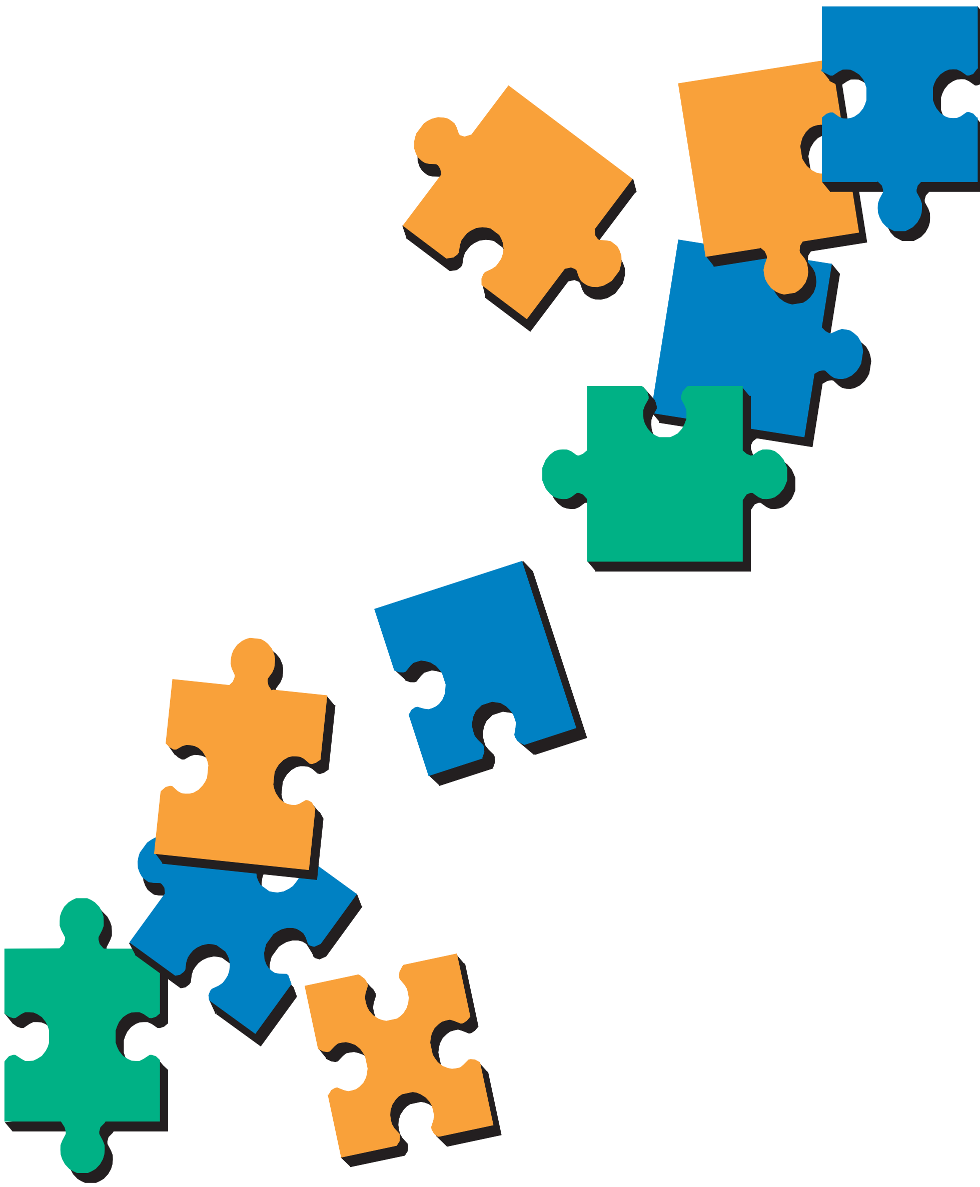
NATURAL GAS MARKET ASSESSMENT

Price Convergence in North American Natural Gas Markets



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Foreword

In granting authorizations for the export of natural gas, the National Energy Board (the "Board") is guided by Part VI of the Act, which requires the Board to have regard to all considerations that appear to it to be relevant. In particular, the Board must satisfy itself that the quantity of gas to be exported does not exceed the surplus remaining after due allowance has been made for the reasonably foreseeable requirements for use in Canada, having regard to the trends in the discovery of gas in Canada.

In July 1987, pursuant to a Review of Natural Gas Surplus Determination Procedures ("GHR-1-87"), the Board implemented a new procedure, known as the Market-Based Procedure ("MBP"). This procedure was founded on the premise that the marketplace would generally operate in such a way that Canadian requirements for natural gas would be met at fair market prices.[1]

The MBP provides that the Board will act in two ways to ensure that natural gas to be licensed for export is surplus to reasonably foreseeable Canadian requirements and that the export is in the public interest: it will hold public hearings to consider applications for licences to export natural gas, and it will monitor Canadian energy supply and demand, and markets, on an ongoing basis.

As a part of its ongoing monitoring, the Board analyzes shorter-term developments in natural gas supply, demand and prices and periodically publishes reports on its findings. The first of these *Natural Gas Market Assessment* ("NGMA") reports was released in October 1988, and four others have been published since then.

As noted, the premise of the MBP is that the market will work to satisfy the needs of Canadians at fair prices. This implies that markets are competitive, there is no abuse of market power, and all buyers have access to gas on equivalent terms and conditions. One purpose of the Board's NGMA reports is to examine whether the market is, in fact, working in this manner.

The objective of this NGMA is to assess the extent to which Canadian and U.S. natural gas markets have become integrated in the post-deregulation era. This assessment is accomplished through a statistical analysis of the price movements in Canadian and U.S. gas markets. The report was prepared by Board staff using the market data sources which are referenced in the body of the text.

Inquiries on this report may be made by telephoning the Board's Information Services at (403) 299-2713. Copies of this report or previous reports are available by contacting the Board at the address or telephone number provided on the back of the title page.

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1 The MBP was modified following subsequent public hearings GHW-4-89 and GHW-1-91.

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Overview

In the mid-1980s, government policy changes and regulatory actions in Canada and the United States effectively deregulated the commodity market for natural gas. The basic assumption behind this initiative was that competitive markets would best serve the interests of both producers and consumers. The Market-Based Procedure, the method by which the Board regulates the long-term export of natural gas, is based on the premise that the market will generally work to satisfy the needs of Canadians at fair prices. This implies that markets are competitive, there is no abuse of monopoly power, and buyers have access to gas on equivalent terms and conditions. One purpose of the Board's NGMA analyses is to examine whether the market is, in fact, working in this manner.

Since then, there has been constant evolution in the North American natural gas market. Initially, producing and consuming regions were not very well integrated and prices across regions were more a reflection of local supply/demand conditions than competitive pressures between regions. However, there are good reasons to believe that industry's response to deregulation has resulted in increasing integration between regional markets. As markets become more integrated, they also become more competitive because a greater number of buyers and sellers can effectively participate in the same market.

The objective of this paper is to determine the extent to which the various regional Canadian and U.S. natural gas markets have become integrated in the post-deregulation era and, by extension, to assess the degree of competition in North American gas markets.

In an integrated market, prices in different regions tend to move in a parallel fashion, with inter-regional price differences reflecting only transportation and transaction costs. This situation is sometimes referred to as "the law of one price". Statistical market evidence that shows that gas prices in different markets move together would provide evidence that the North American natural gas market has become more integrated and, hence, more competitive.

In this paper, we use a statistical analysis of price behaviour in Canadian and U.S. gas markets to assess the degree of "connectedness" between Empress, Alberta and Canadian export points and selected U.S. hubs. The degree of integration between U.S. producing regions is also examined.

Our analysis points to three broad conclusions:

1) On the whole, there has been an increasing degree of integration among North American natural gas markets since price deregulation and the introduction of open access.

2) There is, however, somewhat of a split between eastern and western markets.

3) Alberta's links are stronger with the western U.S. natural gas market than with the eastern U.S. one.

Several factors contributed to the general increase in market integration, including: increased pipeline capacity and additional pipeline interconnections, coupled with the development of market hubs; improved flexibility of access to pipeline transportation services; improved access to market information; and greater trading flexibility which has been facilitated by growing use of electronic bulletin boards and electronic trading systems.

It would not, however, be accurate at this point to claim that there is one North American natural gas market in which the law of one price prevails. The process of integration has not been even across all regions. Our analysis points to an east-west continental split in North American natural gas markets, with the relationship between Permian Basin, San Juan and Rocky Mountain gas prices on the one hand, and the Gulf Coast prices on the other, weakening since about 1993. The recent launching of a new futures contract at Waha, Texas by the Kansas City Board of Trade seems to represent a recognition of this market segmentation.

The strongest single factor which appears to have enhanced the degree of price integration of Alberta with other North American markets has been the growth in export pipeline capacity, particularly in the 1992/1993 period with projects like Iroquois and the Northern Border and Pacific Gas Transmission (PGT) expansions. Prior to these pipeline expansions, intense competition between Alberta producers to get their gas out of the province meant that Empress prices tended to be driven more by intra-Alberta market conditions than by continent-wide supply and demand factors.

The Alberta market, as represented by the Empress price, shows the greatest degree of integration with markets in the western U.S., namely the Rocky Mountain region. The relationship appears weakest with Gulf Coast gas. This seems to confirm the existence of the continental east-west market split, with the Alberta market becoming integrated with the western region. These results lend support to the hypothesis that the recent widening price differentials between Alberta prices and prices at the Henry Hub should be viewed more in the context of the east-west continental market split than in terms of the intra-Alberta supply/demand imbalance. Our analysis also implies that the Waha futures contract provides Canadian producers with a better hedging tool than the traditional New York Mercantile Exchange (NYMEX) contract based on Henry Hub pricing because the basis risk for Canadian producers appears to be correspondingly lower, at least at the present time.

It should be emphasized that this report is not a final statement on the ultimate configuration of North American natural gas markets. Neither the observed east-west split, nor Alberta's closer alignment with the western U.S. regions should be viewed as definitive in the context of natural gas market evolution. Possible future pipeline expansions could increase links between Alberta and the U.S. Northeast, or between western and eastern parts of the U.S., altering gas flows and regional price patterns in the process. Similarly, the fact that Permian gas now flows east suggests that in the future Waha is likely to be influenced more by Gulf Coast pricing, and this may affect Waha's role as a barometer of western region pricing.

Increased market integration has benefited both consumers and producers. The ability of consumers to access least cost supplies and the ability of producers to obtain the best price, regardless of their respective locations, have improved as a result. The increased degree of integration among North American markets also implies that markets have become more competitive, because the effective number of participants on both sides of the market has become greater. As a result, the potential for a dominant market player (or a few dominant market players) to influence prices at any location has diminished.

Chapter One

Introduction

1.1 Background

Government policy changes and subsequent regulatory actions in Canada and the United States in the mid-1980s led to the effective deregulation of the commodity market for natural gas. This was done by the unbundling of pipeline services and the fostering of a competitive market through equal and open access to pipeline transportation capacity by all suppliers and users. Natural gas which was previously sold to local distribution companies as a bundled delivered product at regulated prices was now being sold as a commodity at prices which were freely negotiated between buyers and sellers.

Since the onset of price deregulation, there has been constant evolution in the North American natural gas market. Initially, producing and consuming regions were not very well integrated and prices across regions were more a reflection of local supply/demand conditions than competitive pressures between regions. However, as pipeline interconnections have grown, the speed of information has accelerated, and spot markets have emerged, it is likely that there has been increasing integration between regional markets in the last few years. The extent of natural gas market integration has some important practical implications. Producer access to market opportunities, consumer access to least-cost supplies and the price determination process all depend on the degree to which regional natural gas markets are linked.

1.2 Objective

The objective of this paper is to determine the extent to which the various regional Canadian and U.S. natural gas markets have become integrated in the post-deregulation era. This assessment relies on a statistical analysis of price behaviour in Canadian and U.S. gas markets. Specifically, we examine the price movements at Empress relative to price movements at Canadian export points and selected U.S. hubs. The degree of "connectedness" among U.S. producing regions is also investigated.

In competitive markets, prices in different regions tend to move in a parallel fashion, but with differentials reflecting transportation and other transaction costs. This is sometimes described as the "law of one price". Price differentials which exceed these costs tend to be eliminated as market participants move quickly to take advantage of profit opportunities. Thus, market data that show that prices in different markets move together would provide strong evidence that the North American gas market has become more integrated.

Evidence of strengthening price links between markets would allow one to conclude that prices in any particular spot market are not only the product of local supply/demand conditions but are also influenced by supply/demand conditions in other parts of the continent. The more integrated North American natural gas markets have become, the more competitive they are likely to be because the effective number of participants on both sides of the market is greater. On the other hand, if prices in different parts of the North American network have exhibited varying degrees of connectdness over time, one might wish to explore the causes of these variations in greater depth.

Industry commentators frequently represent Canada to be part of one North American natural gas market. This notion is supported by the recent Canadian LDC contracting practice of using prices on the NYMEX as a pricing reference. The question of the actual degree of connectedness between Alberta and U.S. markets has been of interest to Canadian producers. For example, recently the industry has been concerned about growing price differentials between some U.S. markets and Alberta, and correspondingly low intra-Alberta prices.

Up until now the question of competitiveness of natural gas markets has been explored in the U.S. context, but, to our knowledge, no rigorous attempt has been made in the Canadian context.[2] This report is intended to fill this void. It is also original in that it applies an innovative statistical approach to the subject.

The graphical representation of spot prices in North American basins (Figure 1) suggests that natural gas prices have been quite volatile, exhibiting a seasonal pattern. Even though the prices generally appear to move together, a visual inspection allows us to infer very little, if anything, about the strength of the relationship between prices at different locations. We cannot readily say, for example, which regions are relatively closely linked and whether the strength of these relationships has changed over time. Moreover, in order to shed some light on the question of whether North America comprises one fully integrated natural gas market, one has to weigh the evidence provided by the price data against criteria suggested by economic principles.

An alternative might be to examine price differences between regions (Figure 2). Stability of these differences would indicate that prices in different regions move together. But even here a visual inspection reveals little. Simple data-smoothing techniques, such as rolling averages, which are designed to make data look “tidier” and the underlying trends more manifest, are not appropriate in this context because they obscure short-term market movements which are critical to our investigation. Hence, none of the aforementioned questions can be answered without the use of more refined statistical techniques.

Chapter 2 of this report outlines the underlying theory, methodological approach, and data sources. Chapter 3 presents the results of the analysis and, in chapter 4, we provide our conclusions.

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2 For example, see De Vany and Walls (1993a).

Figure 1: Selected Natural Gas Spot Prices

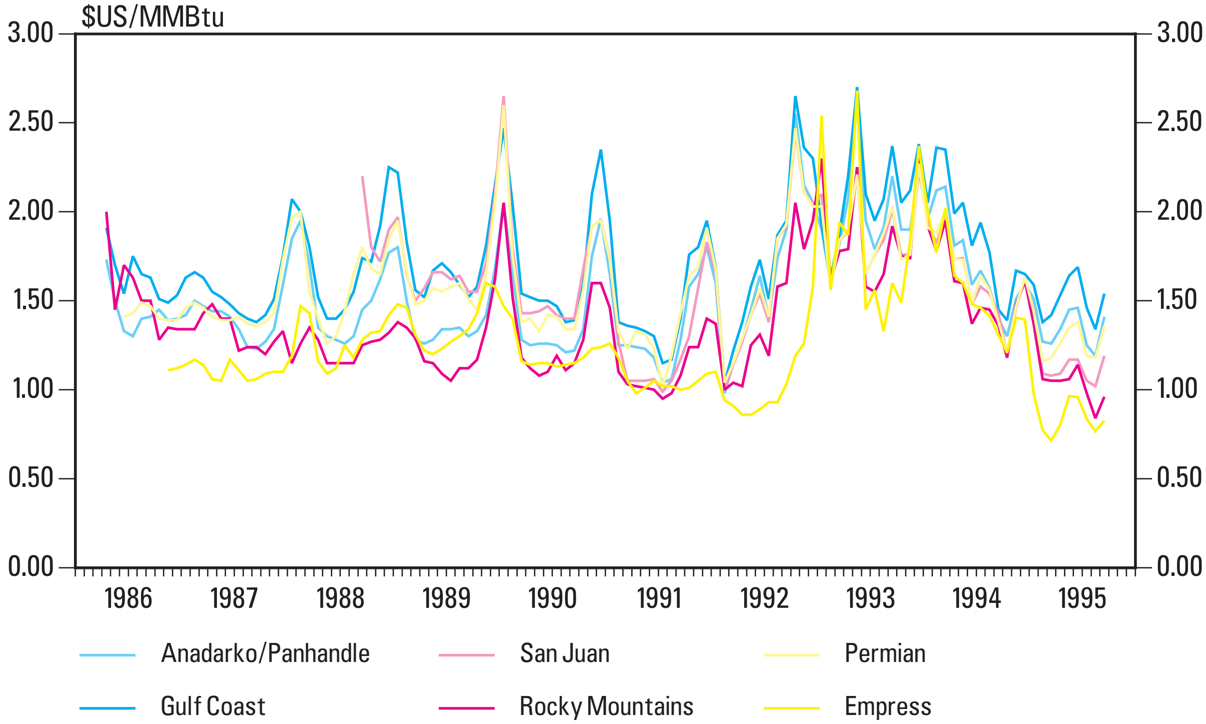
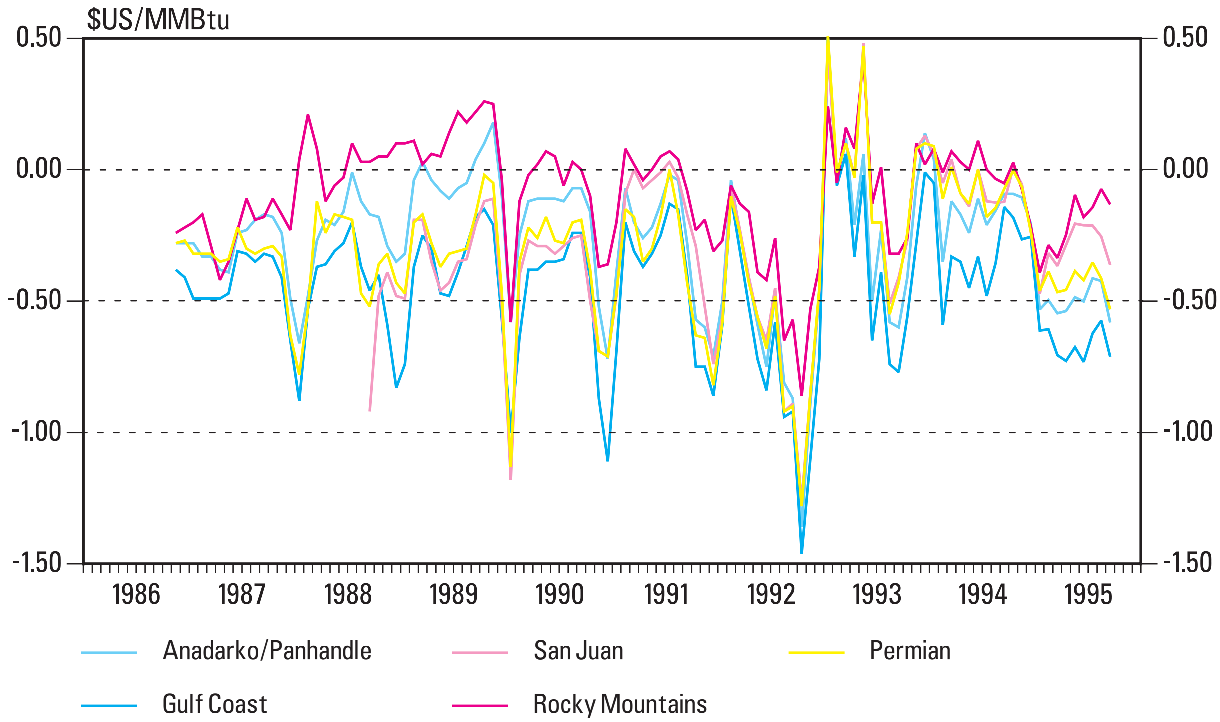


Figure 2: Selected Natural Gas Spot Price Differentials Relative to Empress



Chapter Two

Theory and Statistical Methodology

2.1 Theory

The North American natural gas market consists of a system of producing regions, consuming regions and market hubs, all interconnected by pipelines. The relationships between spot prices at different points within segments of this elaborate infrastructure can provide evidence about market behaviour. If all markets at different locations are integrated into one market, we would expect their prices to be linked and the law of one price to prevail. The extent of a market is traditionally defined as the area within which the price of a good tends to uniformity, with an allowance being made for transportation costs.[3]

Consider, for example, an increase in demand in market A. Initially, the price will rise. This increase will tend to attract additional supplies as buyers and brokers bid up the price. Similarly, prices in other markets will tend to rise because buyers in these markets now must raise their bids to compete for gas supplies which are being diverted to market A. Ultimately, an increase in market demand in market A would cause prices at all locations to rise, other things being equal. While this may seem to be an obvious conclusion, it is worth pointing out that prior to deregulation and open access there was no mechanism to ensure that gas would flow to the highest value markets, or that the lowest cost gas would be sourced first.

The law of one price does not mean that the same price will be charged for a unit of natural gas in all locations. Rather, prices are considered to follow the law of one price if they become equalized up to the cost of transacting so that no profitable arbitrage opportunities remain. In the case of natural gas the difference between prices at two locations would tend to equal the cost of transporting natural gas between these points plus any relevant transaction costs.

In reality, one would seldom find that prices in two places would differ by exactly an amount required to transport gas between them. First, there may be no unique transportation cost, and, second, random shocks to supply and demand may from time to time create divergent price movements. These divergent price movements will usually be limited in size and duration because of the

3 See, for example, Stigler and Sherwin (1985). "If there is a single price (allowing for transportation costs) over a given area, that must mean that either buyers or sellers (or both) can and do consider transactions at any point within the area to be an excellent (in the limit, a perfect) substitute for transactions at other points within the area. Hence the market area embraces the buyers who are willing to deal with any seller, or the sellers who are willing to deal with any buyer, or both." (page 556).

possibility of corrective flows of gas. Consequently, the basic premise remains valid: if we find closely parallel price movements in two locations, we can conclude that the two areas are part of the same market; if the two areas exhibit significant nonparallel price movements, they are likely not part of the same market.

In situations where price differentials no longer reflect the implicit transportation/transaction costs of moving gas between two markets, the differentials will be capturing structural rigidities and market imperfections associated with violations of the law of one price. Nevertheless, the price of gas in one market, denoted as P_j, may still be influenced to some degree by the price in another market, denoted as P_i. The extent of the influence can be investigated through an equation which models the market price at location j as a function of some variant of the transportation/transaction costs, denoted as A_{ij}, and some fraction B of the price in market i. This can be expressed as,

$$P_j = A_{ij} + BP_i \tag{1}$$

Based on the discussion above, the law of one price is a particular case where B is equal to one. This would suggest that the markets are highly integrated in that gas can flow or be arbitraged freely between the two market locations and prices are free to adjust to any extent that equates the price difference with the transportation/transaction costs. **The upshot of this analysis is that a determination as to whether the law of one price holds can be made by a determination as to whether B is equal to, or very close to, a value of one. The closer B is to one, the more integrated are the two market locations.**

2.2 Statistical Methodology

Since the beginning of price deregulation, the natural gas market has been in a constant state of evolution. It is this aspect of market evolution that is at the heart of our investigation of the degree of price integration. In terms of equation 1 above, we investigate how B has been changing through time. Of particular interest is whether it has been steadily moving toward one or fluctuating widely.

Standard statistical approaches such as regression analysis, "rolling" regressions and correlation analysis may seem like useful procedures to assess the value of B. However, they are not well suited for addressing the question of how the value of B has been changing over time since these techniques estimate average relationships for any given time period. In the case of regression analysis the estimates of the intercept and slope of an equation such as 1 are fixed for the whole of the time period under consideration.

THE KALMAN FILTER

The Kalman filter emerged from the engineering literature in 1960 and 1961 as first developed by Kalman (1960) and Kalman and Bucy (1961). The purpose of the Kalman filter for engineers is to determine values for a variable that cannot be directly observed, but for which information exists through related observable variables. These related variables, though having a bearing on the value of the unobserved variable, are often contaminated, or "noisy", containing only partially useful information. The purpose of the Kalman filter is to process, or "filter", this noisy information to obtain precise measurements of the unobserved variable. This is the origin of the "filtering" aspect of the Kalman filter. *The Kalman filter itself is merely a solution method for processing the noisy information related to the unobserved variable*.

The capabilities of this method for statisticians and econometricians began to be explored in the late 1960s and early 1970s – Chow (1984) provides a good review of the literature. This method was adapted to a variety of economic statistical problems that included such aspects as unobservable economic variables, prediction, and time-varying parameters. It is the time-varying parameter approach that is at the heart of our study.

In our study the exact set of coefficients that describe the pricing relationship between gas market locations over time are unknown – A and B in our analysis. These coefficients are time-varying parameters. In our analysis, the Kalman filter processes the spot prices and yields information on the value of the parameters. To illustrate, consider natural gas spot price series that both begin in January 1987 and end in September 1995. With this data at hand, the Kalman filter proceeds in two basic steps. First, suppose that we are interested in generating values for A and B for May 1989. The Kalman filter produces predictions for these parameters by using information for April 1989. In effect, its best guess for May is the value that it generated for April. In the second step, the Kalman filter then processes the information for May and updates its estimates of A and B. In doing so, the filter incorporates its prediction error from the first step. This re-computation of A and B uses not only the prediction error, appropriately weighted, but it also updates additional information concerning the variability (variance and co-variance) of the prediction error. As such, the Kalman filter produces the "best" estimates of A and B for May because it not only incorporates all the information from previous data but uses and weights its prediction error. These two steps are repeated sequentially until all observations have been exhausted.

Since the Kalman filter always produces its estimates by repeatedly "looking back" in the first step and then updating in the second step, it is often referred to as a *recursive solution algorithm*. Herein lies the power of the Kalman filter over other techniques. It is this recursive solution method that produces truly time-varying values of A and B and still fits the statistical criteria of the "best" estimates for A and B. For interested readers, Appendix III provides a more rigorous explanation of the Kalman filter.

In our analysis, the variables A and B of equation 1 are analogous to the intercept and slope of a regression line but are allowed to change through time. A and B are therefore often referred to as *time-varying parameters*. The time-varying nature of A and B can be best evaluated through a statistical approach known as the *Kalman filter*. Appendix II explains the statistical methodology employed in this report, and Appendix III provides a discussion of the Kalman filter and its use. It is not necessary for the reader to have a complete understanding of the Kalman filter in order to review the results of our analysis; the important aspects are the time-varying nature of A and B and that the value of B represents the degree of price integration with the passage of time.

Our study, as well as others which have applied the Kalman filter to the question of the law of one price, use the Kalman filter in such a way that a strict test for the statistical significance of B cannot be applied. Consequently, *a plot of the value of B over time can only lead to a subjective evaluation as to whether or not convergence has occurred*. Theory indicates that in a perfectly integrated market, B should be equal to one and that A should have a value that is equal to the implicit transportation/transaction costs. Simply put, the closer is B to one, the closer is the market to achieving the law of one price; the further is B from one, the more the market is diverging from the law of one price. When B is not equal to one, the law of one price does not hold and all we can conclude about the value of A is that it has an interpretation as being something other than implicit transportation/transaction costs[4].

2.3 Data

The data we use to assess natural gas spot markets are monthly bid-week prices for the major producing North American basins and Canadian export points, as well as beginning-of-the-month prices for several city-gates. All prices are reported in $U.S. per million British Thermal Units (MMBtu). Each price series ends in September 1995 but the starting point for each varies depending on data availability.

We use spot prices because they best reflect market conditions in different parts of the pipeline network. Natural gas has increasingly been traded on a spot basis. Even in cases where sales take place under short- or long-term contracts the pricing provisions often reference a spot market rather than utilizing a price fixed for the length of the contract.

All U.S. natural gas spot prices are drawn from *Inside FERC's Gas Market Report* ("Inside FERC") published by McGraw Hill. The prices we use are the price of gas as of the first day of the month which reflect the prices of contracts for gas to be delivered for a period of thirty days or less during the month.

4 In our analysis, if price convergence has occurred, the specified equation has captured the true structural relationship between prices while the intercept reflects the market's valuation of the implicit transportation/transaction costs. If B does not converge to a value of one, then the intercept term will indicate that the existing equation is inadequate in the sense that it may be mis-specified. This mis-specification could take the form of missing explanatory variables such as regulatory influences or pipeline capacity constraints that are distorting the market pricing relationship. The most important point is that the intercept in this case has no strict interpretation as a monetary value.

The data for Canadian natural gas spot markets come from *Canadian Enerdata Inc.* and cover all of Canada's major natural gas exporting points, as well as the price of gas at Empress, Alberta. Empress prices are typically used to represent an Alberta "border" price. Canadian Enerdata collects its data by export point on a bid-week basis. This makes its information methodologically consistent with the data from Inside FERC. The price data for Empress are slightly different in that the reported price covers all spot contracts negotiated during a given month that call for delivery during the following month. In general, most of the deals at Empress are conducted toward the end of the month, which makes this price series comparable to the bid-week price derived using the Inside FERC methodology. A more detailed description of the data and sources is given in Appendix I.

Ideally, daily data would lend itself to a study such as this. Daily *transaction* prices, rather than *bid* prices, would incorporate changes in market conditions that reflect the "actual" needs of market agents rather than "anticipated" needs as in the case for bid prices. In addition, daily prices at various market centres would be reflecting conditions in the market place at approximately the same time. Monthly bid-week prices are not necessarily set at exactly the same time. This may lead to situations where prices incorporate different market conditions at different times of the same week. However, daily price series do not exist for Canadian markets and some U.S. markets during the late 1980s. Given the consistency of data collection for bid-week prices and the longer available history, we chose to use these prices. A recent work by Brinkmann and Rabinovitch (1995) also uses bid-week prices while investigating issues similar to this study.

Figure 3: Selected North American Natural Gas Spot Markets

Canadian Spot Markets

A = Empress, Alberta
B = Huntingdon, British Columbia
C = Kingsgate, British Columbia
D = Monchy, Saskatchewan
E = Emerson, Manitoba
F = Iroquois, Ontario

U.S. Spot Markets

1 = ANR Pipeline Co.-Oklahoma
2 = ANR Pipeline Co.-Gulf Offshore
3 = Colorado Interstate Gas Co.-Rocky Mountains
4 = Columbia Gulf Transmission Co.-Louisiana
5 = El Paso Natural Gas Co.-Anadarko
6 = El Paso Natural Gas Co.-Permian
7 = El Paso Natural Gas Co.-San Juan
8 = Kern River Gas Transmission Co.-Wyoming
9 = Natural Gas Pipeline Co. of America-Oklahoma
10 = Natural Gas Pipeline Co. of America-Louisiana
11 = Natural Gas Pipeline Co. of America-Texas Gulf Coast
12 = Northern Natural Gas Co.-Texas/Oklahoma/Kansas
13 = Northern Natural Gas Co.-Ventura
14 = Northwest Pipeline Corp.-Rocky Mountains
15 = Panhandle Eastern Pipeline Co.-Texas/Oklahoma
16 = Transwestern Pipeline Co.-Permian
17 = Chicago
18 = New York City

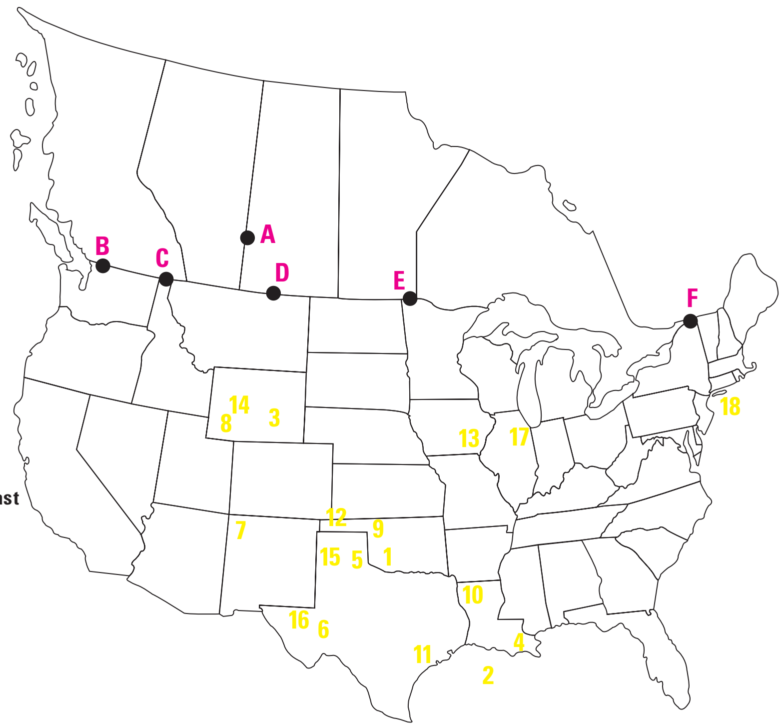
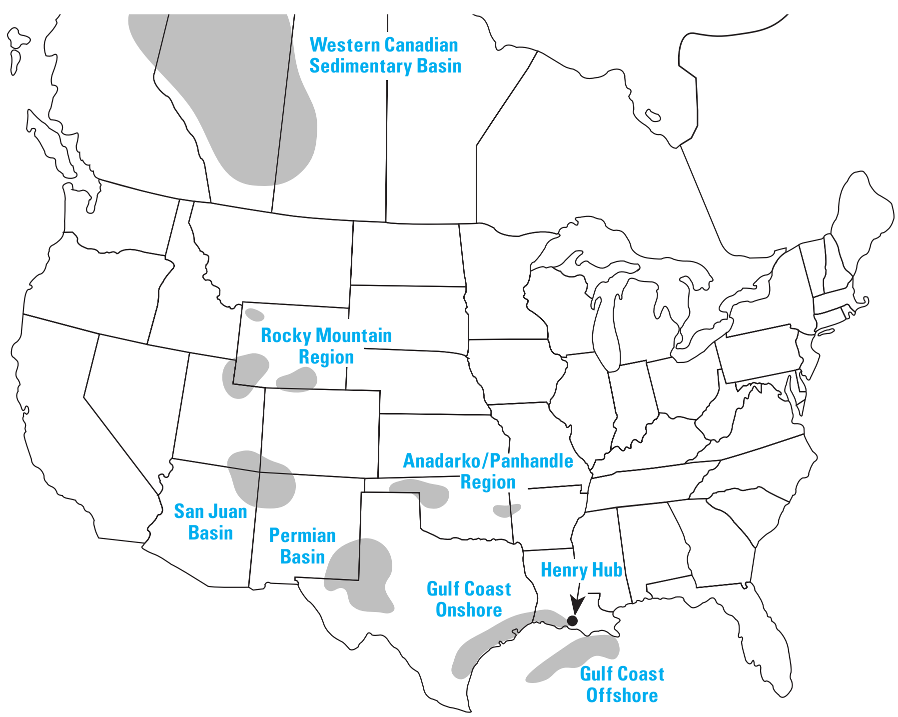


Figure 4: Selected Natural Gas Producing Basins of North America



Chapter Three

Analysis of the Results

Our results are presented in two stages. First, we consider pricing points relative to Empress, Alberta. Empress was chosen because it is representative of the pricing activity for the Alberta market and an active spot market has been in existence at this location since late 1986. Empress prices are analyzed in relationship to prices at the following locations:

1. Canadian export points
2. Hubs in the U.S. producing regions (Gulf Coast, Permian, Anadarko/Panhandle, Rocky Mountain and San Juan)
3. Ventura and city-gate prices at Chicago and New York

The second part of the analysis considers several pricing points in the United States vis-a-vis other U.S. pricing points to present an assessment of the pattern of price integration within the U.S.[5] See Figures 3 and 4 for reference maps.

For all figures used in the analysis below we have deleted the first 12 values of B generated by the Kalman filter. This allows for one complete year of data to be passed through the filter and eliminates any volatility in B which may not be indicative of the underlying relationship between prices.

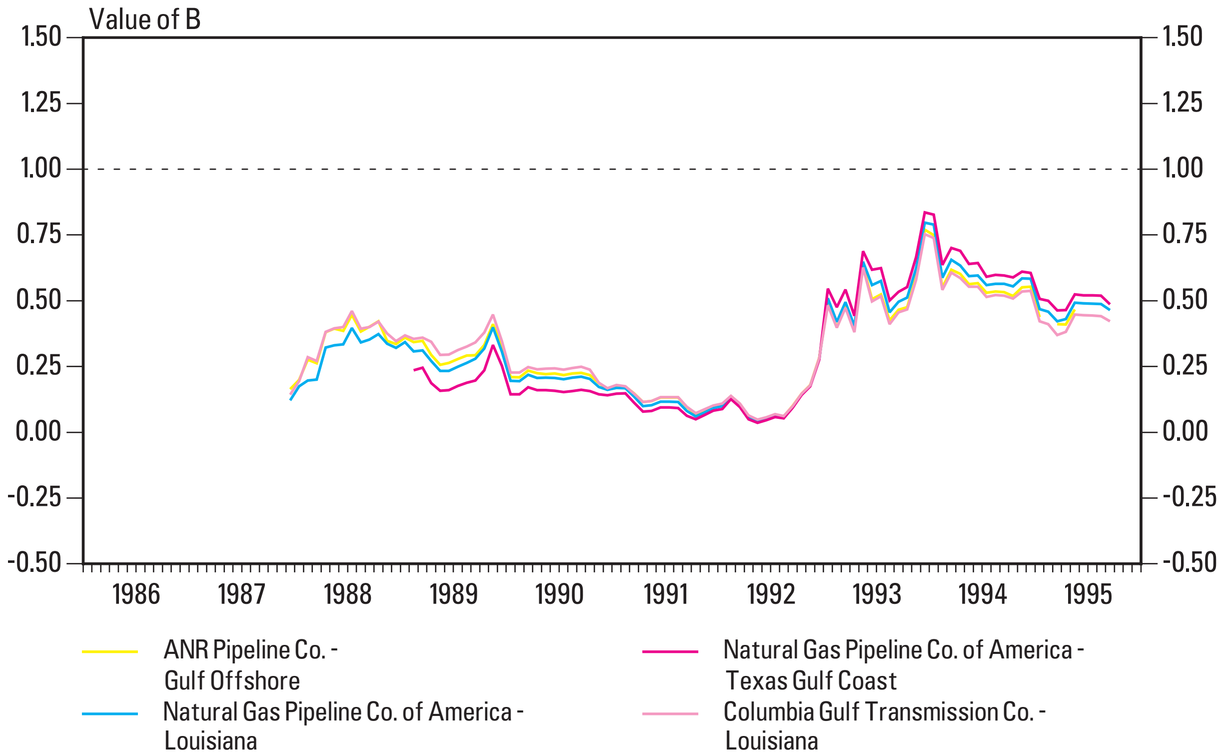
3.1 Natural Gas Spot Price Integration at Empress

Figures 5 to 11 reflect the degree of integration of Empress prices with other primary producing basins in North America and with Canadian export points and U.S. city-gates[6]. The first conclusion that one can draw from these figures is the broad consistency of the pattern of the time-varying parameter B. However, its proximity to the line drawn at the value of one is variable depending on the region under consideration. Each region is discussed in more detail below.

5 In total, we considered 30 individual spot price series covering the United States and Canada. Allowing each price series to be a dependent (left-hand side) variable in equation 1 results in 870 time-varying paths for B that can be plotted. We have chosen combinations that reflect a Canadian perspective on the North American market as well as those U.S. pipelines that allow the analysis to be as geographically far-reaching as possible while keeping the study to a manageable length.

6 We also performed a time-varying analysis using prices for the AECO-C hub. Enerdata provides information for this price series back to March 1993. For this reason, we performed two AECO-C analyses that consisted of the AECO-C data alone and a splice of the AECO-C data with the Empress data. In both cases, the results were qualitatively and quantitatively similar to the results shown for Empress.

Figure 5: Time-Varying Price Integration of Empress with the U.S. Gulf Coast



Empress versus the U.S. Gulf Coast

In Figure 5 Empress is evaluated with respect to the U.S. Gulf Coast region. Receipt prices for the four pipeline companies shown in Figure 5 were chosen as being indicative of the Gulf Coast region7. The price series for Columbia Gulf Transmission Co. was used as a proxy for the Henry Hub.

As illustrated in Figure 5, the degree of price integration of Empress with the Gulf Coast has been modest at best. From late 1989 to the end of 1992, Empress prices essentially decoupled from Gulf Coast prices. This was likely due to the emerging over-supply in the Alberta market combined with a lack of sufficient take-away capacity from Alberta. By the end of 1992, prices in Alberta had become so weak and unresponsive to pricing conditions in the Gulf Coast, that there was no price integration whatsoever.

However, within a few months of the weakest point for the Alberta/Gulf Coast pricing relationship, there was a dramatic reversal with a peak in the strength of the relationship at the beginning of 1994. The degree of price integration becomes stronger but B does not reach one. Based on the data to date, the Alberta market certainly appears to be more integrated with the Gulf Coast than it was in the late 1980s and early 1990s but the relationship has not reached the point where one could assert that the two markets are perfectly integrated.

7 Although data exist for other major interstate pipeline firms in the Gulf Coast region, the results for these price series indicated a very similar pattern *and* magnitude of price integration.

A number of events can explain this sudden shift in pricing relationships. First, the early winter of 1992/93 was very cold in Alberta. This cold weather contributed to a number of price spikes at Empress as gas that was destined for export from the province was "back-hauled" and used in Alberta. This stronger internal demand made prices at Empress more responsive and more closely integrated with demand conditions elsewhere in North America.

Second, the early winter of 1993/94 in the eastern half of North America was exceptionally cold. This cold placed strong demands on Alberta gas which, combined with the previous cold Alberta winter, helped to largely alleviate the over-supply at Empress. In addition, major pipeline expansions helped to increase the number of outlets and volumes for Alberta gas over this time period: the Iroquois pipeline (November 1992) and its subsequent expansions; expansion of Northern Border's export capacity through Monchy (November 1992); and the expansion of the Pacific Gas Transmission pipeline to California (November 1993). These three projects added about 700 billion cubic feet per year of export capacity for Canadian gas. Clearly, Alberta natural gas was no longer "trapped" in the province, driving down internal prices, but could move without pipeline constraint to extra-provincial markets. In effect, Alberta for a time became more "plugged-in" to the North American gas transmission grid.

The reduction in the degree of price integration that has occurred since 1993 coincides with the developing east-west continental market split. In the prior periods, Alberta gas and Gulf Coast gas shared common markets in the Midwest and the Northeast. The excess supplies developing in the western U.S. have replaced some Gulf Coast gas in Midwestern markets, whereas incremental Alberta gas has tended to flow to California following the PGT expansion in November 1993.

In summary, there appear to be two very distinct periods in the price integration of Empress with the Gulf Coast: pre-1993 and then forward from the beginning of 1993. For reasons outlined above, the degree of price integration between Empress and the Gulf Coast has increased, but the relationship remains less than perfect.

Empress versus the Permian Basin

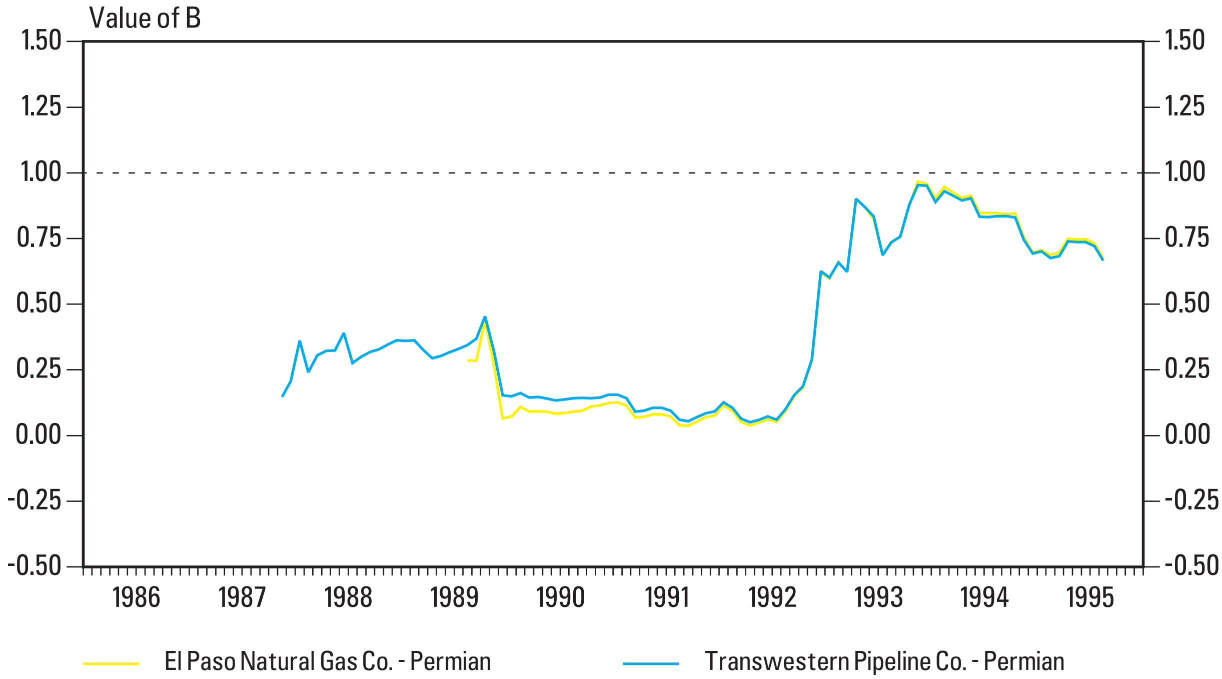
In **Figure 6** we consider the relationship between Empress and two major inter-state pipeline companies that move gas from the Permian basin. Again, we see a very similar pattern to that shown in Figure 5 – the pricing relationship is weak to non-existent (B approaches zero) by the end of 1992. However, the reversal in the time-varying parameter is even larger and B comes close to one by the beginning of 1994.

Empress versus the Anadarko/Panhandle Region

The pattern of Figure 6 is repeated in **Figure 7** which details the relationship of pricing at Empress with pipeline companies in the Anadarko/Panhandle region (Texas/Oklahoma/Kansas)[8]. A period of

8 The plotted line for El Paso Natural Gas ends in February 1995. This reflects the fact that prices for gas have been so weak in recent months in the western United States that no gas is flowing west on El Paso's line from the Anadarko.

Figure 6: Time-Varying Price Integration of Empress with the Permian Basin



weakness is followed by a sharp reversal at the end of 1992 as B approaches one, and then some weakness again emerges. However, this region becomes and remains more closely linked with Empress than the Gulf Coast region.

Empress versus the Rocky Mountain/San Juan Regions

The relationship between Empress and the Rocky Mountain region and the San Juan basin is illustrated in **Figure 8**. This figure presents some compelling evidence for the emergence of the law of one price between the market hubs. After showing some price integration with Alberta in the late 1980s (specifically, Colorado Interstate and Northwest Pipeline), this relationship deteriorated during the early 1990s, although it did not become as weak as that seen in the Gulf Coast and Anadarko/Panhandle regions. With the increase in prices in 1993, Colorado Interstate and Northwest Pipeline become almost perfectly integrated with Empress for a period of about 18 months (May 1993 to October 1994). The two other pipelines also show much closer integration with Empress during this time. Given the evidence from the two cases of Colorado Interstate and Northwest Pipeline, we could conjecture that perfect, or near perfect price integration, existed between Empress and the Rocky Mountain producing region.

Figure 7: Time-Varying Price Integration of Empress with the Anadarko/Panhandle Region

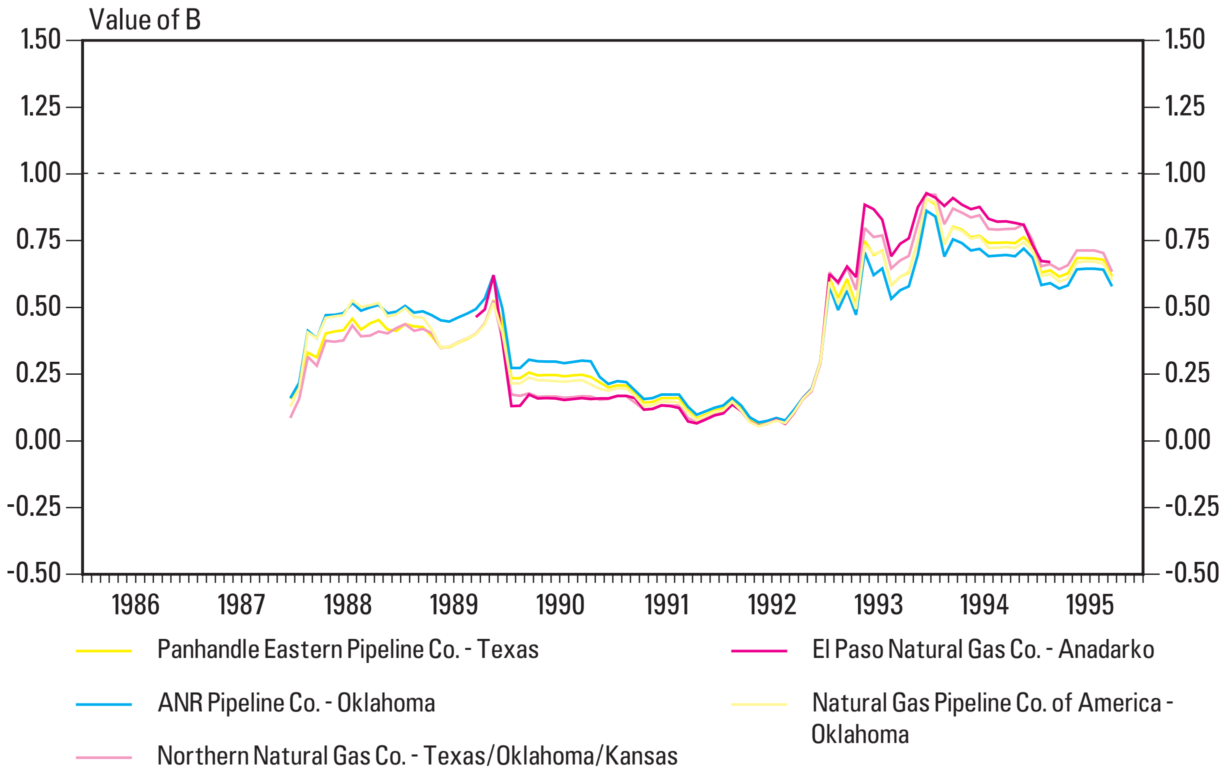
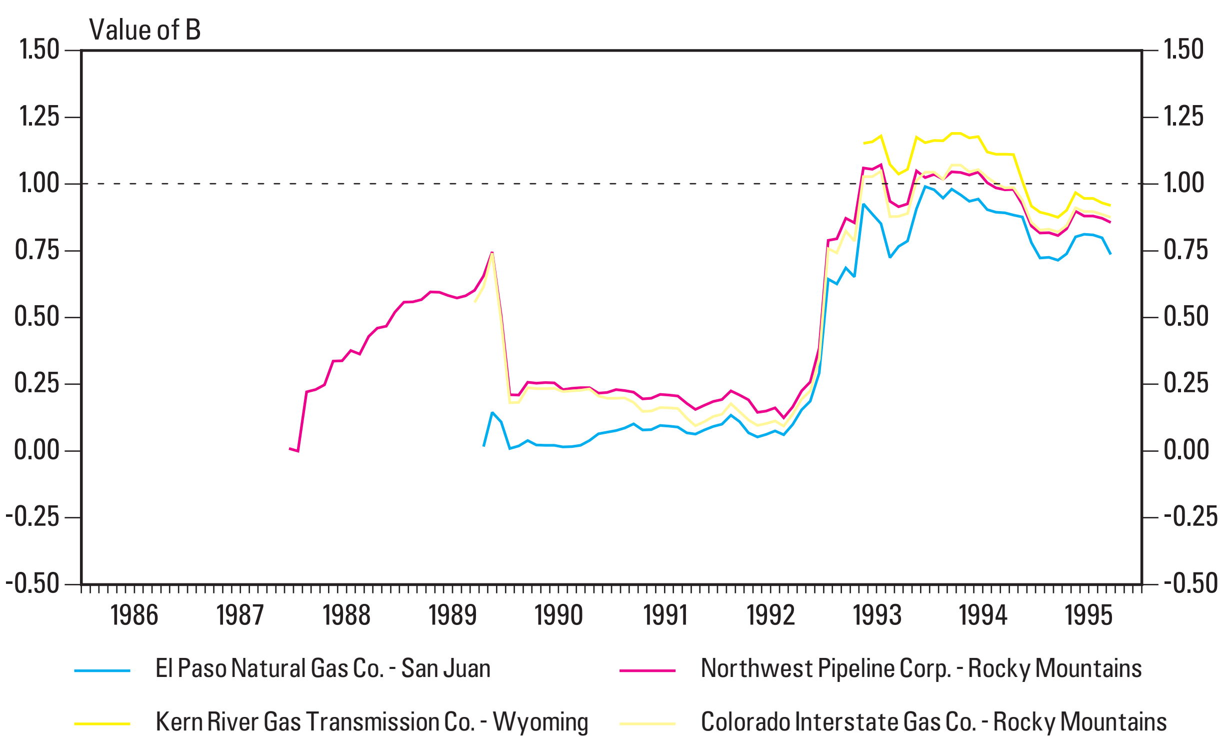


Figure 8: Time-Varying Price Integration of Empress with the Rocky Mountain/San Juan Regions

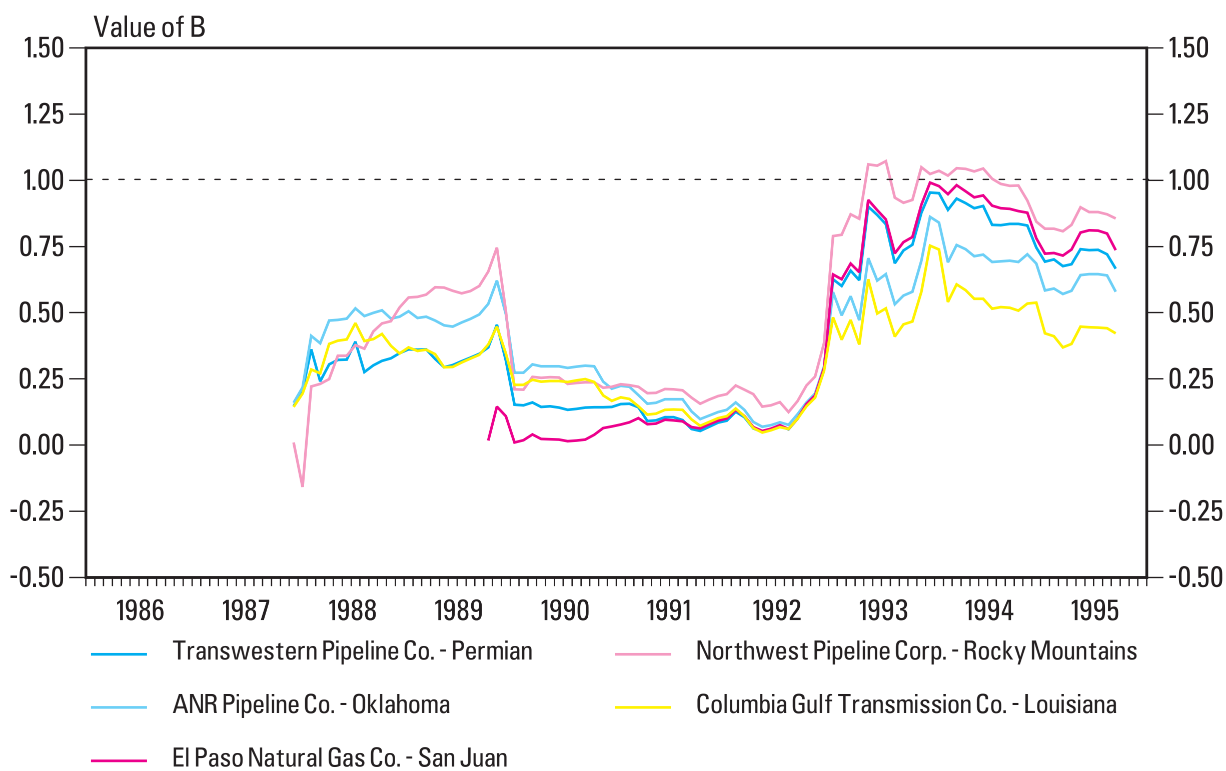


Empress versus Selected North American Basins

In **Figure 9** we plot one time-varying path from each of the regions previously covered in Figures 5 to 8. When viewed together in Figure 9, the time-varying price integration of Empress with the rest of North America becomes much more distinct. Clearly, there is a geographical bias in the degree of Empress price integration. The further away is a pricing region, the less tightly linked it is with Empress. For example, producing regions such as the Rocky Mountain, Permian and San Juan basins, with which Alberta gas is more likely to compete, show a greater degree of price integration. Gas that comes from the Panhandle/Anadarko and Gulf Coast regions show a weaker degree of price integration.

The results shown in Figure 9 are suggestive of an east/west dichotomy in gas pricing. The lack of available gas pipeline transportation from western producing basins to the larger consuming markets of the east has possibly resulted in an over-supply of gas in the western half of North America. Although this is not a new revelation, our results do present empirical evidence which supports the growing gas industry opinion of a pricing split in North American natural gas markets. This industry concern has been the stimulus for the new Western Natural Gas Futures Contract that began trading in August at the Kansas City Board of Trade. The Western Natural Gas Futures Contract calls for delivery of gas to the Waha hub in the Permian basin, a basin which is more closely linked to Empress than the alternate NYMEX futures delivery point at the Henry Hub (proxied by Columbia Gulf Transmission Co.). The stronger link suggests that, at the present time, Canadian gas market

Figure 9: Time-Varying Price Integration of Empress with Selected North American Basins



participants may have a better hedging tool in the form of the Kansas City contract because a stronger link would imply a lower basis risk[9].

Empress versus U.S. City-Gates and Ventura

In **Figure 10**, we consider how B changes through time as the "consuming" market moves further away from Empress. This figure shows the New York City and Chicago city-gate price relationships with Empress as well as Ventura, a major transfer point for Alberta gas that is shipped to the U.S. Midwest. A similar pattern emerges for these "consuming" markets as was seen with the producing regions. Ventura is more closely integrated with Empress than Chicago and New York City. This may reflect the fact that Alberta gas has a larger share of the market at Ventura than at Chicago and New York City. As a result, Alberta gas would play a larger role in pricing relationships at Ventura than it would at the city-gates. Once gas moves away from Ventura towards eastern consuming markets, price integration becomes weaker.

Empress versus Canadian Export Points

In **Figure 11** we illustrate the strength of price integration between the Canadian export points of Huntingdon, Kingsgate, Monchy, Emerson, and Iroquois with Empress[10]. It may seem surprising to see the same pattern of price integration as was exhibited with the producing and consuming regions. However, one must bear in mind the nature of the price at Empress – it is the price of gas before it leaves Alberta. Under conditions of tight export capacity from the province, gas prices would become depressed reflecting an over-supply within the province. Again we can see, in general, that distance has some bearing on the degree of price integration. Although price integration is rather strong in some cases (Huntingdon and Monchy) the relationship is more modest with others[11].

Overall, the results suggest that Empress has become much more integrated with the North American natural gas market in recent years. This likely reflects the presence of greater export capacity and stronger demand conditions that emerged in 1992-94. Although the relationships shown in figures 5 to 11 cannot be said to reflect the law of one price, except in particular cases, the figures do suggest that Empress has become more responsive to a broader and more diverse set of market conditions than existed in the late 1980s and early 1990s. Furthermore, there is evidence that

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9 "Basis" traditionally means the difference between the cash price at the actual point of a gas sale and the futures price (for example, the price of the NYMEX futures contract is based on deliveries at Henry Hub). An Alberta producer selling gas at Empress may protect himself against the risk of a general market decline by selling NYMEX futures. However, he still faces "basis risk", i.e. the risk that the Empress spot price and the NYMEX futures price will not move in tandem. Sometimes "basis" also refers to differences between spot prices in different locations – this is equivalent to the term "aftermarket basis".

10 For the most part, Canadian export points do not serve as trading points, i.e. points at which gas is traded and prices are quoted. Thus, prices published for the export points tend to be derived from other market price data rather than representing independent data series. In that sense, the inclusion of export points here serves as a proxy for those markets where Canadian gas ultimately flows.

11 We would expect the pricing relationship with Kingsgate to more closely follow the path of Huntingdon. The "gap" in the plotted line corresponds to the time when the NEB and the Alberta government restricted new spot sales of gas to California. This lack of data points likely contaminates the relationship making it appear to be weaker than it actually is.

Figure 10: Time-Varying Price Integration of Empress with U.S. City-Gates and Ventura

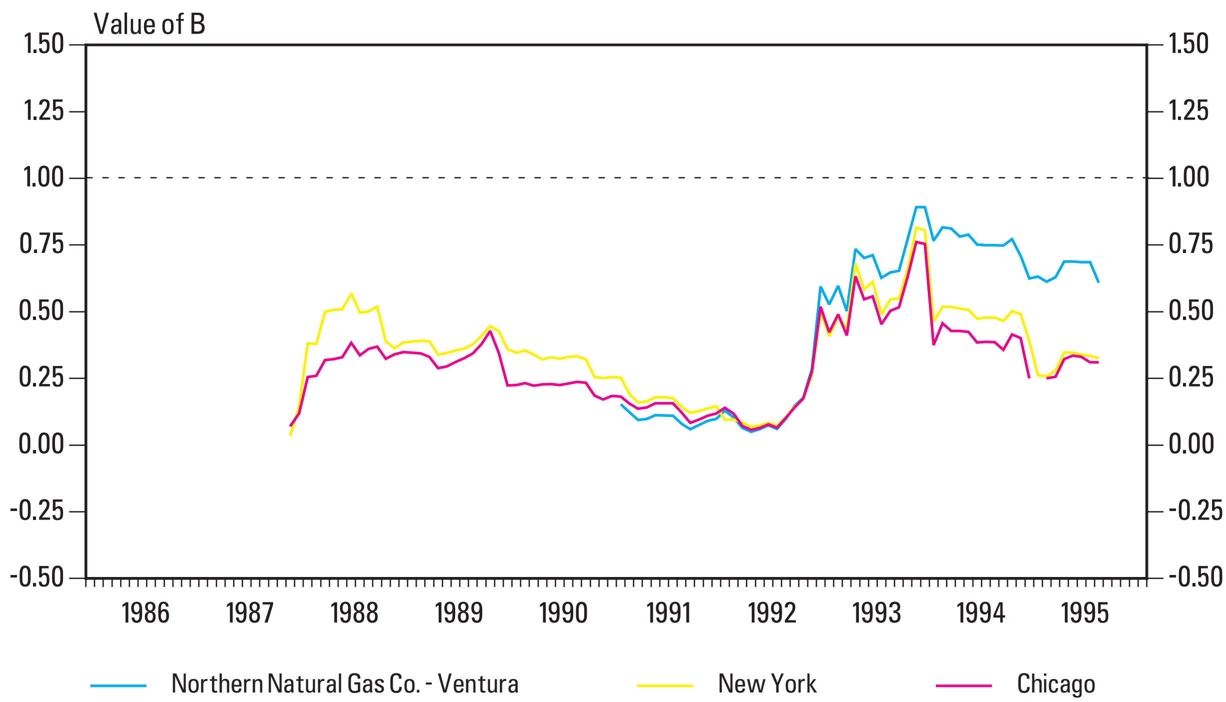
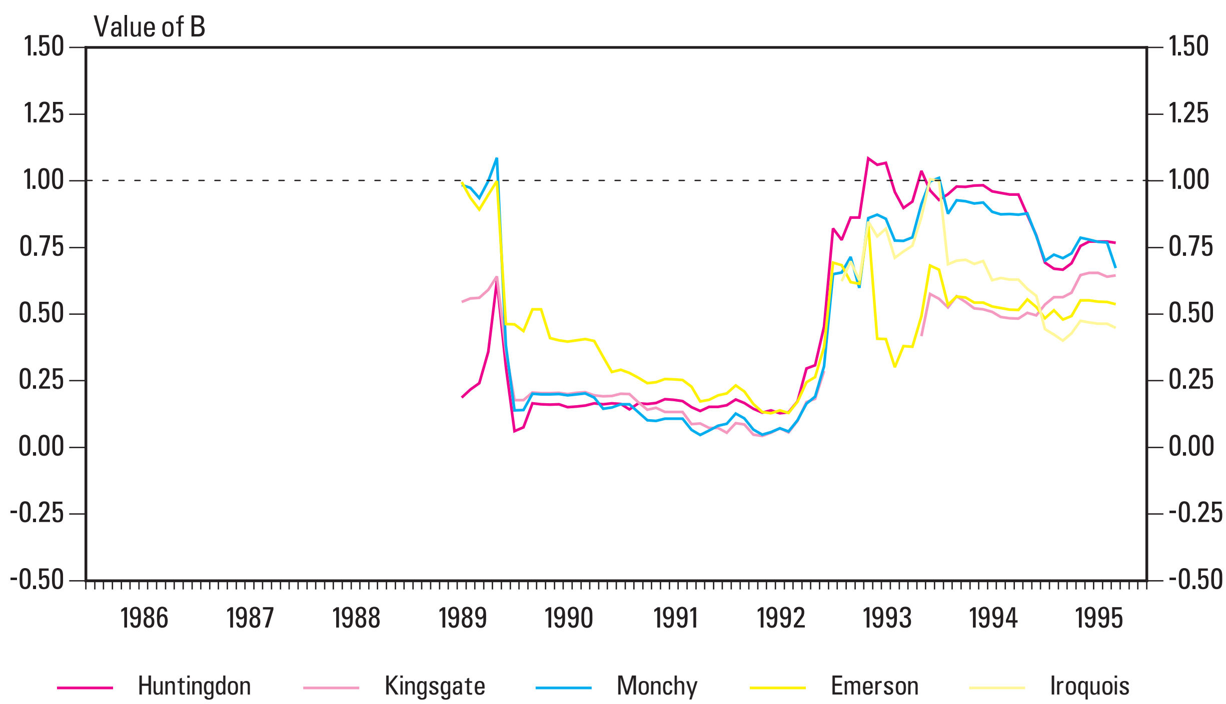


Figure 11: Time-Varying Price Integration of Empress with Canadian Export Points



suggests an east-west dichotomy in pricing in that Empress appears to be more strongly linked with western producing basins than with eastern producing markets such as the Henry Hub, upon which the NYMEX futures contract is based.

3.2 Natural Gas Spot Price Integration within the United States

The degree of price integration within the United States is illustrated in **Figures 12 to 16** by comparing and contrasting those regions that were presented as part of the Empress analysis: Gulf Coast (Henry Hub – proxied by Columbia Gulf Transmission Co.), Anadarko/Panhandle (ANR Pipeline Co. – Oklahoma), Permian basin (Transwestern Pipeline Co.), San Juan basin (El Paso Natural Gas Co.), and the Rocky Mountains (Northwest Pipeline Corp.).

In choosing the five price series above this means that there are twenty possible combinations of the time-varying parameter B that could be plotted. However, we have eliminated those combinations where the dependent and independent price variables would simply "exchange places" in equation 1. This avoids unnecessary overlap of results and helps to keep the analysis to a minimum. For comparison, a figure for each region also includes the parameter B for another pipeline in the same region. Thus, Figure 12 shows the pricing at Henry Hub (Columbia Gulf Transmission Co.) in relationship to the other five producing regions plus relative to ANR Pipeline in the Gulf Offshore. Figure 13 shows the pricing at Anadarko/Panhandle (ANR Pipeline – Oklahoma) relative to the other remaining producing regions (i.e., minus the Gulf Coast) plus relative to another pipeline in the Anadarko/Panhandle region (Panhandle Eastern), etc. The last figure in the series, Figure 16, plots the relationship between two pipelines in the Rocky Mountain region – Northwest Pipeline Corp. and Colorado Interstate Gas Co.

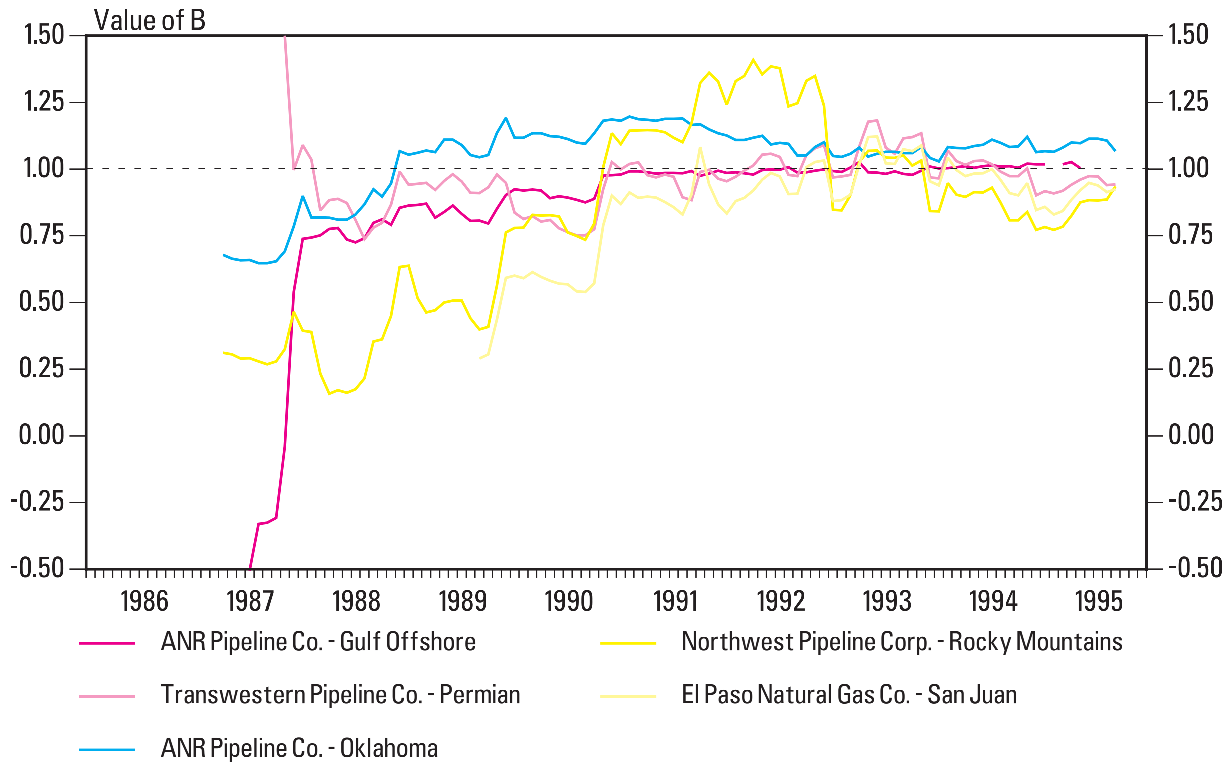
Gulf Coast Region

In **Figure 12** we examine the time-varying price integration of the Gulf Coast. In this case, the Gulf Coast is represented by our Henry Hub proxy. Though the time-varying price integration is tighter than we saw with Empress, there is again, a general geographical distribution in the degree of price integration – the further one moves from the Gulf Coast, the less tight and more volatile is the price integration. For example, ANR's facilities in the Gulf Offshore area illustrate a compelling example of the law of one price. From January 1991 onward, the value of B holds almost exactly at one. This result is not too surprising, but is indicative of the degree of competition and efficiency of price response in the Gulf region. However, other regions, though B has values that are close to one, still have not settled down to a path that could be deemed consistent with a convergence to the law of one price. This is clearly demonstrated by the volatile time-varying path for the Rocky Mountain region (Northwest Pipeline Corp.).

Anadarko/Panhandle Region

Price integration of the Anadarko/Panhandle region is shown in **Figure 13**. Again, we see a pattern similar to that of Figure 12 in which the degree of price integration appears to be generally

Figure 12: Time-Varying Price Integration of the Gulf Coast with Selected U.S. Producing Regions



increasing with the passage of time. In these results, the Permian and San Juan basins show similar paths of volatility as was seen for the Gulf Coast region, but their strength of price integration is less by the end of the sample. However, what is interesting to note, is the very similar degree of price integration that the Permian, San Juan and Rocky Mountains regions have with each other. Conversely, near perfect price integration has existed for Panhandle Eastern's pricing points in this region since the beginning of 1991 – clear evidence for the existence of the law of one price.

Permian Basin

Turning to the Permian basin in **Figure 14** we see further evidence for the close integration between the western producing basins. As expected, El Paso's Permian facilities have near perfect price integration given its location in the same basin. In addition, El Paso's companion facilities in the San Juan basin, have shown very clear price convergence. The Rocky Mountains region has a similar but stronger degree of price integration with the Permian basin than was shown for its relationship with the Gulf Coast in Figure 12; furthermore, the relationship is much more stable.

San Juan Basin and the Rocky Mountains

In **Figures 15 and 16** we present results for the remaining two regions: the San Juan basin and the Rocky Mountains. In **Figure 15** we see a short period of time (August 1992 to January 1994) where

Figure 13: Time-Varying Price Integration of the Anadarko/Panhandle Region with Selected U.S. Producing Regions

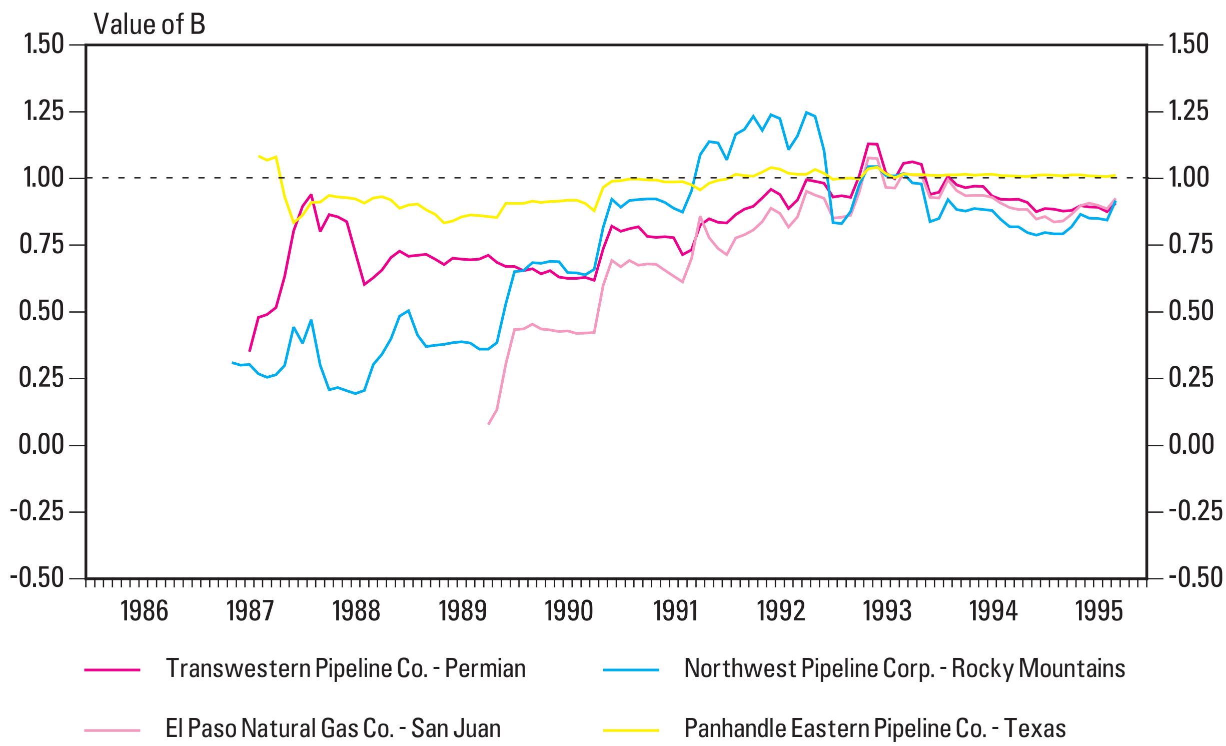
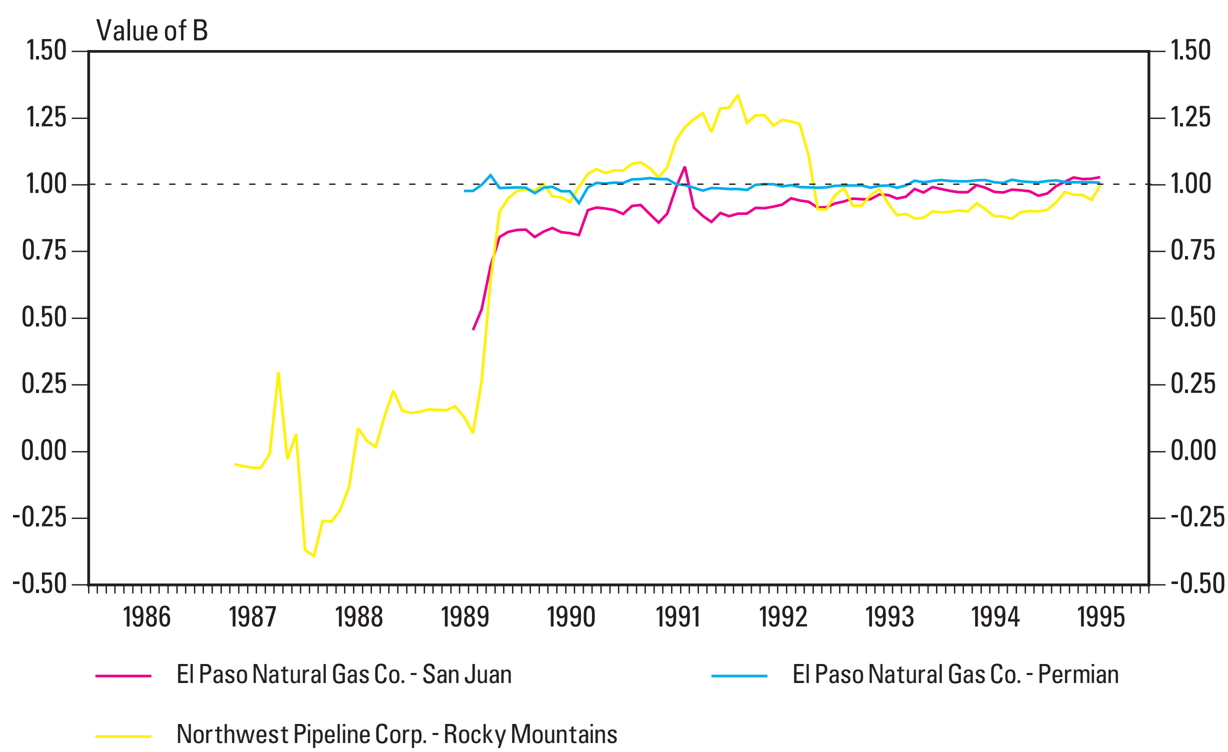


Figure 14: Time-Varying Price Integration of the Permian Basin with Selected U.S. Producing Regions



the Permian basin was near perfectly integrated with the San Juan basin; except for the last few months of observations, this relationship has remained very strong. The relationship between the Permian basin and the Rocky Mountains, though showing some wide swings in the value of B, is less volatile than relationships shown in the previous figures; there is stronger evidence of convergence to a more stable but still imperfect relationship. With our regional pricing combinations exhausted, we consider a single pricing relationship in the Rocky Mountain region – Northwest Pipeline Corp. versus Colorado Interstate Gas Co. in **Figure 16**. This figure allows us to consider how well prices from the same producing region track each other. In this case, there has been a clear and gradual movement to price convergence. The relationship has been very stable since the beginning of 1994 and remains at a value (1.04) that is very close to the law of one price.

Overall, a consistent pattern appears to emerge from the previous figures. There has been a general convergence of the time-varying parameter towards one for all regions. Moreover, in some cases, there is very compelling evidence that the law of one price has emerged and continues to hold for particular pipelines in certain regions. However, the further one moves from the Gulf Coast, the less integrated are the producing basins of the western U.S. with this region; western basins appear to be more closely integrated with each other than with the Gulf Coast.

Figure 15: Time-Varying Price Integration of the San Juan Basin with Selected U.S. Producing Regions

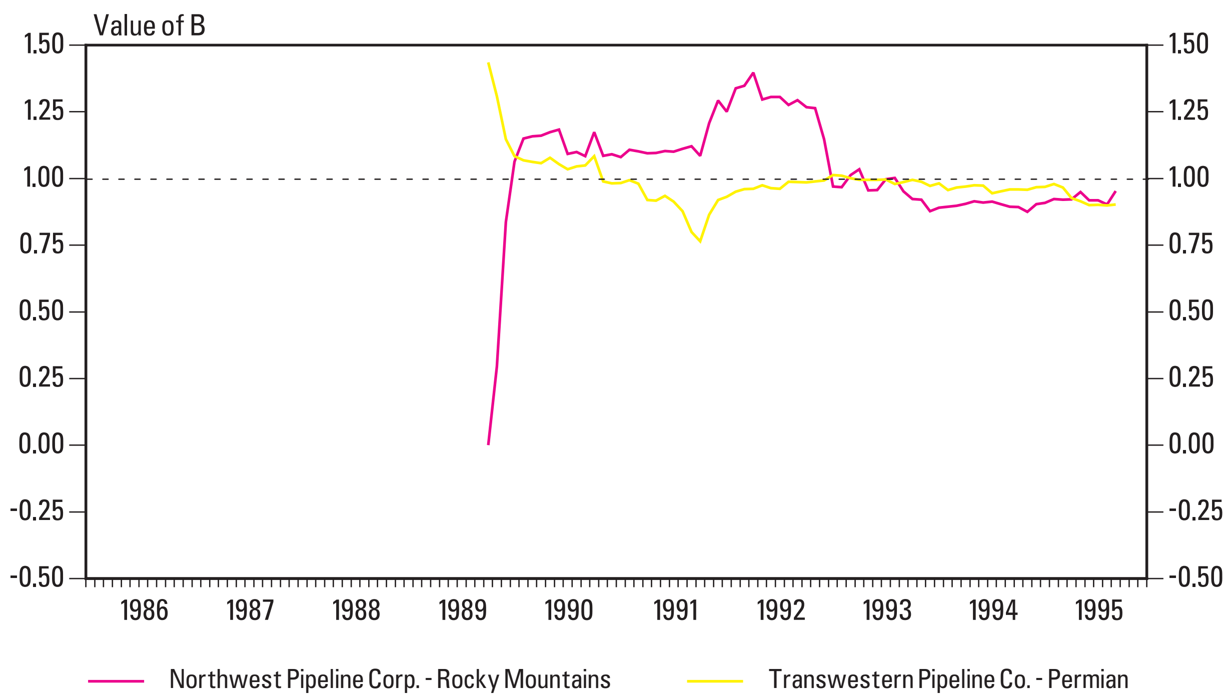
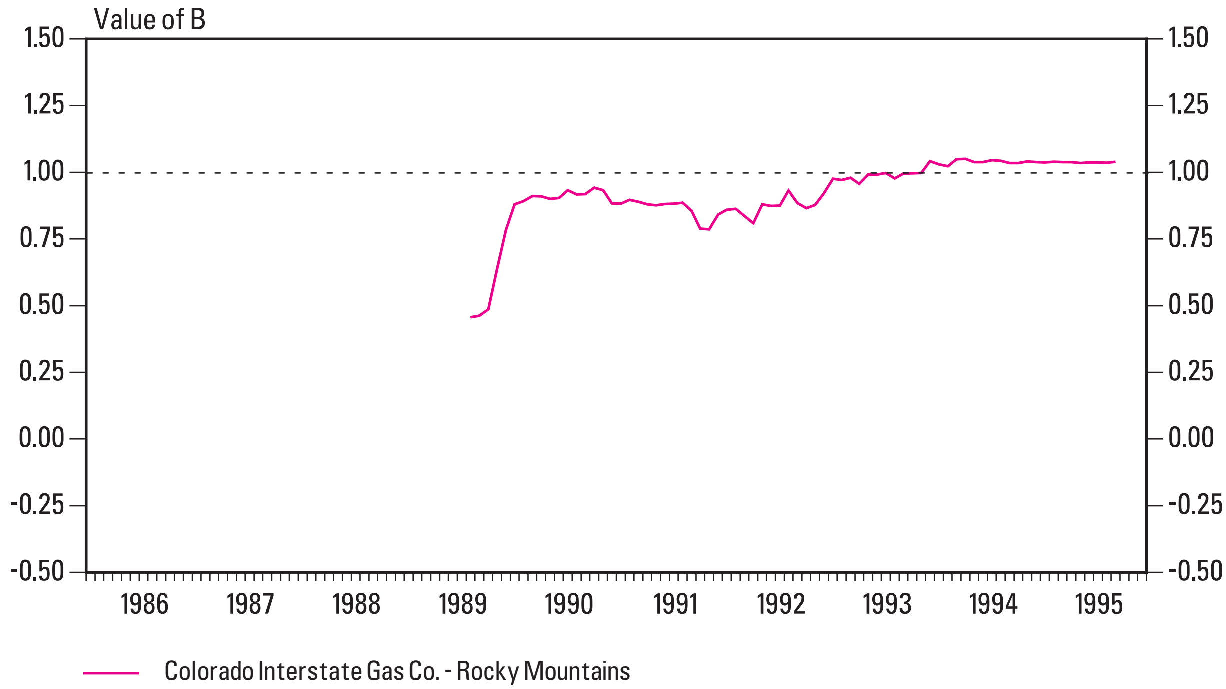


Figure 16: Time-Varying Price Integration between Northwest Pipeline Corp. and Colorado Interstate Gas Co.



Chapter Four

Conclusions

The results of our analysis point to three broad conclusions:

- on the whole, there has been an increasing degree of integration among North American natural gas markets since price deregulation and the introduction of open access;
- there is, however, somewhat of a split between the eastern and western markets; and
- Alberta's links are stronger with the western U.S. natural gas market than with the eastern U.S. natural gas market.

Several important factors can be identified which have improved the efficiency and flexibility of North American markets. These include: the establishment of more market-oriented regulatory regimes (price deregulation and the introduction of open access); growth in market-responsive transportation services; the greater role played by storage; the use of electronic data exchange in commodity trading and price hedging; the use of electronic bulletin boards in the provision of transportation services; and the development of market hubs.

Nevertheless, it would not be accurate to talk at this point about a North American market in which the law of one price prevails. The evidence presented here points to the east-west market split, which appears to have widened since 1993. The rapid development of new supplies in the San Juan basin and in the Northern Rocky Mountain region, combined with additional deliveries of Canadian gas via the expanded PGT system, has exacerbated oversupply conditions in the western part of the continent. This has led to a major change in traditional transportation patterns. Permian gas is now flowing east, San Juan gas has replaced Permian gas as the swing supply for the California market, and Gulf Coast spot gas is being pushed from some of its traditional markets in the Midwest. The recent launching of a new futures contract at Waha, Texas by the Kansas City Board of Trade appears to recognize this market segmentation.

The strongest single factor which appears to have enhanced the degree of integration of **Alberta** with other North American markets has been the growth in export pipeline capacity, particularly over the 1992/1993 period with projects like Iroquois and the Northern Border and PGT expansions. Prior to these pipeline expansions intense competition between Alberta producers to get their gas out of the province meant that the price at Empress tended to be driven more by local Alberta conditions than by continent-wide supply and demand factors.

The Alberta market shows the greatest degree of integration with markets in the western United States, namely with Rocky Mountain gas. The relationship is weakest with Gulf Coast gas, reflecting the continental east-west market split. This result sheds new light on widening NYMEX/Alberta spot price differentials which have been of major concern to Canadian natural gas producers over the past year. Frequently, the recent low Alberta prices have been attributed to insufficient take-away pipeline capacity in the province. Our study lends support to the hypothesis that the recent widening price differentials between Alberta prices and prices at the Henry Hub should be viewed more in the context of the east-west continental split, than in terms of the intra-Alberta supply/demand imbalance.

The relatively greater degree of integration between Alberta and U.S. regions other than the Gulf Coast also suggests that the newly opened futures contract for Waha, Texas could provide Canadian producers with a better hedging tool than the traditional NYMEX contract based on Henry Hub pricing because the basis risk for Canadian producers appears to be correspondingly lower, at least at the present time.

We would like to emphasize that this report is not a final statement on the ultimate configuration of North American natural gas markets. Neither the observed east-west split, nor Alberta's closer alignment with the western U.S. regions should be viewed as definitive in the context of natural gas market evolution. Possible future pipeline expansions could increase links between Alberta and the U.S. Northeast, or between western and eastern parts of the U.S., altering gas flows and regional price patterns in the process. Similarly, the fact that Permian gas now flows east suggests that in the future Waha is likely to be influenced more by Gulf Coast pricing, and this may affect Waha's role as a barometer of western region pricing.

The increased integration of North American natural gas markets has benefitted both consumers and producers. The ability of consumers to access least cost supplies and the ability of producers to obtain the best price regardless of their respective locations have improved as a result. The increased degree of integration also implies that the markets have become more competitive because the effective number of participants on both sides of the market has become greater. As a result, the potential for a dominant market player (or a few dominant market players) to influence prices at any location has diminished.

Appendix I

Data

The data we use to assess natural gas spot markets are monthly bid-week prices for the major producing North American basins and Canadian export points, as well as beginning-of-the-month prices for several city-gates. All prices are reported in $U.S. per million British Thermal Units (MMBtu). Each price series ends in September 1995 but the starting point for each varies depending on data availability. Further specifics are discussed below.

United States Data

All U.S. natural gas spot prices are drawn from *Inside FERC's Gas Market Report* ("Inside FERC") published by McGraw Hill. The published prices are the price of gas as of the first day of the month and the fifteenth day of the month. Our analysis is based on the first day of the month prices.

The first day of the month prices reflect the prices of contracts for gas to be delivered for a period of thirty days or less during the month. The price and volume terms of these gas contracts are negotiated during the "bid week". The bid week is a period of time, typically falling within the last five or six business days of the previous month, during which market participants negotiate spot contracts for the delivery of gas in the following month. It is during this time that Inside FERC conducts its survey and representative prices are determined and published. For example, if the price survey were conducted in the closing business days of June, the published prices would be for spot deals as of the first of July and these would constitute the bid-week prices for July.

The bid-week prices published by Inside FERC refer to the price of gas delivered to pipeline companies and are derived from a survey of market participants. The various pipeline companies surveyed cover all major producing regions of the U.S. For example, the published bid-week price of spot gas for delivery to Transwestern Pipeline Company from the Permian basin would encompass gas produced in the Permian basin and to be delivered under a spot contract to any of Transwestern's connections in the basin. All price series that are listed in this study are named as they appear in Inside FERC.

In a similar fashion, Inside FERC surveys prices at city-gates by determining prices for gas bought under spot contracts by local utility companies and LDCs as of the first day of the month. For publication, these city-gate prices are then aggregated by region. Published data encompass the major consuming regions of the U.S. including, for example, Northern Indiana/Northern Illinois, New York/New Jersey, and Minnesota.

Although there are now many available sources of cash spot prices and bid-week prices for the United States, we chose Inside FERC because it provides price data over the longest span of time collected with a consistent methodology for a wide geographical area. Data series for some of the producing regions that are reported begin as early as the first few months of 1986. There appear to be no sources that report bid-week prices over a wide geographical area prior to 1986. However, post-1986 prices are ideal for our purposes in that they cover the span of time from the beginnings of gas market deregulation to the present day for the United States. Consequently, the evolution of gas price integration in North America can be traced (for certain regions) from just after the beginning of the deregulated market.

The Bid Week

For operational and scheduling purposes, each month pipeline companies require interruptible shippers to notify them of the pipeline capacity they will require for the upcoming month. Since most shippers are uncertain as to how much interruptible capacity they will need for the upcoming month until close to the end of the current month, finalization of interruptible (or spot) gas sales takes place close to the time they nominate their pipeline capacity. Effectively, shippers bid for how much capacity they require once they finalize their spot gas sales contracts. Pipeline companies initially established a ten day period at the end of each month for shippers to nominate capacity. This period of time became known as the "bid week". Thus, bid week gas prices refer to gas sales that are completed during the period of time when shippers are nominating pipeline capacity to ship the gas that they have contracted to sell in the coming month.

With the emergence of the natural gas futures market in April 1990, futures contracts for the upcoming month close 6 business days before the end of the month. Shippers and their customers typically now use the closing price of the futures contract as the starting point for establishing the price for their spot contracts. Thus, the futures market has helped to compress the bid week into a smaller time frame at the end of each month. In addition, the growing interconnections of pipelines often requires shippers to nominate capacity on several different pipelines to ensure that the gas that they have sold will be delivered to the customer. This has also compressed the bid week to some extent since nomination deadlines of the pipeline companies all fall within a few days of each other.

Canadian Data

The data for Canadian natural gas spot markets cover all of Canada's major natural gas exporting points, as well as the price of gas at Empress, Alberta. Empress prices are typically used to represent an Alberta "border" price. These data come from *Canadian Enerdata Inc.* which has been actively publishing prices for the Canadian natural gas industry since the mid-1980s. Like Inside FERC, Canadian Enerdata appears to provide, to the best of our knowledge, the longest continuous coverage of spot price data[12].

Canadian Enerdata also collects its data by export point on a bid-week basis. This makes its information methodologically consistent with the data from Inside FERC. The price data for Empress are slightly different in that the reported price covers all spot contracts negotiated during a given month that call for delivery during the following month. For example, the July price of gas at Empress is an average of the contracts negotiated during June that call for delivery of gas during July. In general, most of the deals at Empress are conducted toward the end of the month, which makes this price series comparable to the bid-week price derived using the Inside FERC methodology.

12 The NEB collects price information for natural gas exports by export point. However, these data refer to gas delivered under short- and long-term contracts, where short-term contracts are those for a duration of one year or less. Since we were interested in spot prices (thirty days or less) that were negotiated during bid week, the Board's collected prices were not used.

APPENDIX II

Detailed Statistical Methodology

The Law of One Price and the Degree of Price Integration

To assess the degree of spot price integration between various producing and consuming regions requires drawing on the principle outlined for the law of one price. Under this hypothesis, prices in any two market locations should differ only to the extent of transportation/transaction costs. This relationship can be more formally presented by drawing upon a simple example in which we compare the spot price of gas at Empress to the spot price of gas at Ventura, Iowa, a major transfer point for Alberta gas.

Consider a market agent at Empress who is in the business of buying and selling gas. In an environment where gas can be purchased from any location, prices are not regulated and there are no restrictions on the availability of information, the market agent is then free to pursue the cheapest gas for purchases and the most profitable market for sales.

Now consider a hypothetical set of prices: suppose gas at Empress is selling for $US 1.00/MMBtu and that gas at Ventura, Iowa is selling for $US 1.25/MMBtu. Furthermore, suppose that transportation and transaction costs to move gas from Alberta to Ventura are 20 cents per MMBtu. The market agent can purchase gas at Empress and move it to Ventura for a total cost of $1.20/MMBtu. In turn, the agent can sell the gas purchased from Empress in the Ventura market for $1.25/MMBtu and pocket the 5 cent profit. However, this situation cannot persist for long since all market agents have access to the same information. All other market participants at Empress would try to take advantage of the same profit opportunity. In doing so, the price at Empress would be bid up while the price at Ventura would fall, eventually reaching a point where the price differential is equal to the transportation/transaction costs and the profit opportunity has been eliminated.

In this simple example, the price at Ventura (P_{VEN}) can be stated as the sum of the price at Empress (P_{EMP}) plus the relevant transportation/transaction costs denoted by $Tr_{V/E}$. In a simple equation we can write,

$$P_{VEN} = Tr_{V/E} + P_{EMP} \qquad (1)$$

This equation embodies the law of one price by asserting that the price at one market location (Ventura) can be determined merely by using the price at another market location (Empress) and adding the relevant transportation/transaction costs. This can be further generalized by considering two prices in any two market locations, denoted as P_i and P_j and adding in the relevant transportation/transaction costs. This, too, can be simply written as,

$$P_j = Tr_{ij} + P_i \qquad (2)$$

We now have an equation that embodies the law of one price for any market location pair i and j. What is important to note about equations 1 and 2 is that they will hold exactly under the conditions in which the law of one price prevails.

In reality, however, situations do arise and persist in which the law of one price does not hold. This could reflect the fact that market agents: (1) do not have perfect access to all information, or (2) there is some physical limitation on flows of gas between the two markets, or (3) prices are restricted to certain limits within one or both markets, or (4) some other form of market imperfection exists which prevents prices from fully adjusting.

In these situations price differentials no longer reflect the implicit transportation/transaction costs of moving gas from market i to market j. Instead, the differentials capture structural rigidities and market imperfections associated with violations of the law of one price. Nevertheless, the price of gas in market j may still be influenced to some degree by the price in market i. The extent of the influence can be investigated through an equation which models the market price at location j as a function of some variant of the transportation/transaction costs, denoted as A_{ij}, and some fraction B of the price in market i. This can be expressed as,

$$P_j = A_{ij} + BP_i \qquad (3)$$

Based on the discussion above, the law of one price is a particular case where B is equal to one. As alluded to earlier, the condition of the law of one price would suggest that the markets are highly integrated in that gas can flow or be arbitraged freely between the two market locations and prices are free to adjust to any extent that equates the price difference with the transportation/transaction costs. **The upshot of this analysis is that a determination as to whether the law of one price holds can be made by a determination as to whether B is equal to, or very close to, a value of one. The closer B is to one, the more integrated are the two market locations.**

Statistical Analysis of the Degree of Price Integration and the Kalman Filter

Since the beginning of price deregulation in the mid-1980s, the natural gas market has been in a constant state of evolution. As pipeline interconnections have grown, the speed of information exchange has accelerated, the pricing mechanism for gas has become more transparent, the structure of the natural gas market and the determination of prices in the various regional markets have changed over time.

It is this change through time that is at the heart of our investigation of the degree of price integration. In terms of equation 3 above, we investigate how B has been changing through time. Of particular interest is whether it has been steadily moving toward one or fluctuating widely. Standard statistical approaches such as regression analysis, "rolling" regressions and correlation analysis may seem like useful procedures to assess the value of B. However, they are not well suited for addressing the question of how the value of B has been changing over time since they estimate average relationships for any given time period. In the case of regression analysis the estimates of the intercept and slope of an equation such as 3 are fixed for the whole of the time period under consideration.

In our analysis, the variables A and B of equation 3 are analogous to the intercept and slope of a regression line but are allowed to *change* through time. As such, A and B are often referred to as *time-varying parameters*. This subtle but important consideration is what separates our approach from standard regression analysis[13].

The time-varying nature of A and B can be evaluated through a statistical approach known as the *Kalman filter*. It is not necessary for the reader to have a complete understanding of the Kalman filter in order to review the results of our analysis; the important aspects are the time-varying nature of A and B and that the value of B represents the degree of price integration with the passage of time.

In the previous section it was demonstrated with a simple equation that if the law of one price holds price differentials are equal to transportation/transaction costs. This implies that B equals one. However, B will only equal one under ideal market conditions. Such conditions include: (1) prices are free to vary without bounds, (2) all market agents have access to the same information at the same time, (3) there are no restrictions on the flow volumes of gas and, (4) each point in the pipeline grid is connected to every other point in the grid.

These conditions have emerged to varying degrees in the natural gas industry over the past decade. Consequently, one would expect that natural gas markets have moved closer to the conditions which would satisfy the law of one price. By applying the Kalman filter to equation 3 we can track the evolution of B over time. An evolution of B towards a stable value of unity can be described as a path to *price convergence*. This does not mean that all prices converge to the same value but rather that the market converges to a relationship which is consistent with the law of one price[14]. Thus, the application of the Kalman filter not only provides a measure of the degree of price integration but can also track price convergence in natural gas spot markets.

In analyzing price convergence, due consideration must also be given to the parameter A since the Kalman filter allows both A and B to change through time. This parameter should behave in a fashion similar to that of B by tending to some constant value and remaining stable. The formulation of equation 3 implies that A should tend to an absolute value that is a stable reflection of the implicit transportation/transaction costs between market pairs. However, this value will be different depending on the spot price pair being considered.

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13 There are other distinctions that separate our approach from regression analysis which are more thoroughly explained in Appendix III. However, an appreciation for the fact that standard regression analysis implicitly assumes a fixed explanatory relationship between variables is more than sufficient to understand the thrust of our approach.

14 Haldane and Hall (1991) and Hall, Robertson and Wickens (1992) take the same approach to testing the law of one price in foreign exchange markets and European inflation rates. In these papers, the conditions for convergence and for the law of one price to hold indicate that the time-varying parameters should converge on their theoretically specified values and remain stable at this value; in this case, B should converge to one and remain stable at one.

Our study, as well as others which have applied the Kalman filter to the question of the law of one price, use the Kalman filter in such a way that a strict test for the statistical significance of B cannot be applied. Consequently, *a plot of the value of B over time can only lead to a subjective evaluation as to whether or not convergence has occurred*. Theory indicates that in a perfectly integrated market, B should be equal to one and that A should have a value that is equal to the implicit transportation/transaction costs. Simply put, the only valid interpretation is that the closer is B to one, the closer is the market to achieving the law of one price; the further is B from one, the more the market is diverging from the law of one price. When B is not equal to one, all we can conclude is that the law of one price does not hold and that the value of A has an interpretation as being something other than implicit transportation/transaction costs[15].

In summary, our statistical approach is to apply the Kalman filter on equation 3. The prices of natural gas in this equation are the bid-week prices that were explained earlier. The Kalman filter then generates values of A and B for each point in time over the period for which the two price series are both available. By plotting the value of B in a chart and seeing how close it is to one, a subjective assessment can be made of the degree of price integration between the two price series – equivalently, we can see how close the two markets are to converging to the law of one price.

15 In our analysis, if price convergence has occurred, the specified equation has captured the true structural relationship between prices and the intercept reflects the market's valuation of the implicit transportation/transaction costs. If B does not converge to a value of one, then the intercept term will indicate that the existing equation is inadequate in the sense that it may be mis-specified. This mis-specification could take the form of missing explanatory variables such as regulatory influences or pipeline capacity that are distorting the market pricing relationship. Most important is that the intercept in this case has no strict interpretation as a monetary value.

Appendix III

The Kalman Filter and Its Use

This third appendix assumes that the reader has some understanding of statistical theory and matrix algebra. Much of the mathematical discussion below can be found in greater detail by referring to Harvey (1981, 1989). A less technical and more lucid explanation can be found in Meinhold and Singpurwalla (1983). Some excellent applied examples as well as an intuitive economic discussion can be found in Cuthbertson, Hall and Taylor (1992) and Bomhoff (1994).

Explanation and Overview of the Kalman Filter

First, consider the original equation as given in Appendix II:

$$P_j = Tr_{ij} + P_i \qquad \text{(A1)}$$

This equation is typically referred to as a deterministic equation in that it will always hold exactly as written. However, there are may be other factors, each with a small and possibly unpredictable influence, that cannot be identified or measured. Their total effect is captured by adding a disturbance term to the equation. This disturbance term is also called the random error term. Furthermore, including the general parameter A in place of Tr_{ij} and allowing for time variation in the parameters (denoted with the subscript t) yields:

$$P_{jt} = A_t + B_t P_{it} + \varepsilon_t \qquad \text{(A2)}$$

In this case, the equation is the same as that introduced in the main body of the text except for the inclusion of the error term (ε_t). Moreover, when performing statistical analysis, the researcher often makes certain assumptions about the properties of the error term. Specifically, these assumptions deal with the mean (arithmetic average) and the variance and co-variance (the variability of ε_t and its relationship to other errors at other points in time). These assumptions are that the error term has a zero mean and that the variance-co-variance can be expressed with the matrix H_t. This is written as:

$$\varepsilon_t \sim NID\ (0,H_t) \qquad \text{(A3)}$$

where the ~ NID denotes: "normally and independently distributed as". In this case H_t is simply a 1x1 variance-co-variance matrix.

Returning to equation A2, let us simplify the notation slightly by replacing A_t and B_t with the single column vector Γ_t (2x1) and the explanatory values with the row vector P_t (1x2). Thus, our stochastic price equation becomes:

$$P_{jt} = P_t\Gamma_t + \varepsilon_t \qquad \text{(A4)}$$

In the Kalman filter methodology, the above equation is referred to as the *measurement equation* because it "measures" the outcome of the dependent variable P_{jt}. At this point, it is necessary to note that all the price series are fixed in the sense that the price data for all time periods t, for t in the interval t = 1.......T, is already known. It is the values in Γ_t at each point in time that are unknown and constitute our unobserved coefficients (see the Kalman Filter text box in the main body of the text). We can describe the values of these unknown coefficients in terms of their past values with the following equation:

$$\Gamma_t = \Gamma_{t-1} + \eta_t \qquad \text{(A5)}$$

This equation is referred to as the *transition equation* because it describes how the coefficients undergo transition from one time period to the next. Furthermore, the components of Γ_t are often referred to as *state variables*. Once the state variables are determined, they are placed in the measurement equation and determine the outcome (in conjunction with P_t), or the "state-of-nature", of P_{jt}. Hence, the name state variables. Again, assumptions are made concerning the mean and the co-variance matrix of the error term η_t

$$\eta_t \sim NID\ (0, Q_t) \qquad \text{(A6)}$$

where Q_t is a 2x2 matrix. The error term η_t is assumed to be completely independent of the error term of the measurement equation such that $E\ (\varepsilon_s, \eta_t) = 0$ for all s,t = 1.......T.

In considering the transition equation, the time varying aspect of Γ_t comes from the presence of the error term η_t. In this context, the state variables represent the unobserved components to be used in the Kalman filter. They are unobserved in the sense that they are free to evolve as the data are passed through the filter while the time-varying aspect comes from the time-varying error term.

As mentioned in the explanatory box in the main body of the text, the Kalman filter starts by forming an estimate for the state variables at time t on the basis of the information it has obtained at time t-1. Therefore, predictions for the state variables are required. This is accomplished with

$$\Gamma_{t/t-1} = \Gamma_{t-1} \qquad \text{(A7)}$$

where t/t-1 denotes the estimate of Γ at time t conditional on information at time t-1. An important consideration in the Kalman filter is that, by the very nature of the transition equation, Γ_t is stochastic. This means that the coefficients are drawn from a random distribution, with a potentially different mean and different variance at each point in time, with the distribution itself being time dependent. Thus, the variance of the coefficient distribution can be different at any point in time.

Under ordinary regression analysis, the coefficient estimates are estimated on the basis of one single distribution which is assumed to be time-invariant; that is, regression analysis computes the coefficients on the basis of minimizing the variance for a time-invariant distribution. However, with the potential of random time-variant distributions, the Kalman filter does not consider minimizing the variance of the coefficients but rather with minimizing the *prediction error* of the coefficients.

If we define the 2x2 matrix Ω_t as the co-variance matrix of the prediction error, then we can define the conditional estimate of this co-variance matrix as

$$\Omega_{t/t\text{-}1} = \Omega_{t\text{-}1} + Q_t \qquad \text{(A8)}$$

where the co-variance matrix $\Omega_{t\text{-}1}$ is defined as

$$\Omega_{t\text{-}1} = E[(\Gamma_{t\text{-}1/t\text{-}2} - \Gamma_{t\text{-}1})(\Gamma_{t\text{-}1/t\text{-}2} - \Gamma_{t\text{-}1})'] \qquad \text{(A9)}$$

where the difference between $\Gamma_{t\text{-}1/t\text{-}2}$ and $\Gamma_{t\text{-}1}$ represents the prediction error of the state variables. In this case $\Gamma_{t\text{-}1/t\text{-}2}$ is the conditional prediction of $\Gamma_{t\text{-}1}$ made at t-2 using information at t-2 and $\Gamma_{t\text{-}1}$ is the updated estimate of the state variables which includes information available in t-1. Collectively equations A7 and A8 are called the *prediction equations* of the Kalman filter.

After making its predictions, the Kalman filter then moves to the second stage of the solution by using the information contained in the price series at time t. In doing so, it updates it estimates of the coefficients and the co-variance matrix of the prediction error. The equations used to accomplish this are:

$$\Gamma_t = \Gamma_{t/t\text{-}1} + K_t(P_{jt} - P_t\Gamma_{t/t\text{-}1}) \qquad \text{(A10)}$$

$$\Omega_t = \Omega_{t/t\text{-}1} - K_t P_t \Omega_{t/t\text{-}1} \qquad \text{(A11)}$$

where

$$K_t = \Omega_{t/t\text{-}1} P'_t (P_t \Omega_{t/t\text{-}1} P'_t + H_t)^{-1} \qquad \text{(A12)}$$

Equations A10 to A12 are referred to as the *updating equations* of the Kalman filter. Taken together, equations A7 to A8 and A10 to A12 constitute the complete solution algorithm of the Kalman filter through which the price data is passed.

An additional feature that must be mentioned is that the matrices H_t and Q_t must be supplied by the user of the filter in advance. These two matrices act similar to scaling variables for the underlying variance that is computed for the filter. This variance is computed through a process called maximum likelihood. The maximum likelihood approach utilizes an equation known as the *prediction error decomposition* when computing the variance. The reader is referred to Chapter 3 (pg. 126-127) of Harvey (1989) for further details and proofs.

In the Kalman filter it is important to note the presence of equation A12. This equation is referred to as the *Kalman gain*. It is this equation that allows for the explicit incorporation of a "weighting" scheme on the prediction error of the state variables in the updating process. This is a "capability" that ordinary regression analysis does not have. For instance, in equation A10, the term $(P_{jt} - P_t\Gamma_{t/t\text{-}1})$ is the estimation error of the dependent variable. This error is weighted by the gain matrix K_t and this information is incorporated into the updated estimate of Γ_t.

Overall, the Kalman filter is merely a solution method for producing optimal recursive estimates of the state variables. It is a method that is more robust and has greater power for dealing with a much wider class of time series models and dealing with dynamic change in the evaluation of economic theories.

The Advantages of the Kalman Filter over "Traditional" Analysis

When referring to "traditional" analysis we are considering such approaches as: (a) regressions estimated over a fixed time period; (b) rolling regressions – sequentially adding one observation to the end of the sample period; (c) rolling "window" regressions – using a fixed number of observations that sequentially move forward through the sample; or (d) correlation analysis – using the correlation coefficient from regression analysis as an indication of the strength of co-movement in time series.

Based on the analytical overview presented above for the Kalman filter, it has a number of advantages over traditional regression analysis. These include:

(1) The explicit presence of time-varying parameters allows for a more precise detection of structural change in the model. This detection of structural change takes the form in our model of both the magnitude of change and its timing.

(2) In rolling regression analysis, the changing value of the coefficients depends only on previous values of the explanatory variables. In the case of the Kalman filter, the presence of the Kalman gain is what takes into account previous values of the explanatory variables and appropriately "weights" the previous prediction error and factors this into the updated estimation of the coefficients. It is this weighting by the Kalman gain that allows the Kalman filter to "adapt" more quickly to structural change than would be the case under standard regression techniques. Ledolter (1989) provides a proof and additional details.

(3) The Kalman filter can account for specific levels of integration or cointegration in the data and still allow for a specification to be tested in the levels of the series – see Bomhoff (1992).

(4) Other types of models that rely on discrete switching coefficients, systematic parameter variation, and random coefficient models can all be encompassed by the Kalman filter – see Tegene (1991). In fact, it can be shown that ordinary regression analysis is just a special case of the Kalman filter – see Chow (1984). As such, the Kalman filter is an extremely robust procedure for dealing with a wide range of time series models.

(5) Unlike correlation analysis, the Kalman filter allows for the specific formulation and testing of an economic theory in the context of time-varying parameters. In this study, the set-up for the Kalman filter (the transition and measurement equations) allow us to explicitly formulate and test an equation for the law of one price.

Why T-Tests of B are Inappropriate

A factor to consider in the transition equations is the way in which they are formulated. This type of formulation is typically called a random walk in the coefficients or an imposed unit root in the coefficients. It is this formulation that allows for truly time-varying coefficients because we have allowed the present value of the coefficient to be simply the previous period's value plus the error term which is computed from the maximum likelihood procedure. However, this time-varying aspect does come with a price in the sense that it prevents us from carrying out significance tests on the coefficients.

When a time series contains a random walk it can be shown that the mean and the variance of the series are time dependent – a situation that is referred to as non-stationarity. Non-stationarity of a time series means that standard tests such as the t-test cannot be applied because they are based on the premise that the underlying time series is stationary – the mean and variance are not time dependent. In the case of non-stationarity, the best that can be done is to compute the coefficients and plot them.

The Setting of Priors

In all the Kalman filter equations, it becomes clear with the recursive solution technique that there must be some sort of starting values to which the equations can be applied at time t = 1. Such values are called *priors*. The econometric software that we used for the analysis, TSP (Time Series Processor) automatically computes a set of priors for the recursions by applying a standard regression to the first 3 observations. The information that is generated from this regression is then used to set the starting values for the coefficients (equation A7) and the corresponding co-variance matrix of the prediction error (equation A8). In this case, the Kalman filter then works it way forward from time t = 3 to the end of the sample. It should also be noted that for this reason we delete the first three values generated by TSP from the state vector in addition to the twelve observations that we delete as a means of eliminating some of the volatility in B at the beginning of the sample.

We also used our own set of priors, under the assumption that there was no relationship at the beginning of the sample, by setting B equal to zero and A equal to the spot price difference in the first available observation. Our results were little changed from the time paths for B shown in the main body of the text. As a result, we chose to stick with the results generated by the default settings in TSP mentioned above. These default settings are consistent with the methodology suggested by Harvey (1981 pg. 113, 1989 pg. 128) for models that involve a random walk in the transition equation.

The Question of Convergence

Hall, Robertson and Wickens (1992) neatly lay out the conditions for convergence in the context of applying the time-varying parameter Kalman filter. The notion of convergence itself is quite simple – the difference between two (or more) time series should become arbitrarily small or converge on some constant with the passage of time. In our context, this implies that the price differential should converge to the implicit transportation/transaction costs. This, in turn, implies that B should converge to a value of one.

In statistical terms, this means that upon taking expectations we should have

$$E\{\lim_{t\to\infty}(P_j - P_i)\} = Tr_{ij} \qquad \text{(A13)}$$

where Tr_{ij} is the implicit transportation/transaction costs for any price pair i and j. The outcome of this convergence implies that

$$E\{\lim_{t\to\infty} B_{ij}\} = 1 \qquad \text{(A14)}$$

should also hold for any pricing pair i and j. Furthermore, Hall, Robertson and Wickens show that this definition of convergence can be stated in terms of *strong* and *weak* convergence. Strong convergence is the case where equations A13 and A14 hold for all i and j, whereas weak convergence is the case where equations A13 and A14 hold only for some i and j. Clearly, the results presented in the main body of the text are reflective of only weak convergence.

Related Empirical Studies of Natural Gas Spot Markets

A number of empirical studies have emerged in recent years that have analyzed the natural gas spot market and have considered the question of price linkages and price integration. Some of this work includes De Vany and Walls (1992, 1993a, 1993b, 1994), O'Donnell and Benet (1994) and Walls (1991, 1993a, 1993b, 1994) – a number of these papers are neatly summarized in De Vany and Walls (1995). Specifically, the works of De Vany and Walls have purported to test for price convergence in natural gas spot markets using the cointegration techniques of Engle and Granger (1987), Johansen (1988) and Johansen and Juselius (1990).

Cointegration techniques analyze the degree of co-movement between time series by accounting for particular unit root properties of the data. De Vany and Walls (1993a) and Walls (1994) use this approach to investigate whether or not the number of cointegrating price relationships has been increasing when the data are broken down into sub-periods. Their results show that the number of cointegrating price relationships increases with each successive sub-period. They take this as evidence that price convergence is occurring. However, these techniques are not well suited to addressing the question of convergence since cointegration is not a test for a movement from non-convergence to convergence – see Hall, Robertson and Wickens (1992). Rather, convergence must have already taken place for cointegration to be detected. Since convergence is typically a gradual and on-going process, the time-varying parameter method of the Kalman filter is ideal for detecting a movement from non-convergence to convergence.

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