

# Natural Gas Price Volatility

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## Lessons from Other Markets

Report for the American Clean Skies Foundation  
and the Task Force on Ensuring Stable Natural Gas Markets

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# Natural Gas Price Volatility: Lessons from Other Markets

## Preface

The main comparative advantages of natural gas – ample domestic supply, low carbon content, economical extraction – are increasingly making it a fuel of choice for the United States. Deeper market penetration in all sectors is a vivid possibility: in the electric power sector through greater installation of gas-fired generation; in the industrial, commercial, and residential sectors through less reliance on fuel oil as a primary or secondary energy source; and in the transportation sector through increased use as fuel for a new fleet of natural gas-powered vehicles. Beyond the market opportunity and technical possibility, increased market penetration is favored by sustained low prices, particularly if gas prices remain decoupled from oil and cheaper on a unit-of-energy basis.

Yet natural gas consumers have been subjected to large price shocks in the past 15 years, raising some concern that over-reliance on the fuel could increase cost uncertainty and risk for a growing number of consumers – from large industrial companies down to individual households. The goal of this research report is to glean lessons from other markets to determine (1) how natural gas markets are structured in the largest consuming regions of the world, (2) the effect that natural gas price shocks have had on corporate earnings, and (3) how natural gas price movements relate to those of other commodities. The report looks at the United States, Europe, and Asia, which account for one-third, one-fifth, and one-sixth of total global natural gas consumption.

This report comes in the context of a series of reports that have been commissioned by the American Clean Skies Foundation in support of the Task Force on Ensuring Stable Natural Gas Markets for the National Commission on Energy Policy (NCEP). Other reports have looked at (1) projections for future natural gas supply, (2) the history of price instability in the U.S., (3) price hedging strategies employed by natural gas producers and electric power companies, (4) the existence and use of long term<sup>1</sup> contracts in the energy markets, and others are underway or under consideration.

## I. Introduction and Summary

While this report is fundamentally an analysis of global natural gas price patterns during the past 20 years, it is in many ways a report about American competitiveness in the global economy. Of all the many important inputs to economic productivity, nothing is more centrally important than primary energy. Natural gas accounted for over one fifth of primary energy in the United States in 2009, and the steep increase in potential reserves accessible through unconventional recovery methods has raised all projections of future domestic supply and flattened the forward price curve.

The U.S. is the world's largest producer and consumer of natural gas, and is therefore highly sensitive to price volatility. Reliance on natural gas is nothing new; it has played a significant role in the energy mix for decades. But price volatility is fairly new, since natural gas prices were still highly regulated even as recently as 25 years ago. Until that time, structural flaws limited the way pricing signals were transmitted between producers and consumers, and chronic pricing dislocations led regulators to believe that fixing prices at the wellhead would ensure stable supplies and steady prices. After years of unsatisfactory results a series of measures were taken to deregulate pricing.

### **Lessons from other natural gas markets**

The first section of this report presents an overview of natural gas markets in five markets: the United States, the United Kingdom, Germany, South Korea, and Japan. It presents supply and demand dynamics and historical price levels and discusses drivers of pricing in each market. It finds strong regional differences in natural gas demand that affect each region's ability to cope with changing prices. Germany and South Korea, with high consumption by the residential sector, are less likely to see price-induced demand changes than the U.S. and Japan, where a greater share of natural gas is used by the electric power sector. The U.S. has the most well-established market-based system for natural gas pricing, but there is a general trend in other markets toward freer prices and shorter-term purchasing. Many devices are available to help mitigate price volatility between the wellhead and the end user, including storage, transportation, and increased use of liquefied natural gas. The threats of supply shortages and potential price spikes have motivated investment in exploration, production, and delivery infrastructure in all regions, and this should help quell future price volatility.

### **Lessons from corporate earnings**

The second section identifies recent price shocks in all five markets and looks for same-year economic impacts on 12 large companies that rely on natural gas as a fuel or feedstock input. It finds that reporting on company filings is imprecise and inconsistent, but provides some insights into how companies have coped with unexpected price swings. In most cases companies were well protected headed into periods of unexpected price changes, or were able to adjust business plans so as to minimize price impacts. There were no apparent regional differences in the degree to which companies could cope with price volatility. This analysis is anecdotal and focuses on a single year. As such, it does not capture impacts on long term investment decisions or corporate strategies. But within the narrow scope of the analysis, price volatility does not appear to pose a disproportionate risk to companies that depend on natural gas. Devices to mitigate risk include financial and strategic hedges, pricing power, and access to substitutes.

The goal of companies' natural gas procurement strategies *per se* is not to gamble and make money on unexpected price movements in the markets; the goal is to average out to some reasonable, sustainable

cost level that leaves room for other operating expenses and a reasonable rate of return.<sup>2</sup> Large companies are often sophisticated when it comes to managing price volatility, and treat natural gas price volatility as they do other unavoidable risks from exchange rates, economic cycles, natural disasters, and political factors – to name just a few.

### **Lessons from global commodity markets**

The third section of this report branches out to look at a larger set of global commodities. It presents a variety of analytical views of monthly average spot prices for seven different commodities, finding that U.S. and UK natural gas prices have been the most volatile of any of them over the past 20 years, with increasing volatility in the past decade.

Natural gas has received attention for its volatility but it is not uniquely volatile. While its volatility has been relatively high in recent years, so has it been for other commodities (and indeed for nearly every other asset class). Volatility is highest when supply and demand are inelastic, meaning that a small change on either side leads to a large deviation in prices. During calmer economic cycles natural gas seems to move in tandem with other commodities, but during more tumultuous periods it takes on a life of its own. It is never as correlated to other commodities as oil has been, and a time lag may buffer its impact on corn, soybeans, and other commodities that depend on it directly. Moreover, spot prices only tell part of the story. The actual transaction prices experienced by buyers and sellers often deviate from the market's spot prices due to the use of purchase contracts and hedges.

### **Observations**

The overall conclusion of this report is that volatility is more severe in U.S. natural gas markets than in most other commodities, but U.S. companies have demonstrated an ability to manage price risks through the most turbulent commodity markets in history. It is highly likely that price volatility will continue. Numerous future shocks are almost assured, although the timing and magnitude are highly uncertain. From the domestically-supplied U.S. market to the import-dependent South Korean market, and from the short term pricing in the UK to the long term contracts of Japan: each market is changing just as the global market changes. Future dislocations are inevitable as the UK opens storage capacity, Germany builds more pipelines, the U.S. begins to tap its shale reserves, Japan rewrites decades-old purchase contracts, and all of this is layered on top of shifting demand patterns, seasonal purchase fluctuations, changes in production and distribution costs, and so many other factors. The history of each market offers clues to what has worked in the past, and the future provides a chance to improve on successful decisions and test new approaches. Market-based systems have offered innovative ways to mitigate risk, and should continue to provide companies ways to meet the challenges of the future.

As is pointed out in a 1998 report by the International Energy Agency (IEA), a comparison between regional commodity markets is bound to be an imprecise exercise because of the tremendous number of variables at play in every stage of the value chain, from gas reservoir to burner tip. To that extent, not every observation in this report leads to a conclusive policy recommendation. No single data point is ever enough to predict the future. But many individual observations, taken together, can ensure that decisions are informed by some – or even most – of the available information.

### **Next steps**

Because answers always lead to questions, this report presents some ideas for further research:

1. What impact will liquefied natural gas (LNG) markets have on natural gas price volatility?
2. How are residential and small commercial and industrial sectors affected by price volatility, and are they sufficiently protected by market regulations?
3. Electricity pricing, though complex, plays an important role as a key natural gas-dependent energy input, so future work might analyze the natural gas price-induced effects of electricity price volatility.
4. Does a comprehensive econometric study support the conclusions about the resiliency of corporate earnings amidst a well-hedged energy procurement strategy?
5. What is the public relations dimension to price volatility, and is there a need to address problems brought on by public (mis)perceptions about natural gas price volatility?

## **II. Global Natural Gas Markets**

### **Market Overview**

Global natural gas consumption grew from 73 trillion cubic feet (Tcf) in 1990 to 110 Tcf in 2008, the most recent year for which global data are available. This equates to a 2.1 percent compound annual compound growth rate (CAGR). Much of this took place in regions with the greatest economic growth during the period: natural gas use grew six percent per year in Asia and 4.5 percent in Central and South America, as compared to CAGRs of 2.3 percent in Europe and 1.3 percent in North America. Global trade in liquefied natural gas was 8.7 Tcf in 2009,<sup>3</sup> or just under eight percent of total global consumption.

### **Country-level Supplies<sup>4</sup>**

Sources of natural gas vary greatly around the world as a function of a country's proximity to production zones, access to pipelines, trade agreements, LNG processing capacity, supply contracts, and prices. Whereas the United States relies almost exclusively on gas piped from domestic and Canadian production fields, supply-starved nations such as Japan depend almost entirely on LNG imports. The

global supply picture is by no means static: each year new import agreements are established, new pipelines enhance transportation capacity, and production volumes change. Asian countries are building new transportation capacity while the UK adjusts to becoming a net importer and the U.S. calculates the supply potential of its newly-discovered shale reserves.

### *United States*

The United States is the world's largest producer and consumer of natural gas, with over 6,300 producers that range from the 21 active large oil and gas "majors" to hundreds of small producers. Domestic production accounts for over 90 percent of consumption, with the remainder imported from Canada and Mexico (3.6 Tcf) and from Egypt and Trinidad as LNG (400 billion cubic feet, or Bcf). The U.S. has constructed substantial LNG capacity in the past decade. Ten LNG terminals provide capacity of 18 Bcf per day (Bcfd), which exceeds current LNG consumption by a factor of 16 to one.

The major gas producing regions of the country are in Texas, Wyoming, and Oklahoma, which together produce almost two-thirds of domestic supply. In recent years the discovery of deep shale resources has reshaped the supply picture by increasing the total estimated recoverable resource base and putting new regions on the map, such as the Marcellus Shale region in the northern Appalachia. Shale discoveries have boosted both estimated reserves and actual production from existing fields: output from the Barnett Shale in Texas rose from one Bcf per day in 2004 to 5.6 Bcf per day in 2010<sup>5</sup>, and production in the Haynesville Shale in Texas and Louisiana is expected to triple from 2009 to 2010.<sup>6</sup>

### *United Kingdom*

The UK is the second-largest producer of natural gas in the European Union, behind Norway. Most production is in the Shearwater-Elgin area of the North Sea. Until 2004 the UK was a net exporter of natural gas but production peaked in 1999 and the country became a net importer in 2004. The UK produced 2.1 Tcf in 2009, 16 percent below 2008 and roughly two-thirds of its total consumption. Imports have risen to cover the supply deficit and the country has built four LNG terminals to ensure sufficient receiving capacity. LNG imports are now almost 40 percent of total gas imports, and the UK as a whole has become the world's eighth-largest importer of LNG.<sup>7</sup> Other gas imports come through the Interconnector pipeline that runs between England and Belgium, although this pipeline is also used to export gas at certain times of the year depending on the UK supply/demand balance. A second pipeline runs from Norway's Frigg gas field in the North Sea, and other pipelines are under consideration.

### *Germany*

Because domestic natural gas production in Germany supplies less than one-fifth of the country's needs, it relies on pipeline imports from Russia's Gazprom for over 40 percent of supply. Other supply comes by

pipeline from Norway and the Netherlands (roughly 25 percent each) and other countries.<sup>8</sup> LNG terminals are under construction and nearing completion, and expected to relieve some of Germany's vulnerability to the vagaries of Russian natural gas supply. LNG import capacity would allow Germany to source natural gas from a larger set of countries, particularly Qatar and other producers in the Middle East. Germany will likely procure some gas by investing directly in foreign production capacity.

### *Japan*

The Minami-Nagaoka gas field on the western coast of Japan produces a mere four percent of Japan's total supply, or 165 Bcf in 2009. Additional domestic exploration is taking place but is largely believed to be uneconomical with low global natural gas prices. Most of the country's supply comes via imports from Indonesia, Malaysia, Australia, Qatar, and elsewhere. More than 40 LNG terminals operate near population centers around the country and provide excess processing capacity. Inpex, Mitsubishi, Mitsui, and various other Japanese companies are actively involved in domestic and overseas natural gas exploration and production to strengthen the country's supply.

### *South Korea*

South Korea similarly depends on imports for over 98 percent of its total supply. Nearly 80 percent of that is imported as LNG, making South Korea the world's second largest LNG importer after Japan. One third of LNG came from Qatar in 2008, 23 percent from Malaysia and 17 percent from Oman. South Korea has four LNG terminals with the capacity to process nearly twice the country's total annual natural gas supply. Because of its import dependency, South Korea invests actively in exploration and production in 11 other countries. The government aims to secure 25 percent of imports from equity production sources by 2017. There are no international pipelines for oil or natural gas, but a new pipeline from Malaysia to South Korea is set to begin construction in early 2011 and will increase South Korea's leverage as an importer.

Within these five countries, access to domestic supply is one driver of a country's willingness to reduce price controls and embrace higher volatility. The U.S. and UK, with the largest relative shares of domestic production, have the most active short term purchasing markets and have experienced the highest price volatility. Japan and South Korea, on the other hand, have the greatest import dependency and also the least liquid trading markets. The U.S. has the most stable supply position of any country, and even if supplies are not immediately responsive to demand shifts, the ability to tap domestic reserves should provide a way to stem price volatility over the long term.

## Sector-by-Sector Consumption<sup>9</sup>

Chart 1 summarizes the major gas-consuming sectors in each of the five countries. All countries use natural gas in the commercial sector to roughly the same degree, but use by other sectors varies considerably. The greatest contrast is between Japan and Germany: Japan uses 59 percent of its natural gas for electric power generation, 9 percent for the industrial sector, and 10 percent for residential applications, while Germany uses only 9 percent for electric power, 28 percent for the industrial sector, and 47 percent for residential uses.

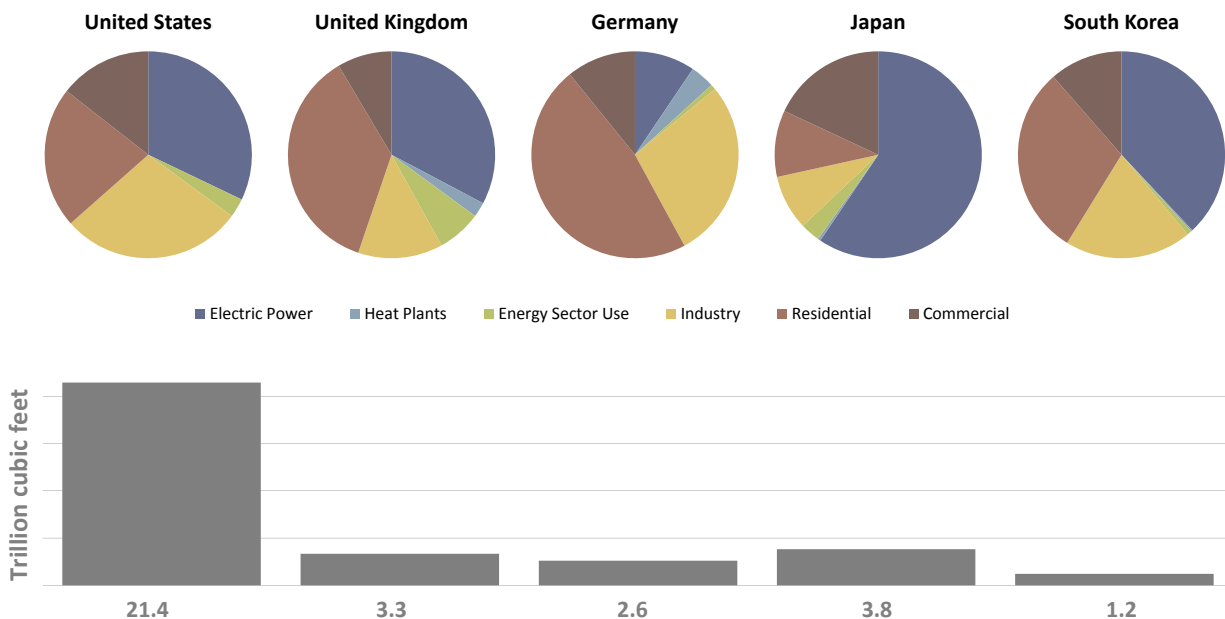


Chart 1: Global Natural Gas Uses and Total Consumption by Region, 2008 (Sources: IEA, EIA, MJB&A)

### United States

The U.S. consumed 22.7 Tcf of natural gas in 2009. The electric power sector is the largest consumer, responsible for 33 percent of natural gas consumption in 2009. This has increased from 22 percent in 1999 and surpassed the industrial sector, which stands at 27 percent of consumption. The major demand centers for natural gas are in the populous U.S. Mid-Atlantic and New England regions and the industrial areas in the U.S. South. Warmer areas of the country rely more on natural gas for electric power generation to serve air conditioning loads, while cooler parts of the country rely on natural gas as a heating fuel. Even though relative consumption by sector has changed significantly since 1990, total consumption has grown at less than one percent per year – far less than the rate of growth of the overall economy. This has led to a belief in a “balancing” effect in the U.S. economy – that over the long run, declines in consumption in one sector are met with increases in consumption in other sectors. Fuel switching is a factor over both the short run and the long run, as many industrial and power sector users

have the ability to choose their fuels depending on market prices (short run) and invest in new equipment based on expected prices (long run).

### ***United Kingdom***

Natural gas consumption in the UK was 3.1 Tcf in 2009 and accounted for approximately 40 percent of total primary energy consumption.<sup>10</sup> UK consumption has exhibited lower price elasticity than that seen in other European countries due to the large consumption by the residential sector and limited ability to fuel-switch in the electric power sector. Consumption has been steady for the past ten years, dipping only slightly in the 2008-2009 recession.

### ***Germany***

At 3.4 Tcf per year, German consumption is about equal to that of Japan and the UK. Almost one-half of this is used for residential sector heating, although a hard push from the government has caused some fuel switching to renewables over the past three years, with further switching seen in both the residential and commercial sectors.<sup>11</sup> A further 28 percent is used by the industrial sector. Electric power generation only claimed 13 percent of Germany's natural gas consumption in 2008. The largest electric sector feedstock, coal, does not fit with the country's environmental goals, and an uneasy stance on nuclear could lead to decommissioning of some of the older plants by 2020 – leaving few alternatives other than renewable energy. Gas could pick up the slack if Germany is able to shore up its natural gas import contracts and infrastructure.

### ***Japan***

Japan consumed roughly 3.3 Tcf of natural gas in 2009 and despite the country's limited domestic production capability, has made a strong commitment to using natural gas as a fuel of choice due to its environmental advantages over oil and coal. An aging fleet of oil-fired power plants is due to be retired and likely to be replaced by natural gas-fired plants, which today produce 30 percent of the country's electricity. Another 25 percent of electricity is generated from coal, which could be switched to gas if clean coal technologies do not reach commercial viability. The limited penetration of central heating systems in Japan's housing stock means that kerosene (through space heaters) is much more widely used as a heating fuel than natural gas; this explains the proportionally small share of consumption taken by the residential sector. Widespread district heating and cooling in cities relies on both fossil-based energy and waste heat and helps explain heavy use by the commercial sector.

### ***South Korea***

South Korea's 2008 natural gas consumption was 1.2 Tcf, the lowest of the five regions considered here. The country has been undergoing a long term fuel switch away from oil. In the electric power sector this

means increased reliance on natural gas, although coal use has also doubled in the past 15 years and continues to rise steeply. Unlike in Japan, 30 percent of South Korea's demand goes to the residential sector, primarily for heating.

### ***Elasticity and price sensitivity***

Intuition says that the overall risk to any single country's economy from price volatility will depend on the way natural gas is split among sectors. If a larger share of natural gas flows to end users with the ability to hedge prices or fuel switch than to those who can't hedge and aren't otherwise protected from price shocks, volatility will have less of an impact overall. Further research to confirm this point through empirical work may be warranted.

Demand elasticity over the short run – the responsiveness of demand to changes in prices – will depend on the degree to which a given sector has options for conservation or alternative fuels. Overall consumption levels should be more responsive to prices in countries where a large share of natural gas is used by the industrial and the power sectors, such as the U.S. and Japan. Firms should be able to practice short-run fuel switching to or away from gas. For example, in the U.S. low natural gas prices have made gas-fired generation competitive with coal, moving natural gas farther down the dispatch stack to baseload generation and increasing consumption. Consumption in countries where a large share of gas goes to the residential sector, as in the UK and Germany, will be less responsive to price changes, as homeowners have few short-run alternatives for domestic use.<sup>12</sup>

Changes to long-run market penetration – the future level of consumption in each market – will be shaped by the degree to which a sector already relies on natural gas for its energy needs and feels comfortable with greater exposure to natural gas and gas prices. The German utility E.ON has acknowledged that the residential and industrial sectors, which use three-quarters of the country's gas, are highly exposed to its prices.<sup>13</sup> In contrast, most of Japan's residential sector uses kerosene for space heating and thus overall penetration could increase significantly if given the right infrastructure. On the other hand, the high cost of natural gas compared to electricity may lead to a preference for electricity as a fuel of choice for heating and cooking.

### **Storage Capacity**

The U.S. Department of Energy (DOE) wrote in its report on price volatility, "storage dynamics have a dominant role in influencing volatility levels" in the United States. Storage levels have been shown to be clearly linked to volatility, which is greater when storage levels rise above or below five-year averages.<sup>14</sup> Storage can be expected to have a similar impact on unregulated markets outside the U.S. Storage allows sellers to regulate supply into the market, and provides a buffer to ensure that seasonal demand

fluctuations are absorbed from the supply side without interruptions. The greatest effect of storage in a natural gas market is to indicate to buyers, producers, and sellers whether a market is adequately supplied with an excess margin that can absorb demand shocks. Storage capacity is determined by investment levels but is limited by space and geology, since depleted gas fields, aquifers, and underground salt domes provide the natural repositories that enable quick injections and withdrawals. Upstream, midstream, and downstream players in the natural gas market may all make use of storage to varying degrees, although the largest storage capacities are found upstream.

### *United States<sup>15</sup>*

The U.S. made use of roughly 400 storage sites in 2009 that had a maximum working capacity of 4.3 Tcf of natural gas, or 19 percent of one year's demand. The U.S. makes extensive use of natural underground formations for gas storage, which require greater volumes of "cushion gas" than man-made storage tanks. As a result, total storage volume is roughly twice the usable ("working") capacity. Since most U.S. production serves the domestic market, the large storage resources primarily benefit domestic markets, but with excess LNG capacity and a growing international trade in natural gas, U.S. storage will increasingly benefit natural gas consumers around the world.<sup>16</sup> In order for this to happen, though, U.S. LNG terminal owners need to invest in facility upgrades that make them capable of "backhauling" – transporting natural gas against the usual direction of flow.

### *United Kingdom and Germany*

The United Kingdom has only enough underground storage capacity to fill four percent of demand. The lack of storage capacity stems from the fact that until recently the UK had access to a surplus of production capacity in the North Sea, and once that surplus reversed the market lacked incentives for developers of storage capacity. This is beginning to change as the government streamlines permitting and creates other incentives.<sup>17</sup> A new offshore storage project is expected to increase storage capacity by 40%.<sup>18</sup> Demand fluctuations in the meantime are handled through swing capacity that can be activated as needed. The reversible Interconnection pipeline provides the UK some access to the comparatively larger storage resources in continental Europe, where storage capacity equals 14 percent of demand. Germany's storage capacity is higher than average, corresponding to about 21 percent of annual consumption, and plays an important role by absorbing disruptions to Russian supplies.<sup>19</sup>

### *Japan and South Korea*

Asian natural gas storage capacity is generally limited given the absence of production fields. Large scale LNG storage has been discouraged due to safety concerns, high energy costs, and space constraints, but advances in safe storage technology have enabled the construction of several large-scale facilities, such as

one Korean facility that has storage capacity for 107 million cubic feet.<sup>20</sup> Across Asia, storage capacity is around eight percent of consumption, all of which is in LNG.<sup>21</sup>

### ***Storage and Price Volatility***

Storage can play a central role in mitigating price volatility by easing the tenuous balance between supply and demand. Of the five countries analyzed here, the U.S. and Germany have the largest relative storage capacities; the U.S. is the largest in absolute terms. In the current system of mostly isolated regional natural gas markets, storage is advantageous because it provides flexibility. But in a world with a global LNG trade, domestic storage becomes everyone's storage. It may be worth examining the potential dynamics of the growing global LNG market to consider how storage capacity might be used most strategically by the U.S.

### **Market Competition, Regulation, and Pricing Dynamics**

The numerous iterations of natural gas market regulation over the past two decades illustrate the challenges of finding the right market mechanisms across the entire natural gas value chain. At the production stage, profit-seeking companies need to be able to capture economic rents as a reward for taking exploration risk. Midstream companies need to know that they will be able to earn a return on large capital investments in infrastructure for processing and transporting natural gas. Downstream buyers need to be able to procure reliable supplies with some certainty about future price levels. Vertical integration has its perils, as it can lead to unfair market advantages and monopoly pricing.

There is significant room for error in the regulatory puzzle, but market controls, contracting devices, and various incentives have been employed to provide a stable natural gas market for end users. This section presents an overview of some of the mechanisms used in each country.

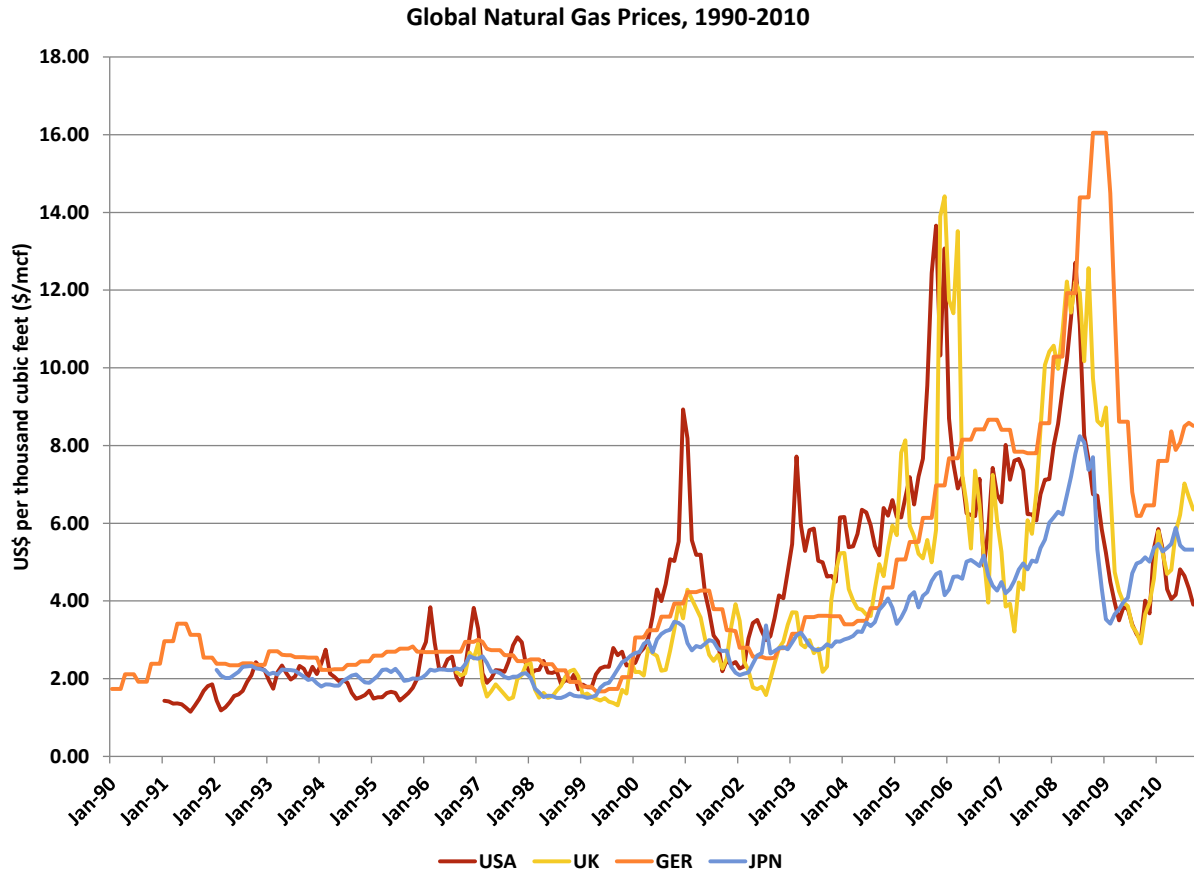


Chart 2: Average Monthly Natural Gas Prices, 1990-2010

### *The Law of Price Obscurity*

The actual natural gas price experienced by end users in any market is virtually impossible to discern except in a state-planned economy (but there the state is unlikely to hand over the information anyway). Chart 2 shows spot prices for U.S. natural gas at the Henry Hub, UK gas at the National Balancing Point (NBP), German gas coming from Russian sources, and Japanese LNG coming from Indonesia. The curve of actual prices paid by consumers in any given month would bear little resemblance to this chart because realized prices are a blend of numerous supply agreements ranging from one day to 25 years in duration. In Asian markets, in particular, most gas is procured through long term contracts, whereas the price index above refers to the spot price. Actual volatility experienced by Asian companies is likely to be much lower than is suggested by the spot price series. But because of the impossible task of figuring out an economy-wide average price for each country, this analysis focuses on spot prices since they represent the shadow price of natural gas – what a buyer would pay if it were to consume one additional unit of natural gas procured on the open market without recourse to hedges, contracts, or other price risk mitigants.

## *Market Regulation and Volatility*

### **U.S. and UK**

The U.S. left decades of price controls behind in 1989 with the passage of the Natural Gas Wellhead Decontrol Act and now has free-floating wellhead prices and a highly liquid trading market. Producers operate in a free price environment and under limited regulation, although several government agencies regulate drilling rights and operations. The midstream sector is regulated by the Federal Energy Regulatory Commission (FERC), whose Order No. 636 in 1992 was the final pen stroke toward creating competitive markets for transportation, storage, and marketing of natural gas. The Order enables local distribution companies (LDCs) to purchase gas competitively by requiring that pipeline companies publish information about the gas available in a pipeline at any given time.<sup>22</sup> Even though natural gas is a homogenous good, it is marketed as a differentiated product and at any point in time different suppliers could theoretically sell the same physical unit of gas at four different prices, depending on the deals they strike with buyers.

For the first fifteen years after deregulation the U.S. had the most volatile natural gas prices of all the regions studied. It also has the most deregulated and liquid natural gas market, which is no coincidence. The greater the share of natural gas that is traded in the short term, the greater the likelihood of price fluctuations. The same has been true in European markets: markets with less price regulation have higher levels of short term purchasing and more derivatives trading, and tend to experience higher levels of price volatility.

In the spirit of competition, the U.S. production, transmission, and retailing markets are populated with many different providers – 160 pipeline companies, 123 storage companies, 260 marketing companies, and 1,200 local distribution companies, according to the estimates of the Natural Gas Supply Association. A simple but illuminating observation about price volatility is that it tends to increase with the release of new information about natural gas markets.<sup>23</sup> Markets with a greater number of actors, operating in a greater number of places, with a more substantial and complex infrastructure base, will have a higher frequency of new information. It follows that the U.S. market – highly diversified from a supply perspective – will tend to have higher volatility. At the same time it has a fairly elastic supply base compared to other regions, because producers and storage facilities can be called online on fairly short order to respond to demand increases.

The UK went through its own process of deregulation during the 1980s but the market has not diversified to the same degree as in the U.S. due to the fact that there is less onshore production in the UK. Until 2005 the gas transmission sector was controlled by National Grid, which sold four of its eight

pipeline networks to other private companies. Centrica, which was spun off from British Gas, the former government-run gas company, still remains the largest distributor.

The spot NBP price has been highly volatile since deregulation because the UK has limited storage capacity and significant seasonal variations in consumption and production. The market has, moreover, been busy adjusting to its new status as a net importer.<sup>24</sup> The Interconnector allows UK firms to trade natural gas with Continental Europe on a limited basis. NBP prices have therefore been stabilized to a limited degree by the longer-term oil-linked contracts used in Europe. Nevertheless the UK market is dominated by short term purchases that are less correlated to the price of oil.<sup>25</sup>

### **Germany**

Over on the continent, Germany and other European markets are currently engaged in the implementation of the Third Gas Directive, which requires member countries to unbundle supply and transportation services by 2011. The decision to force this restructuring was taken in response to concerns that the gas market structure gave too much power to a few large, vertically integrated firms and the supply industry was not sufficiently competitive. The European Commission has provided a number of options for companies to comply with the Directive, ranging from asset dispositions to subjecting to tighter regulation and oversight by the Commission. It also has included a provision to prevent state-owned foreign gas companies from entering the market to buy assets, which would defeat the goal of the measure.<sup>26</sup> In addition to creating more competition in EU markets, the Directive is intended to increase energy security in the EU by encouraging greater intra-regional cooperation so as to avoid gas crises like the one experienced acutely in Germany in January 2009. Not surprisingly, Russia's Gazprom has objected to the forced unbundling, which it sees as a threat to its pricing power.<sup>27</sup>

The limiting factor for competition in Germany is the scarcity of distribution capacity, which is owned by NetConnect Germany and E.ON. Early in 2010 the European Commission ruled that E.ON, by booking large supplies of gas at import entry points, had booked enough of the transportation pipeline's capacity that it hampered new entrants into the gas market by limiting access to the market. The Commission ordered the utility to reduce the level of its booked capacity.<sup>28</sup>

Much of Germany's supply comes from long term oil-linked contracts with Russia's Gazprom. Over time, as Germany diversifies its supplier base and enhances its in-country infrastructure, market players may feel more comfortable with freer-floating prices. But the lack of responsive supply, and the relatively few market players, present structural challenges and do not lend themselves readily to a fully deregulated market.

## Asia

Markets in Japan and South Korea are far more controlled than those in Europe and the U.S., but more for structural reasons than out of a particular aversion to market-based pricing. Three-quarters of the natural gas supplier market in Japan is in the hands of three companies – Osaka Gas, Tokyo Gas, and Toho Gas – in spite of efforts by the Japanese government to increase competition in the market. Regulations allow utilities and natural gas distribution companies to sign LNG contracts directly with suppliers to mitigate price risk. The highly concentrated market structure does not favor liquid, short term trading.

Korea's gas sector is run by Korea Gas Corporation (KOGAS), the largest single LNG importer in the world. KOGAS controls the imports and wholesale market for natural gas, operates three of the country's four LNG terminals, and owns the country's only pipeline network. Retail distribution is handled by utilities, and gas is sold directly by KOGAS to power generation companies. KOGAS is one-quarter owned by the Korean government.

Natural gas buyers in Japan and South Korea are price-takers in the global LNG trade, to the extent that there is little swing capacity, no option to choose between dry gas and LNG, and competition from other buyers of LNG. KOGAS is looking to increase reliability and gain pricing power by buying into joint exploration ventures in overseas gas fields.<sup>29</sup>

### *Long Term Contracts and Indexed Pricing*

Simple logic and a wealth of empirical research have shown that long term contracts are an effective way to mitigate price volatility. Whether natural gas prices are systematically lower or higher in long term contracts is a matter of debate, and there may be no clear answer. Both buyers and suppliers entering into such contracts are seeking to mitigate risk by securing either fixed prices or prices indexed to the global oil price, but it is not clear whether the premium buyers are willing to pay for price certainty is greater or less than the discount sellers are willing to offer for the opposite end of the deal.<sup>30</sup>

Long term contracts were ended in the U.S. during deregulation in the mid-1980s but are still used in all of the other four regions of study, although the UK has moved mostly to an over-the-counter market structure and any long term contracts tend to be index-linked, rather than tied to the price of oil. The European Commission has taken a negative stance on long term contracts, arguing that they act as a barrier to market entrants who inevitably must buy gas at more volatile market prices.<sup>31</sup>

As mentioned above, pricing in Asia is driven by the international LNG market, although the terms of purchases are negotiated individually and the use of long term contracts may be waning. Many active

contracts today date to the 1970s and 1980s when the dynamics of the natural gas market were wholly different.

Contracts for pricing natural gas tend to follow several different models. Whereas European contracts use prices indexed to oil, oil products, and fuel substitutes, Japan and Korea (along with Taiwan and China) index LNG contracts to oil prices directly. The formula for LNG prices in Japan is calculated from a base price of a basket of crude oil imported into Japan, known as the Japanese Crude Cocktail (JCC), which is often slightly below the U.S. West Texas Intermediate (WTI) crude price. The index is weighted by an agreed upon amount, and then adjusted in proportion to one or more weighted inputs, such as the price of other commodities.<sup>32</sup>

Historically Japanese long term contracts have been written in “take-or-pay” terms, where the buyer takes volumetric risk on the commodity and is prohibited from reselling it. In fact the short term market for LNG did not exist before 1990.<sup>33</sup>

Much uncertainty lies in the future of East Asian natural gas purchases. On the one hand, import-dependent countries such as Japan and Korea depend on the certainty of supply and pricing that comes from a long term purchase. But as the global LNG market grows, and the U.S. stands ready to enter with its storage capacity and promise of massive reserves, pricing dynamics could shift fundamentally, leading to significant increases in short term trading volumes.

In any case, renegotiation of terms seems inevitable, as the relatively recent entrance of China as a natural gas importer has changed the demand side of the equation. Recently an Australian LNG producer agreed to sell to China at a 20 percent discount to what Japanese buyers were paying.<sup>34</sup> KOGAS has so far held to a long term contracting strategy, using spot purchases mostly to correct supply imbalances. However the share of gas purchased through long term contracts fell from 99% in 1998 to 77% in 2007, signaling a fundamental shift in procurement strategies.<sup>35</sup>

### **III. Natural Gas Volatility and Corporate Earnings**

One of the end goals of this report is to gain insight into the effects of natural gas price volatility on the U.S. economy and others around the world. The questions are straightforward. Does natural gas price volatility have a negative effect on overall economic output, thereby placing at a disadvantage those countries that face higher volatility levels? How does volatility impact corporate investment, and does it show up in corporate earnings?

The ideal way to determine this would be through a detailed econometric modeling exercise to identify the impacts that natural gas market prices have on corporate earnings and GDP growth, controlling for

unrelated factors. This is not within the scope of this exercise, but could be considered by the Task Force for future research.

Aside from being a tremendously complex undertaking, one of the challenges of such work is that backward-looking analysis of corporate behavior may or may not provide insights into how markets will react in the future. In all of the markets considered in this report, the past five years have seen unprecedented price variability in natural gas prices, but in spite of sustaining numerous short term price jumps over 100 percent, none of the economies has suffered the consequences that one might have expected *a priori* in a world with so much unexpected variation in the cost of an essential input. The expected consequences might have included widespread inflation, consumer and corporate bankruptcies, massive earnings declines, the exodus of fuel-dependent businesses, and aggressive fuel switches.

### **Corporate Price Exposure and the Motive to Hedge**

In reality none of these things has come to pass. One explanation is that price volatility is actually quite familiar territory for companies that are sensitive to movement in the price of any single exogenous factor – whether that be the cost of steel or labor, a change to interest rates, or foreign exchange rate volatility. Oil, too, has been market-traded and volatile for decades. In the 1980s alone the decade opened with nominal prices at \$35 per barrel; they subsequently moved up above \$40, down below \$10, and settled back up near \$20 by the end of the decade – to say nothing of the price fluctuations in the 1970s. Price volatility has been a clear and present risk since the invention of capitalism and hedging strategies have tended to evolve in step with buyers' and sellers' needs to insulate themselves from price shocks. Indeed the first mention of futures contracts dates to the time of Aristotle and modern futures trading has been in existence for several hundred years.

This analysis and others have looked at the spot price for natural gas because it represents the price a buyer would pay on a given date to procure the commodity in the market. (In economic terms this would be referred to as the “shadow price.”) The actual price experienced by the end buyer is a composite of many different contracts, ranging from day-ahead purchases to 25-year contracted supply agreements. While some contracts have transparent prices, price data for others are impossible to obtain.

Even if it were possible to identify the actual composite price of natural gas paid by a given end user, price is only the beginning of the story. Inevitably the commodity expenditure is followed up by hundreds of other decisions before a final economic outcome is realized. Decisions are made both over the short run (less than one year) and the long run (more than one year). Over the short run, as an example, a power company dispatches electric generating units based on the spark spread – the margin between the cost of fuel and the cost of power. A fertilizer or a polyethylene manufacturer may choose temporarily to

increase production activity at one facility where spot natural gas prices are lower, and reduce production where they are higher. Over the long run, price signals will be reflected in investment decisions. These signals will be based on the expected average price of fuel, rather than the spot price – inclusive of all hedging costs, fuel substitutes, and other adjustments that can and will be made to maximize gross profit margins.

Customer prices are also a major factor in determining how natural gas price volatility affects a company. If gas price increases can be passed on directly to customers, the actual effect of an increase in wellhead price could be borne directly by, say, a German household burning gas to stay warm in winter – not the gas retailer itself. More likely there will be some form of regulatory protection to smooth out prices over time, as seen in the U.S. retail gas utility market where rate increases must be approved by a regulatory body (often a public utility commission), which most often creates a lag between the initial price shock and the impact on the consumer.

The result is a strong incentive for the most exposed buyers to employ a variety of techniques to stabilize prices over time. A typical rule for companies in the U.S. is to hedge 80 percent of year-one consumption, 40 percent of year-two consumption, and 10 percent of year-three consumption. This approach provides near-term certainty about input costs while providing freedom to adjust as market conditions evolve. The decision of when, how, and how much to hedge is individual and highly variable. As written in another Task Force report:

“Depending on their size, diversity of products and markets, types of competitors, ability to pass on costs, regulatory oversight, demand predictability, horizon of investing and contracting, and ability to make non-financial adjustments to operations as gas prices rise or fall, [buyers] may have little or no use for hedging, or a very strong need.”<sup>36</sup>

Contrast this, for example, with 25-year oil-linked LNG contracts and it is clear that the U.S. approach enables buyers to adapt to structural changes in the gas and oil markets, such as the decoupling of gas and oil prices that has been a factor since 2007. (Historically WTI prices were linked to oil prices with a 6:1 ratio, which corresponds roughly to the relative heat content of a barrel of oil and a thousand cubic feet of natural gas. At today’s prices this ratio is closer to 20:1.)

A big issue in Asian economies is *not enough* variability in pricing, as a result of the binding terms of LNG contracts. As a result many firms are moving, if not to free-floating prices, at least toward demanding “price re-opener” clauses in their supply purchase agreements.<sup>37</sup>

Because of hedges, the economic effect of a period of natural gas price volatility is impossible to quantify because only a small fraction of consumption is procured at spot prices. And because only a small fraction

of futures contracts are settled for physical delivery, the futures price is similarly an imperfect representation of final prices. Trading volumes on financial markets are 10-12 times the volumes in physical (spot) markets and feature a wide range of contracts, delivery dates, and prices.

### Corporate Earnings Analysis

Corporate hedge positions are reported to varying degrees on financial statements, although rarely in much detail. Extraordinary impacts on a company’s earnings (if any) may be explained in the Management’s Discussion and Analysis (MD&A) section. This section of the report looks at financial results for 12 companies in the five countries covered by this paper. It focuses specifically on clearly disclosed gains and losses due to hedge portfolios, as well as pertinent comments in the MD&A. The time periods were chosen based on historical volatility: 2005 for the U.S., 2006 for the UK, and 2008 for Germany, Japan, and South Korea. The companies are shown in Table 1.

Company	Country	Sector	Natural Gas Need
Dow Chemical	US	Materials	Feedstock for chemicals
Exelon	US	Utilities	Electric power generation
Agrium	US	Materials	Feedstock for fertilizers
National Grid	UK	Utilities	Power & gas gen/distrib
Centrica	UK	Utilities	Retail gas distribution
BAE Systems	UK	Industrials	Internal energy use
BASF	Germany	Materials	Feedstock for chemicals
Siemens	Germany	Industrials	Feedstock; internal energy
E.On	Germany	Utilities	Power & gas gen/distrib
Tokyo Gas	Japan	Utilities	Retail distribution
Kepeco	South Korea	Utilities	Electric power generation
Samsung	South Korea	Industrials/I.T.	Internal energy use

Table 1: Natural Gas Price-Sensitive Companies

Following is a summary of the reported impacts of natural gas prices for the “shock years” chosen. All of the information is as reported in financial statements, with the earnings impacts estimated based on the companies’ itemized statements and their comments on how the price environment affected results.

#### ***Dow Chemical (2005): earnings unaffected***

Revenues on hydrocarbons and energy sales increased 29 percent mainly due to price increases. The cost of purchased feedstocks increased 26 percent due to price. Feedstock cost increases resulted in feedstock accounting for 47 percent of total production costs and operating expenses, up from 43 percent in the prior year. Cost pass-through was possible because of favorable industry supply/demand balances.

***Exelon (2005): earnings unaffected***

Fuel adjustment clause allows company to recover excess cost burden through quarterly adjustment to rates. No impact on revenues.

***Agrium (2005): earnings unaffected***

Nitrogen production costs rose 37 percent from 2003-2005 because of natural gas price increases. Temporarily idled several facilities to limit exposure to high prices, and increased imports from offshore sources. Adjusting production rates and sourcing supply helps reduce exposure to high natural gas costs.

***National Grid (2006): earnings +18 percent***

Gains on hedging instruments added £40 million to net income.

***Centrica (2006): earnings -65 percent***

High wholesale prices resulted in large loss to British Gas Residential. Customer loss prompted significant restructuring of rates and services. Financials mention “over-exposure” to wholesale energy costs. £931 million loss from mark-to-market of energy portfolio.

***BAE Systems (2006): earnings +86 percent***

Company uses fixed-price sale contracts, which limits ability to pass through costs. However the company’s hedge portfolio added £909 million in value.

***BASF (2008): earnings -2 percent***

Slight negative impact due to higher natural gas costs and inability to pass through immediately to customers. BASF also booked losses on derivatives portfolio used for hedging.

***Siemens (2008): earnings -1 percent***

Greatest impact was due to the indirect effect that energy price fluctuations had on global macroeconomic conditions. A slight loss was recorded on the hedging portfolio.

***E.On (2008): earnings +0.5 percent***

Company was able to raise prices to customers in 2008 to compensate for higher input costs. It also makes extensive use of trading and hedging capabilities and was thus able to limit the impact.

***Tokyo Gas (2008): earnings +1 percent***

Gas rate adjustment lag created a gap between rising costs and rising revenues, lowering earnings performance by 1.8 percent, but hedging was able to cover this with room to spare. Company implemented “special measures” to mitigate gas price impacts on the residential sector. Ten long

term contracts for LNG from six countries provide supply diversification and a high degree of price certainty.

#### ***Kepeco (2008): earnings unaffected***

Increased fuel costs led to higher prices for purchased power, but Kepeco was able to pass the additional costs through to its customers. The company also said the volatility triggered changes to management and a renewed emphasis on fuel price risk mitigation.

#### ***Samsung (2008): earnings unaffected***

Commodity prices appear on a long list of challenging conditions but did not materially increase business risks.

### **Discussion**

While this sample is by no means exhaustive or statistically rigorous, it suggests a pattern of adaptability in all regions. Shocks to the spot price may be due to variability in the underlying commodity price or variability in the costs of transport and storage, but the ultimate price experienced by the buyer is highly specific to each organization and determined by a company's ability to pass through fuel costs and take advantage of any fuel price hedges that are in place.

It is possible that short, sudden spikes in the spot price, followed by returns to pre-spike levels, will increase measured price volatility but will not have a material impact on corporate earnings. Companies tend to find ways to cope, whether through the use of hedging, strategic reinvestment and repositioning, or other means. Dow Chemical, for example, is reportedly considering vertical integration into hydrocarbon supplies so as to achieve more certainty around its input costs.<sup>38</sup> According to its 2009 10-K, Dow's expenditures for hydrocarbon feedstocks and energy in 2009 accounted for 35 percent of its production costs, procured through a combination of short- and long-term contracts.

The review of financial performance led to another interesting observation. For companies with multi-national operations, foreign exchange rate risk was equally troublesome as – if not entirely more severe than – the risk of natural gas price fluctuations. The earnings impacts of currency fluctuations were often described as being highly significant and given as much attention as energy price impacts.

On the other hand, the risk of unstable long term prices has undoubtedly led some businesses to shutter factories or forego investing in certain markets altogether. This happens when price risks and the expected costs of hedging are not justified by the expected returns on investment. Greater volatility pushes hedging costs up, because the premium for price certainty is linked to the implied volatility of the

underlying commodity. So even though economic costs do not clearly show up in the data above, they aren't zero.

Finally, high prices and high volatility are not one and the same. Higher prices have not been correlated to higher volatility; rather, volatility is highly sensitive to storage levels, with the greatest volatility happening when storage levels are above or below 5-year averages. Cold months have also been shown to be a statistically significant indicator of greater volatility, as short term demand rises.<sup>39</sup> For this reason, companies often include weather derivatives in their portfolio of hedging instruments.

### Observations

Even when companies are exposed to natural gas price shocks, strategic and financial hedges appear to offer sufficient protection from risk to mitigate substantial earnings shocks. This claim should be taken within the context of a small sample set and the fact that the analysis looked at single-year earnings performance. It does not capture any negative long term effects that may be wrought by price volatility. But over the short term it offers an encouraging insight, namely that large companies have access to many mechanisms to reduce their price sensitivity:

1. Proactively by hedging through financial instruments, building storage capacity, and lining up redundant supply relationships
2. Reactively by redirecting resources and reorienting production toward facilities with the lowest production costs
3. Implicitly by diversifying their businesses so that they have both long and short exposure to the cost of inputs

Through all of these methods, corporate plans are fortified and adjusted in real-time to cope with changing price conditions and ensure that natural gas – in spite of its high volatility – is just another input cost.

Hedging instruments may not always offer risk protection at a reasonable cost. Indeed some businesses have surely avoided investing in the U.S. market because the volatility of natural gas prices, and the cost of stabilizing them, raises input costs beyond an acceptable level. The negative impacts on the U.S. economy are likely to be felt over time and would escape notice under a single-year analysis.

In addition to the gaps already mentioned, two important topics fall outside the scope of this analysis: electricity prices and the sub-multinational business and consumer segments. First, electricity prices in many markets are likely to be tied to the price of natural gas, which is often the price-setting marginal fuel. Finding and analyzing data on electricity prices is a complex undertaking given the complexities of

dispatch decisions and the way commercial electricity prices depend on time of day, transmission costs, capacity, and other factors. A future analysis might consider the multiplying effect that happens when companies have exposure to natural gas prices through both the price of gas itself and the price of electricity.

A second topic ignored by this analysis is the effect of natural gas prices on small businesses and the consumer segment, which are not as well positioned to hedge, either financially or strategically, given their small financial scale, the simplicity of their operations, their lack of negotiating leverage, and their inability to integrate vertically. Future research might consider the impact of price volatility on these important segments of the economy.

#### **IV. Global Commodity Price Volatility<sup>40</sup>**

The analysis shifts now into a more quantitative gear, broadening its scope and looking at prices of global commodities during the 1990-2010 timeframe. The focus is on how natural gas price volatility compares to volatility in agricultural and industrial metals commodities. As above, electricity prices are not included because of the difficulties involved in data discovery and the highly regional nature of price variations. The commodities include: aluminum, copper, iron, lead, corn, nickel, oil, soybeans, wheat, and the four regional natural gas price levels in the U.S., the UK, Germany, and Japan.

##### **Price Return vs. Price Level**

Throughout the first part of this analysis the graphs refer to “price return” rather than “price level.” The U.S. Department of Energy released a thorough analysis of volatility in natural gas prices in 2007 that has been referenced numerous times by recent reports on the natural gas market because it presents a clear explanation of the notion of volatility.<sup>41</sup> To wit, volatility is defined separately from variability as the standard deviation of log-normalized *price returns*, multiplied by the square root of the number of periods.<sup>42</sup> For a detailed explanation of the statistical theory behind this formula it is worth consulting the DOE report. Some studies on volatility have simply used the standard deviation of the price level, but what’s lost with this approach is the insight that comes from understanding *relative* percentage changes in the natural gas price. A two dollar jump in price is very different if the starting point is two dollars (100 percent) compared to ten dollars (20 percent). Price return measures the percentage price change from one period to the next, providing a clearer sense for the relative magnitude of a price movement between the periods.

##### **A Brief History**

Global commodity price trackers had a fairly dull job for the 50-year period after World War II up until the beginning of the 21<sup>st</sup> century. This was especially true in non-energy commodity prices, which

declined in real terms over that period and, with the exception of some bumps in the 1970s, were fairly stable. Energy prices were equally stable until the supply shocks of the 1970s, which caused severe but temporary spikes before prices dropped back toward earlier levels.

Things have been different more or less since the year 2000, when commodity prices shifted to a new phase. It remains to be seen whether the observed price volatility in this new decade marks a transition to a permanent state of volatility, driven by supply scarcity and constantly shifting supply and demand dynamics, or is simply a cyclical phase on the way toward a secular pattern of steeper long term price growth. The decade from 2000-2010 contained just about every exogenous price influence imaginable. It was preceded by a period of strong global economic growth, with demand at cyclical highs. Yet supply had not yet caught up with this demand, as many firms were slow to make the investments in production capacity to match the greater demand levels. An increase in growth in emerging economies drew down the global appetite for the U.S. dollar, which was further weakened by two recessions over the ten-year period. Meanwhile money supplies were loose, with interest rates low and government spending on the rise, fueling price inflation. These drivers were coupled with a global surge in demand for biofuels, leading to (mostly unrealized) fears that food supplies would be redirected to energy uses. The result was a massive price run-up in virtually every commodity that peaked in 2008.<sup>43</sup>

### **Comparisons of Volatility**

To begin, Chart 3 presents a busy but illustrative picture of monthly relative price changes over a 20-year period for a basket of energy and non-energy commodities, chosen based on their centrality to the global economy. The graph gives a sense for relative price changes and periods of volatility, with natural gas prices in red and other commodity prices in gray. There is a clear pattern of higher volatility among natural gas commodities than other commodities, and of a transition over time to greater and more frequent price movements outside of the single standard deviation bands. In particular, from January 1990 to 2004 there are fewer price spikes than from 2004-2010, when price movements grow more severe, punctuated by the steep full-market price drop in 2008. The effects of certain global events are also visible on the chart in periods of higher co-movement and variability of prices: (1) the first Gulf War; (2) U.S. natural gas storage reaches all-time lows; (3) the dot-com bust and ensuing U.S. recession; (4) the global financial crisis and ensuing economic damage.

**Monthly Relative Price Changes  
Natural Gas and Other Commodities, 1990-2010**

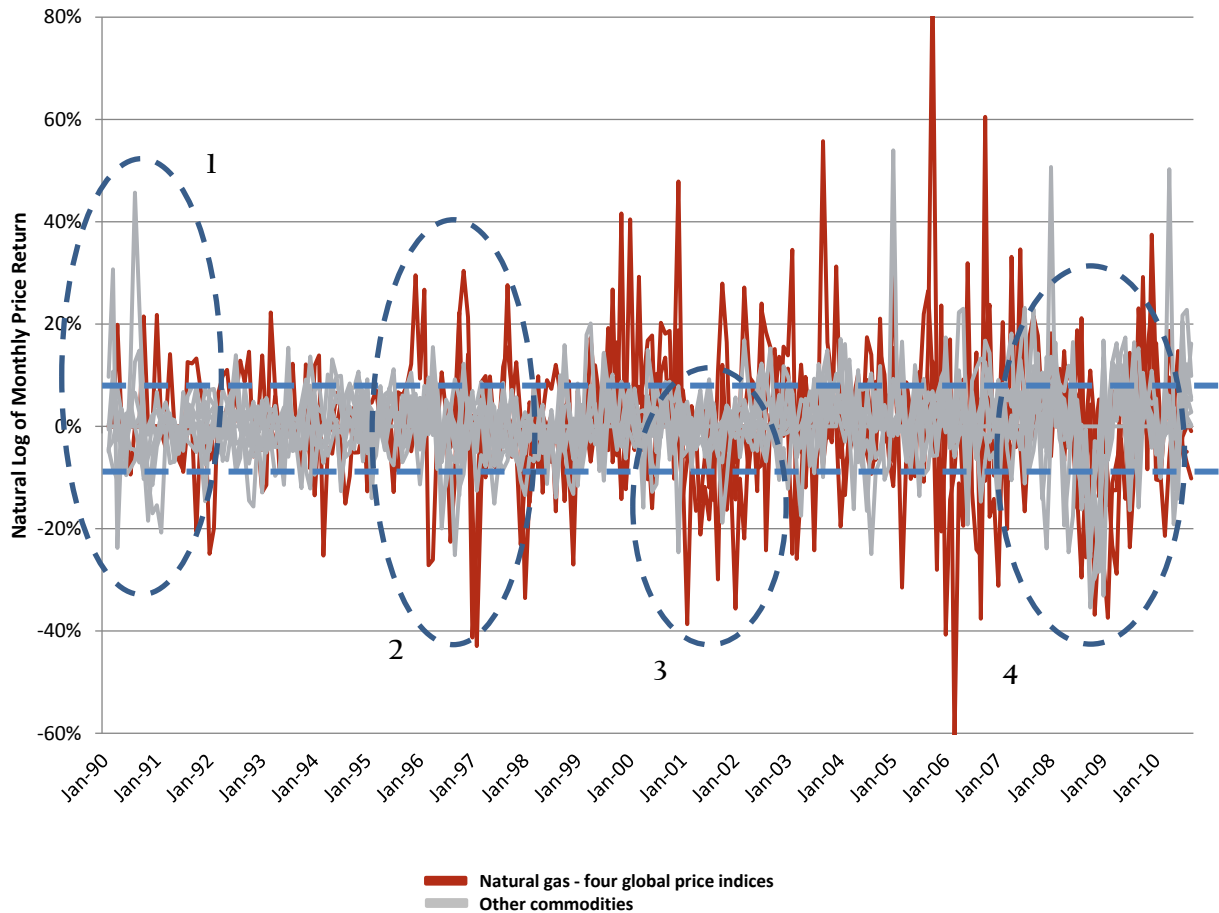


Chart 3: Monthly Price Changes, Selected Commodities, 1990-2010.

*Volatility increases over time among global prices, with well-defined event-driven periods of volatility and a pattern of higher volatility among natural gas commodities than among agricultural and metals commodities.*

Chart 4 presents a histogram of the same price return data for the same period. The three lines correspond to the distribution of price movements in (1) all commodities except natural gas, (2) the four natural gas indices, and (3) U.S. natural gas prices on their own.

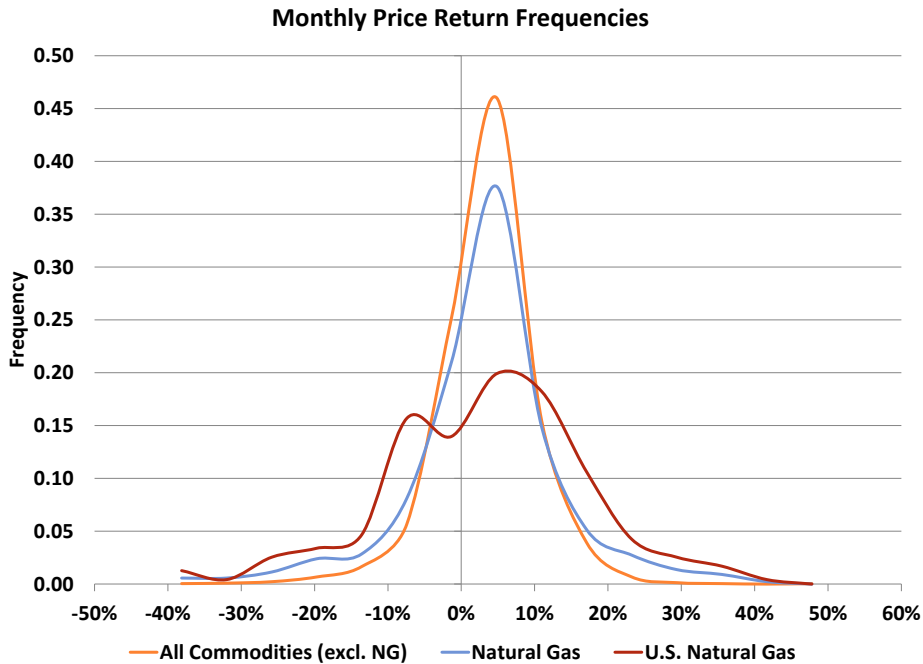


Chart 4: Monthly Price Returns for Natural Gas and Other Commodities, 1990-2010.

*U.S. natural gas prices have “fatter tails” than other commodities and the whole basket of natural gas prices.*

*Natural gas on the whole is more likely to experience larger monthly price movements than other commodities.*

The distribution of price returns for the general basket of commodity prices is taller and narrower than that of the combined four natural gas price levels in the U.S., UK, Germany, and Japan, suggesting a narrower range of price movements. U.S. natural gas prices have a much wider distribution around the mean. This so-called “fat tail” curve indicates greater volatility in U.S. natural gas prices than in other commodities. Further, a positive mean for all commodities indicates an upward price trend over the period – prices have been more likely to move up than down.

Applying the aforementioned DOE formula for price volatility to the full-period commodity prices shows that natural gas price volatility has exceeded volatility in all other commodities (Table 2). UK natural gas has the highest price volatility of all commodities. This can be explained in part by the shorter time series (data for UK prices are only available from 1996-2010) and the fact that the UK market’s structure benefits from fewer price cushions, as described earlier.

Table 2: Full-period monthly commodity price volatility, 1990-2010.

ALUM	COPPER	IRON	LEAD	CORN	NG-GER	NG-JPN	NG-USA	NG-UK	NICKEL	OIL	SOYBEANS	WHEAT
82.5%	106.3%	103.8%	121.9%	91.3%	65.5%	95.1%	214.5%	239.9%	135.9%	139.5%	91.4%	99.9%

U.S. and UK natural gas volatility far exceeds even those commodities that were notoriously shocked by the commodities boom of 2006-2008, including corn, nickel, and copper. Using the same volatility measure in a time series (Chart 5) shows that U.S. and UK natural gas price volatility was fairly high across the entire period, whereas commodity prices for other commodities began their upward trend in 2004.

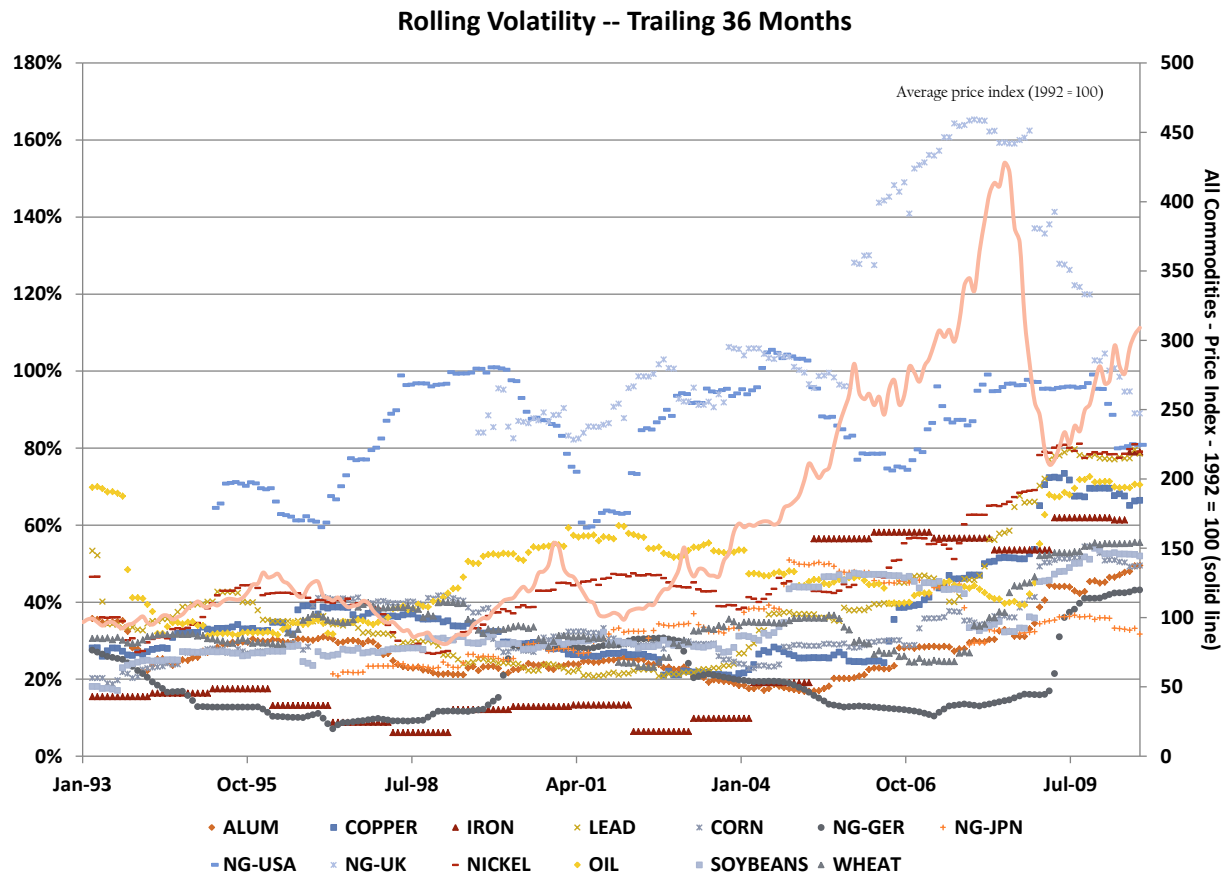


Chart 5: 36-month Rolling Price Return Volatility, Selected Commodities

*A time-smoothed chart shows that natural gas prices in the U.S. and UK have been more volatile than other commodities, and that overall higher commodity prices appear to have been met with higher volatility.*

### Observations

Natural gas prices in the U.S. and UK have been more volatile than other commodities, including those that were at the center of the global commodity price boom in 2006-2008. U.S. price volatility appears to be somewhat cyclical on a 3-year rolling basis, with oscillations between 60 and 100 percent over five-year periods. Yet it would not be fair to say that volatility is predictable. Research has shown that it is more linked to short-run influences such as weather and storage than to any long term pattern.

Commodity prices on the whole appear to be getting more volatile, having shifted from a fairly calm 15-year period from 1990 to 2004, to an upward trend from 2004 to 2010. Whether this represents the new normal is anyone's guess. The initial shock that led to the 2006-2008 boom appears to have subsided but many of the initial drivers remain, including greater demand from emerging markets and a rise in biofuel production. Whether these factors will simply push prices upward, or will in fact lead to higher average volatility, remains to be seen.

Finally, currency factors have played a role in commodity price movements, but the strength of the U.S. dollar is likely to have the smallest impact on U.S. natural gas. All of the global commodities are listed and traded in U.S. dollars, which lost value against other currencies during the period mid-2000s period. When the U.S. dollar loses value, the commodity prices rise, all else equal. But currency factors should play more of a role in pricing commodities that are globally fungible, such as corn. Prices for U.S. natural gas, which is mostly consumed in the U.S., should not be as sensitive to exchange rates since most domestic consumers and producers of natural gas have dollar-denominated balance sheets.

### Correlations between All Commodities

The next portion of this analysis focuses on price correlations within the selected set of commodities. The graphs in this section refer to actual price levels, rather than price returns, because the objective is to identify co-movement in prices and develop some intuition for whether natural prices are likely to move when other commodity prices are moving, and vice versa. Table 3 presents a correlation matrix for each of the commodities for the entire period from 1990-2010. Higher levels of correlation are indicated by darker cells.

Table 3: Price Correlation Matrix for Selected Commodities, 1990-2010

	ALUM	COPPER	IRON	LEAD	CORN	NG-GER	NG-JPN	NG-USA	NG-UK	NICKEL	OIL	SOYBEANS	WHEAT
ALUM	1.00												
COPPER	0.89	1.00											
IRON	0.67	0.84	1.00										
LEAD	0.79	0.91	0.80	1.00									
CORN	0.61	0.71	0.72	0.73	1.00								
NG-GER	0.70	0.78	0.86	0.72	0.69	1.00							
NG-JPN	0.81	0.87	0.86	0.81	0.67	0.87	1.00						
NG-USA	0.70	0.59	0.54	0.54	0.39	0.67	0.77	1.00					
NG-UK	0.71	0.67	0.67	0.61	0.59	0.78	0.80	0.77	1.00				
NICKEL	0.86	0.87	0.66	0.82	0.56	0.65	0.74	0.62	0.50	1.00			
OIL	0.84	0.91	0.87	0.86	0.70	0.85	0.97	0.76	0.79	0.77	1.00		
SOYBEANS	0.54	0.69	0.74	0.75	0.89	0.67	0.68	0.41	0.53	0.50	0.73	1.00	
WHEAT	0.67	0.75	0.69	0.80	0.88	0.71	0.71	0.49	0.69	0.60	0.75	0.84	1.00

Oil has the highest average overall correlation to other commodities, reflecting its central role in the global economy. Its price is closely linked to industrial metals and to Japanese natural gas prices, which have the highest correlation of any pair, reflecting the fact that many natural gas contracts in Japan are

linked to oil prices, as discussed earlier. Interestingly, some of the lowest correlations in the table are between U.S. natural gas and agricultural commodities. One might intuitively expect grain prices, which depend in part on the price of natural gas as a fertilizer feedstock, to be highly correlated to gas prices. One possible explanation is that the two are linked but lagged – it takes time for higher gas prices to show up in higher fertilizer prices, and it may take a full growing season before they show up in commodity prices.

Chart 6 shows average correlations for all pairs of commodities over rolling 36-month periods. The lines indicate the average price correlations between pairs of commodities. (Note that the data sets for natural gas prices do not span the full time period, so there are kinks in the curves where each additional gas price set begins.)

Non-gas commodities appear collectively to have become increasingly correlated to one another, as indicated by the general upward trend in the lighter (orange) line. Similarly, natural gas has gotten increasingly correlated to other commodities, as seen with the upward-sloping darker (blue) line.



Chart 6: Average 36-month Rolling Price Correlations

*Correlations between all commodities may be increasing over time. Natural gas on the whole does not always transition through periods of higher and lower correlation in the same way that other commodities do.*

Natural gas has behaved differently than other commodities during several periods. During the early 2000s natural gas prices tracked commodity prices more closely than correlations between non-gas commodity prices. Then during the period from 2006 to 2008 gas was less correlated as commodity prices ended their run up and then crashed. Natural gas prices moved independently during this period.

### **Natural Gas and Commodity Groups**

What follows now is a look at how regional natural gas prices have moved relative to three indices – industrial commodities, agricultural commodities, and metals. First up is U.S. natural gas, which displays a modest correlation to all three indices (Chart 7). Close matching between the lines suggests the high degree of correlation between all non-energy commodities that was observed earlier. In the early to mid ‘90s gas prices appear with zero to negative correlation to other commodities. U.S. gas markets were still adjusting to deregulation and did not yet have the robust and liquid derivatives markets that existed in other commodities. A notable split occurs with the gas-agriculture correlation line in 2003. Agricultural commodity prices did not run up as much as other commodities during this period. Lower correlation amidst the frenzied period suggests a more stable demand pattern for food-based commodities.

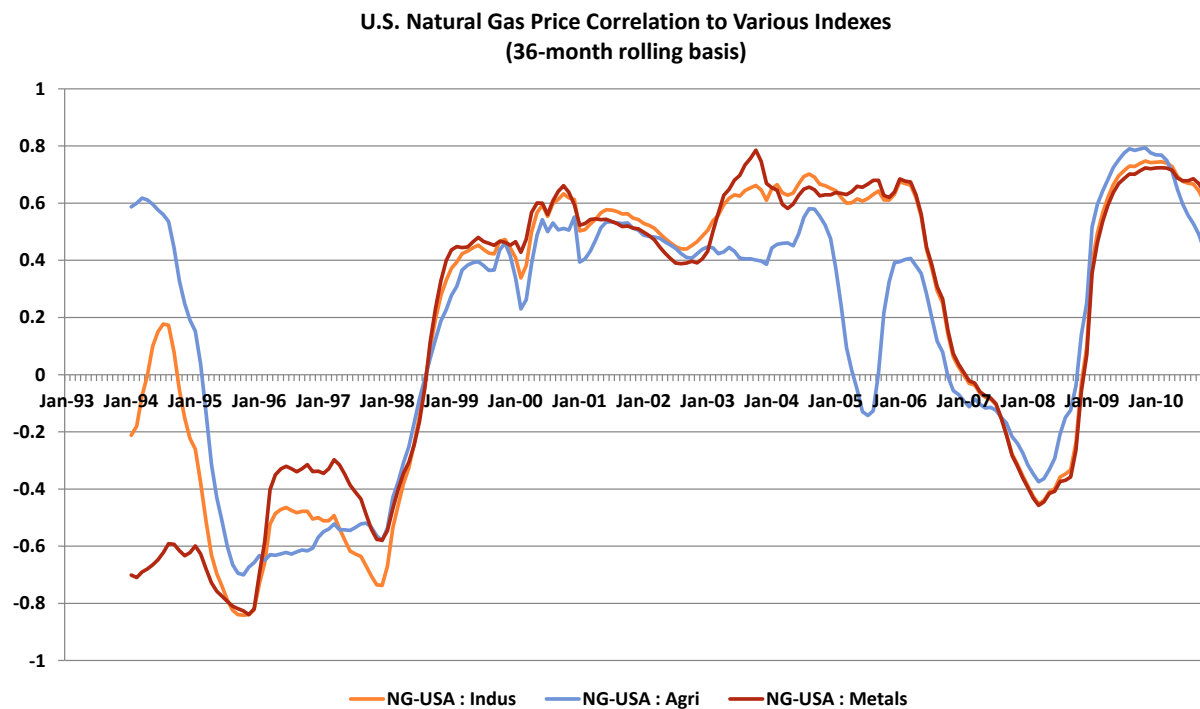


Chart 7: Average 36-month Rolling Price Correlations, U.S. Natural Gas

*U.S. gas prices are not always as highly correlated to agricultural prices as to other commodities. This stability may reflect the centrality of food commodities in the global economy.*

The UK time series in Chart 8 is shorter but exhibits a pattern similar to the others. Agricultural commodities drifted on their own in the early 2000s before all correlations dropped in the 2008-2009 timeframe. Oil-linked contracts in use in the UK likely influenced the NBP spot price and therefore helped push correlations with other commodities higher.

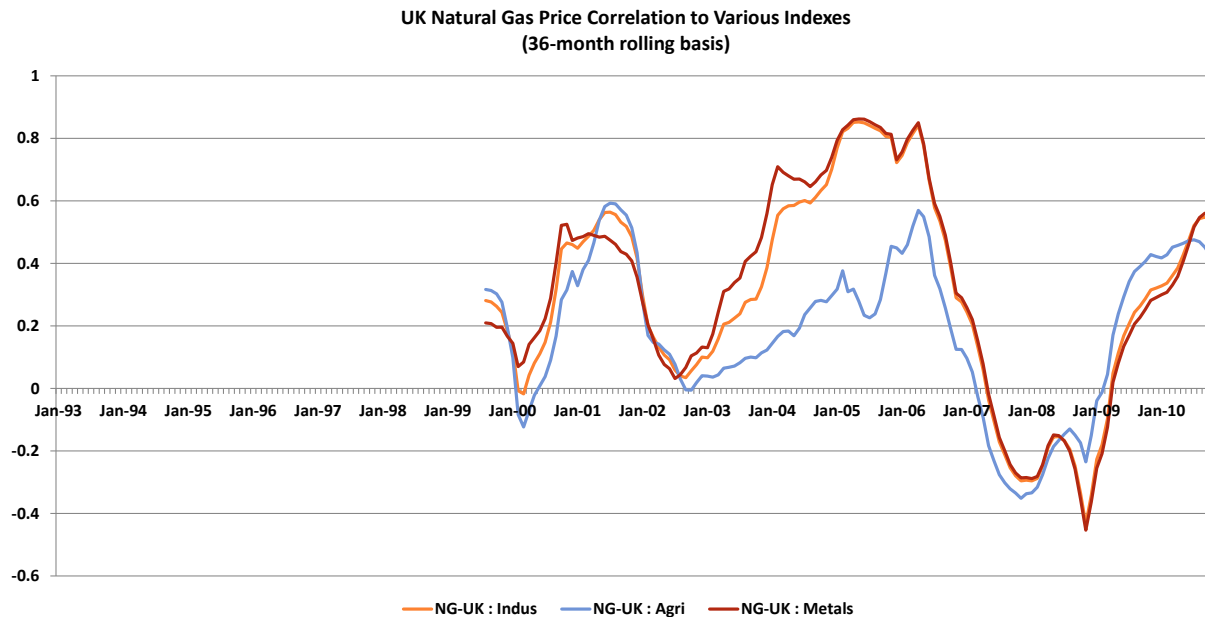


Chart 8: Average 36-month Rolling Price Correlations, UK

*Correlations fell during the commodity market boom of 2006-2008. UK natural gas was left out of the steep commodity price run-up and subsequent crash. As prices have stabilized since then, correlations appear to be regaining historical levels.*

German natural gas prices, measured through the price of Russian natural gas at the German gate, peak at a much higher level of correlation to the three indices (Chart 9). Their correlation is characterized by two humps, the first in the late 1990s and the second in the mid-2000s, both relatively calm intervals on the global economic scene. For German prices, economic dislocations appear to reduce correlations. This may reflect the delicate balance of German supply.

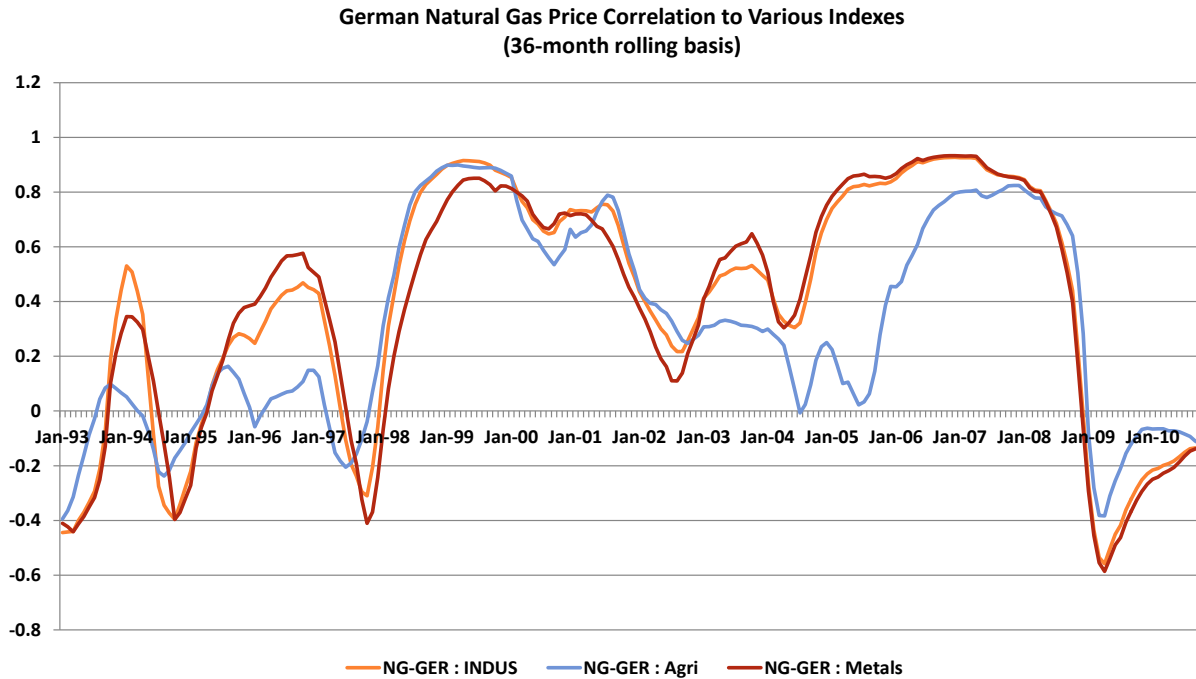


Chart 9: Average 36-month Rolling Price Correlations, Russian Gas at Germany

*Lower correlations happen during periods of economic dislocation. With few options for supply, when the going gets tough, German-gate Russian gas prices take on a life of their own.*

Finally, Japanese natural gas prices are correlated to a significant degree with the price of oil, and oil is correlated to the price of all commodities – and this is the governing principle behind the fairly high and steady levels of correlation in Chart 10. In addition to being correlated to oil, Japanese prices are also less volatile than both German and U.S. natural gas prices. It is difficult to explain the low correlations in the mid-1990s although the global economic shock from the Asian debt crisis and low oil prices may have been factors.

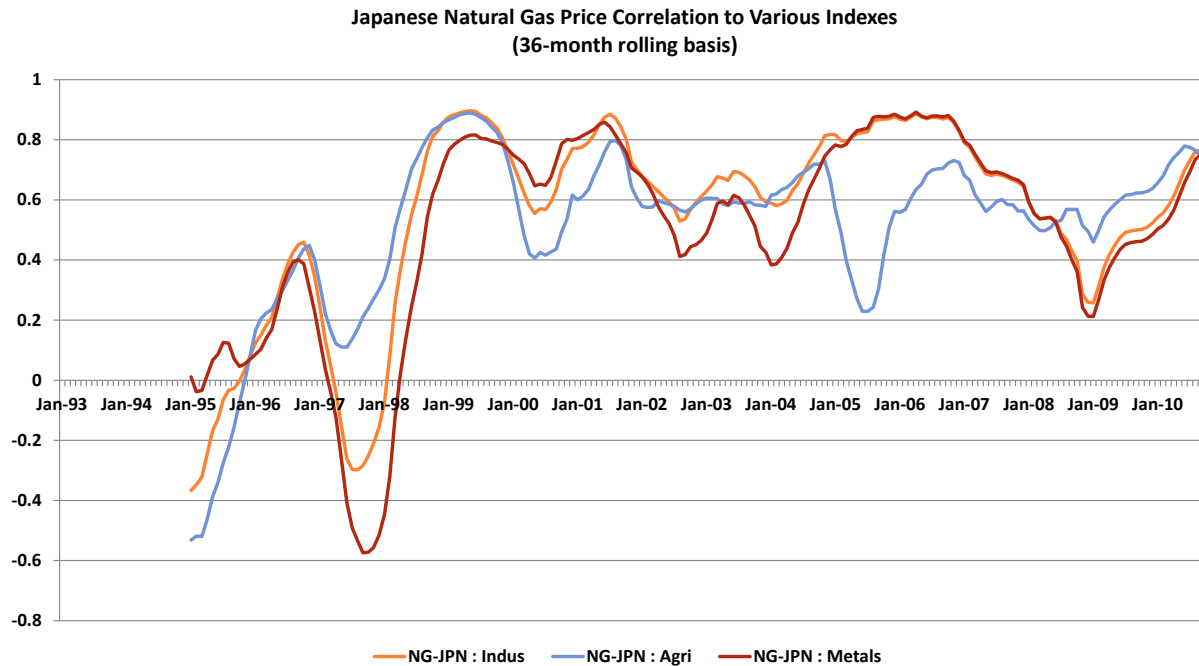


Chart 9: Average 36-month Rolling Price Correlations, Indonesian LNG at Japan

*With oil highly correlated to all commodity prices, and Japanese LNG linked to oil prices, correlations are high across the board. The same agricultural commodity index dislocation is seen here as in other graphs.*

### Observations

Natural gas prices appear to be linked fairly closely to other commodity prices in all markets except during times of economic dislocation. Under unusual circumstances, natural gas prices may follow their own market fundamentals rather than tracking broader commodity price movements. If natural gas consumers have exposure to multiple commodity prices, they are unlikely to find the economic shock during these periods magnified by high correlations.

Of the three baskets of commodities, prices in agricultural commodities seem to be most likely to split from natural gas prices. Again, this may provide some hope for consumers who are sensitive to both natural gas and food prices. The two won't always move together.

Finally, the differences between the regional graphs suggest that while global commodities are traded with a single price, natural gas prices remain decidedly regional and subject to the supply and demand characteristics of each market.

## V. Conclusions and Next Steps

The analysis presented in this report provides a foundation for a discussion about natural gas markets outside the U.S. as well as a handful of non-energy commodities. It shows that major structural differences between markets in the US, UK, Germany, Japan, and South Korea set up fundamental differences in the key drivers of pricing in each market – the ever-changing mix of supply, consumption, and storage. With history as a guide, the one certain thing is that these markets will never become static. Continuous movement and increasing interdependence will drive each country to refine its own unique regulatory approach to managing markets. Price shocks will no doubt continue, and each shock will inevitably create winners and losers.

The large corporations reviewed in the research appear to have managed price fluctuations over the short run by accessing financial and strategic tools to relieve the uncertainty and adjust their business plans. Individual companies may feel disproportionately affected by volatility, but from a policy maker's point of view the costs of coping with volatility are justified *at the economy-wide level* if they are exceeded by the benefits of having a free-moving natural gas market. This, of course, would require further effort to measure and evaluate.

Natural gas prices do not always move in step with other commodities, but the least regulated markets of the U.S. and UK have seen greater natural gas price volatility than a core set of other global industrial, agricultural, and metals commodities – this in spite of the notorious commodity market boom and bust cycle that happened from 2006 to 2008. Yet excess volatility in the natural gas market may not, in the end, be cause for alarm. Price volatility is both a necessary and permanent part of a liquid market, as concluded in a 2003 study by the American Gas Foundation.<sup>44</sup> It may be that, to paraphrase President Franklin Roosevelt, the only thing we have to fear is fear of volatility – not volatility itself. If a free and open market lets buyers, sellers, and traders innovate and use market-based tools to cope with price fluctuations, the net economic costs may be trivial.

### Policy Relevance

This analysis presents some goals to policymakers:

- ▶ Create and support a set of policies that preserve the unique characteristics of the U.S. natural gas market: a strong, diverse, competitive domestic supply base; ample coverage from transportation pipelines; robust storage capacity; diversified supply chain; liquid trading markets
- ▶ Recognize that short term supply and demand swings are inevitable in the natural gas market, and work to ensure that the system integrates mechanisms to cushion the impact
- ▶ Embrace some price volatility as it is an indication of a healthy market and offers market information that is not provided by fixed prices

- ▶ Consider the very real possibility that a global LNG market will develop, shifting some power to Middle Eastern producers such as Qatar; recognize that if U.S. producers choose to sell into this market the dynamics of supply and pricing may shift in the U.S.
- ▶ Understand the value of a diversified energy mix: the natural gas market has adjusted to shocks because its consumers come from all sectors, and because all sectors have access to fuel alternatives
- ▶ Provide access to financial, physical, and strategic hedging instruments at a reasonable price
- ▶ Implement programs to assist those segments of the natural gas consumer base that are less equipped to manage price risk proactively, such as small businesses and residential users
- ▶ Create incentives that fully account for the environmental attributes of natural gas as a fuel choice relative to other alternatives

The report has also raised a number of questions that might be worth addressing through future research efforts. These questions include:

*The future of LNG:* The U.S. is poised to become a major player on the global LNG scene, with a significant supply base and excess processing capacity. Other countries are building LNG terminals to reduce supply vulnerabilities and storage capacity. LNG is currently traded as a regional commodity, not a global one, but if a market emerges what will this do to natural gas prices in the U.S.?

*Middle market and individual consumer price sensitivity:* This report looks at how price shocks have affected a small sample of large multinational corporations, but these entities only represent one segment of the global economy – a segment that happens to be best positioned to take full advantage of a range of mechanisms to mitigate price risks. It is also worth considering the impacts on the residential and small commercial and industrial sectors, about whom financial information is more difficult to discover but on whom the impact of volatility is likely to be more severe.

*Electricity prices and natural gas:* Global electricity prices will be tied to natural gas prices wherever natural gas is used for generation and sets prices as the marginal fuel. Electricity, like primary fossil-based energy sources, is a fundamental input to the global economy and its price matters to consumers. Although electricity pricing is complex, natural gas price volatility in general could lead to higher volatility in electricity prices and complicate resource planning for the electric sector. Electricity may also be a substitute for natural gas in some markets. Future work might analyze this situation.

*Rigorous corporate earnings analysis:* A cursory review of corporate earnings history and natural gas price volatility is not enough to make compelling predictions about the effect of volatility on long term earnings trends. A deeper econometric analysis could analyze earnings data for companies for which natural gas accounts for a certain percentage of costs or revenues. The goal would be to isolate the effects

of natural gas prices and determine whether there is a statistically significant connection to earnings. A key consideration here would be to identify the ways that pricing power differs between companies and between industries.

*Volatility from a PR perspective:* The idea of price volatility may prove to be more fearsome than price volatility itself. Future work might evaluate public perceptions of volatility – however it is portrayed in the media – and find ways to manage negative reactions by shaping the message and providing facts to correct the record.

## **VI. Definition of Certain Terms**

### ***Backhauling***

The process of transporting natural gas through a pipeline or other infrastructure against the normal direction of flow. Backhauling often requires modifications to infrastructure to enable the flow reversal.

### ***Futures market***

A market where buyers and sellers transact in contracts that govern the exchange of goods at some point in the future. Most of the trades on a futures market never involve physical delivery of the underlying good. Futures markets are one way for traders to lock in a guaranteed future price since the contracts are binding between parties.

### ***Hedge***

A measure taken by a party to protect itself against a range of outcomes. There are numerous ways to hedge but the ultimate goal is to achieve a desired payout with the minimum amount of risk and uncertainty.

### ***Henry Hub***

The physical location in the State of Louisiana used as the common delivery point for physical units of natural gas. U.S. gas uses many regional price benchmarks but the Henry Hub is the most commonly cited.

### ***Japanese Crude Cocktail***

The average price of crude oil imported into Japan, which is typically used as an index for Asian LNG contracts.

### ***Liquefied Natural Gas (LNG)***

Natural gas that has been compressed can be transported and stored at cool temperatures as LNG. The use of LNG allows natural gas to be transported without the use of fixed pipelines and greatly expands the possibilities of global trade.

### ***National Balancing Point (NBP)***

The UK equivalent of the Henry Hub, the NBP is a virtual location for trading natural gas on the spot market.

### ***Shadow Price***

In a given economic scenario, the price of consuming or producing one additional unit of a good. The shadow price reflects the economic consequences of a decision that was not taken. It is instructive in that it captures the economic implications of something not happening.

### ***Spark Spread***

For a natural gas plant, the difference between the price of power and the price of natural gas used to generate that power. The amount is the gross profit margin that is used to cover operating expenses and capital costs.

### ***Spot market***

Gas purchased on the spot market is contracted and sold on a short term basis, often one day before delivery. Prices on the spot market are generated through short term transactions rather than long term contracts, forward purchases, or futures contracts.

### ***Variability***

Price variability refers to fluctuations in prices over time. Variability is expected and happens seasonally and in response to changes in market drivers. Variability is not to be confused with volatility, with a key difference being that variability often follows a pattern and may even be predictable.

### ***Volatility***

Price volatility (defined eloquently in the DOE study referenced herein) refers to relative price variation. Volatility is often seen as a measure of risk because it is unpredictable in magnitude, direction, and timing. Volatility may disrupt or compound normal variability.

### ***West Texas Intermediate (WTI)***

West Texas intermediate (WTI), also known as Texas light sweet, is a type of crude oil used as a benchmark in oil pricing and is the underlying commodity of New York Mercantile Exchange's oil futures contracts.

### ***Working Gas***

The usable gas contained in a storage facility. Not all of the reported storage volume of a given storage reservoir is accessible for withdrawal because it may be contained in tight rock formations, and because it may be necessary to keep the reservoir pressurized in order to enable withdrawals. Total storage capacity is the sum of “cushion gas” and working gas.

## VII. Endnotes

<sup>1</sup> This paper refers to “short” and “long” term. Although these terms are not exact, the usage is based on the financial convention wherein short term is anything less than one year and long term is anything greater than one year. The terms are occasionally used to invoke an economic sense as, for example, short run vs. long run investment decisions.

<sup>2</sup> “Managing Natural Gas Price Volatility: Principles and Practices Across the Industry,” Frank Graves and Steven Levine, The Brattle Group, July 2010.

<sup>3</sup> BP Statistical Review of World Energy 2010,

[http://www.bp.com/liveassets/bp\\_internet/globalbp/globalbp\\_uk\\_english/reports\\_and\\_publications/statistical\\_energy\\_review\\_2008/STAGING/local\\_assets/2010\\_downloads/statistical\\_review\\_of\\_world\\_energy\\_full\\_report\\_2010.pdf](http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf)

<sup>4</sup> Unless noted otherwise, country-level data taken from the EIA’s country analysis briefs, accessed at

<http://www.eia.doe.gov/cabs/index.html>

<sup>5</sup> Railroad Commission of Texas, Newark, East (Barnett Shale) Statistics, September 22, 2010.

<sup>6</sup> Chesapeake Energy, Haynesville/Bossier Shales,

<http://www.chk.com/operations/unconventional/pages/haynesvilleshale.aspx>

<sup>7</sup> UK Department of Energy and Climate Change, Energy Statistics. Accessed at

<http://www.decc.gov.uk/en/content/cms/statistics/source/gas/gas.aspx>

<sup>8</sup> ENI Distrigas corporate overview. Accessed at <http://www.distrigas.eu/content/germany/de-en/natural-gas-de-en/european-market-de-en.html>

<sup>9</sup> Consumption figures drawn from IEA’s energy database, accessible at <http://www.iea.org/stats/index.asp>

<sup>10</sup> BP Statistical Review. Cf. note 2.

<sup>11</sup> E.ON presentation to Gas Industry mCHP Workshop, May 2008, accessed at

<http://www.marcogaz.org/events/downloads/Session1/Situation%20of%20natural%20gas%20in%20the%20domestic%20sector%20by%20Stefan%20R.ppt>

<sup>12</sup> “Natural Gas Pricing in Competitive Markets,” International Energy Agency, 1998, accessed at

<http://www.iea.org/textbase/nppdf/free/1990/gp98.pdf>.

<sup>13</sup> E.ON. Cf. note 10.

<sup>14</sup> “An Analysis of Price Volatility in Natural Gas Markets,” Energy Information Administration, Office of Oil and Gas, August 2007. Accessed at

[http://www.eia.doe.gov/pub/oil\\_gas/natural\\_gas/feature\\_articles/2007/ngprivolatility/ngprivolatility.pdf](http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2007/ngprivolatility/ngprivolatility.pdf)

<sup>15</sup> “Underground Natural Gas Storage Capacity,” U.S. Energy Information Administration, accessed at

[http://www.eia.gov/dnav/ng/ng\\_stor\\_cap\\_dc\\_uus\\_a.htm](http://www.eia.gov/dnav/ng/ng_stor_cap_dc_uus_a.htm)

<sup>16</sup> “Natural Gas Security,” seminar materials from William Ramsay, International Energy Agency, January 2007, accessed at [http://www.iea.org/speech/2007/ramsay/natgas\\_security.pdf](http://www.iea.org/speech/2007/ramsay/natgas_security.pdf)

<sup>17</sup> “U.K. OKs First Step for Major Gas-Storage Site,” The Wall Street Journal, February 15, 2010. Accessed at

<http://online.wsj.com/article/SB10001424052748704431404575067101794535996.html>

<sup>18</sup> “UK Natural Gas Storage,” Financial Times, April 21, 2010, accessed at <http://blogs.ft.com/energy-source/2010/04/21/the-politics-of-uk-natural-gas-storage/>

<sup>19</sup> Cf. note 7. See also [http://www.cessa.eu.com/sd\\_papers/berlin/CeSSA\\_Berlin\\_104\\_Groenendijk.pdf](http://www.cessa.eu.com/sd_papers/berlin/CeSSA_Berlin_104_Groenendijk.pdf)

<sup>20</sup> “Inchon LNG Terminal, South Korea,” Net Resources International, accessed at <http://www.hydrocarbons-technology.com/projects/inchon/>

<sup>21</sup> “Prestressed LNG Storage Tanks in Japan,” Fujikazu Sakai and Yukio Mentani, Structural Engineering International, May 1, 1997.

<sup>22</sup> “The History of Regulation,” Naturalgas.org, accessed at <http://www.naturalgas.org/regulation/history.asp>

<sup>23</sup> “Volatility and Risk Sharing in European Gas Markets,” Frank Asche, Petter Osmundsen, Marius Sikveland, and Ragnar Tveteras, University of Stavanger, 2007.

<sup>24</sup> Cf. note 21.

<sup>25</sup> Ibid.

<sup>26</sup> “Liberalisation of the EU Gas Sector,” EurActiv.com, June 26, 2009, accessed at

<http://www.euractiv.com/en/energy/liberalisation-eu-gas-sector/article-171067>

<sup>27</sup> “Pipeline Politics? Russia and the EU’s battle for energy,” EurActiv.com, August 20, 2009, accessed at

<http://www.euractiv.com/en/energy/pipeline-politics-russia-eu-battle-energy/article-177579>

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- <sup>28</sup> “Antitrust: E.ON’s commitments open up German gas market to competitors,” European Energy Forum, May 4, 2010, accessed at <http://www.europeanenergyforum.eu/archives/european-union/eu-general-topic-file/eu-competition-and-economic-matters/antitrust-e-ons-commitments-open-up-german-gas-market-to-competitors>
- <sup>29</sup> Cf. note 3.
- <sup>30</sup> Cf. note 21.
- <sup>31</sup> Cf. note 24.
- <sup>32</sup> “A Formula for LNG Pricing,” Gary Eng, Report for the New Zealand Ministry of Economic Development, June 16, 2006.
- <sup>33</sup> “The Global Liquefied Natural Gas Market: Status and Outlook,” U.S. Energy Information Administration, accessed at <http://www.eia.doe.gov/oiaf/analysispaper/global/lngmarket.html>
- <sup>34</sup> Ibid.
- <sup>35</sup> “Supply and Demand Trends and Plans for Natural Gas in South Korea,” An Tae-Hoon, Institute of Energy Economics, Japan, March 2009, accessed at [http://www.eaber.org/intranet/documents/96/2115/IEEJ\\_Tae\\_Hoon\\_2009.pdf](http://www.eaber.org/intranet/documents/96/2115/IEEJ_Tae_Hoon_2009.pdf)
- <sup>36</sup> “Managing Natural Gas Price Volatility: Principles and Practices Across the Industry,” Frank Graves and Steven Levine, The Brattle Group, July 2010, p. 52.
- <sup>37</sup> “Uncertain LNG price environment turns focus on price revision clauses,” Kenneth S. Culotta et al., King & Spaulding LLP, April 2008.
- <sup>38</sup> “Dow Chemical Mulls Energy Field Stake,” Reuters, October 14, 2010, accessed at <http://www.reuters.com/article/idUUSTRE69C4OV20101014>
- <sup>39</sup> “An Analysis of Price Volatility in Natural Gas Markets,” Energy Information Administration, Office of Oil and Gas, August 2007. Accessed at [http://www.eia.doe.gov/pub/oil\\_gas/natural\\_gas/feature\\_articles/2007/ngprivolatility/ngprivolatility.pdf](http://www.eia.doe.gov/pub/oil_gas/natural_gas/feature_articles/2007/ngprivolatility/ngprivolatility.pdf)
- <sup>40</sup> Data for this section taken from the International Monetary Fund (IMF) “Primary Commodity Prices” price series, accessed November 5, 2010 at <http://www.imf.org/external/np/res/commmod/index.asp>. UK NBP price data are from Platts.
- <sup>41</sup> Cf. note 37.
- <sup>42</sup> Because changes in the natural logarithm are roughly equal to percentage changes in the original series, it follows that the slope of a trend line fitted to logged data is equal to the average percentage growth in the original series. See, for reference, <http://www.duke.edu/~rnau/411log.htm>
- <sup>43</sup> “Placing the 2006/08 Commodity Price Boom into Perspective,” Policy Research Working Paper #5371, The World Bank, July 2010.
- <sup>44</sup> “Natural Gas and Energy Price Volatility,” American Gas Foundation, October 2003.