGRATION TEST RESULTS FOR HAYNESVILLE SHALE GAS FULL TIME PERIOD (2000:01 - 2018:06)

Price-Pair	H_0: rank=r	Trace test	Maximum Eigenvalue Test	Speed of Adjustment Parameters (standard error in parentheses)
CP_TX & CP_AR	r=0 r<=1	53.90999* 1.848137	52.06186* 1.848137	-0.144562 (0.05077)
CP_TX & CP_LA	r=0 r<=1	31.39276* 3.059852	28.33291* 3.059852	-0.028618 (0.14120)
CP_TX & CP_NM	r=0 r<=1	26.53158* 2.911915	23.61966* 2.911915	-0.194857 (0.10073)
CP_TX & CP_OK	r=0 r<=1	37.09982* 2.018534	35.08128* 2.018534	-0.207392 (0.07892)
CP_LA & CP_TX	r=0 r<=1	31.39276* 3.059852	28.33291* 3.059852	-0.553745 (0.15146)
CP_LA & CP_AR	r=0 r<=1	63.82002* 2.397854	61.42216* 2.397854	-0.158358 (0.05405)
CP_LA & CP_NM	r=0 r<=1	25.91612* 4.831561*	21.08456* 4.831561*	-0.256252 (0.08540)
CP_LA & CP_OK	r=0 r<=1	38.41857* 2.268475	36.15010* 2.268475	-0.257060 (0.07652)
CP_TX & CP_USA	r=0 r<=1	34.47965* 1.868188	32.61147* 1.868188	-0.481478 (0.13178)
CP_LA & CP_USA	r=0 r<=1	34.64211* 1.606129	33..3599* 1.606129	-0.491427 (0.11471)
CP_TX & Henry Hub	r=0 r<=1	32.13889* 2.731718	29.40717* 2.731718	-0.179658 (0.08613)
CP_LA & HenryHub	r=0 r<=1	27.91649* 4.390356	23.52613* 4.390356*	-0.245373 (0.08252)

Notes: *denote significance at 5%