Shale Gas and U.S. National Security

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What has the “shale revolution” meant?
The “50,000 Foot” Natural Gas View in 2000: LNG is coming to North America
The “50,000 Foot” Natural Gas View in 2011: Over 6,600 tcf of technically recoverable shale*
A Paradigm Shift
The view of natural gas has changed dramatically in only 10 years. Most predictions were for a dramatic increase in LNG imports to North America and Europe. Today, growth opportunities for LNG developers are seen primarily in Asia.

Study Objective
Examine the impacts of shale gas development, if allowed to proceed unfettered, by comparison to a counterfactual case in which the conventional views of the early 2000s hold to be true.
Executive Summary
Geopolitical Repercussions of Expanded U.S. Shale Gas Production

• Growth in U.S. shale gas output has turned expectations upside down in less than a decade. In fact, rapid growth in shale gas production...
  
  – virtually eliminates U.S. LNG imports for at least two decades
  – substantially reduces Russia’s market share in Europe from 27 percent in 2009 to 13 percent by 2040, reducing the chances that Moscow can use energy as a tool for political gain
  – reduces the future share of world gas supply from Russia, Iran, and Venezuela; without shale discoveries, these nations would have accounted for about 33 percent of global gas supply in 2040, but with shale, this is reduced to 24 percent.
  – reduces the opportunity for Venezuela to become a major LNG exporter and thereby lowers long-term dependence in the Western Hemisphere and in Europe on Venezuelan LNG
• ... growth in shale gas production...
  – reduces competition for LNG supplies from the Middle East, thereby moderating prices and spurring greater use of natural gas, an outcome with significant implications for environmental objectives
  – reduces U.S. and Chinese dependence on Middle East natural gas supplies, lowering the incentives for geopolitical and commercial competition between the two largest consuming countries and providing both countries with new opportunities to further diversify their energy supply
  – limits Iran’s ability to tap energy diplomacy as a means to strengthen its regional power or to buttress its nuclear aspirations
But, nothing is certain...

• In general, multiple issues face shale development: some are global, some are not.
  - **Market Structure** – transportation regulatory structure (unbundled access vs. incumbent monopolies); bilateral take-or-pay obligations or marketable rights; existence of gathering and takeaway capacity and hurdles to development; competing resources (RPS, coal, nuclear, etc.); pricing paradigms; etc.
  - **Water** – volume and availability for production; water rights and resource management regulation; flowback options (recycle and/or treatment and disposal) and native infrastructure; concerns about watershed protection during drilling operations (casing failures and fracture migration); etc.
  - **Resource Access** – mineral rights ownership; acreage acquisition; resource assessments; environmental opposition; etc.
  - **Other issues** – earthquakes related to disposal injection of produced water; long term environmental effects of methane (and other gases) escape; concerns about potential chemical and/or radiation contamination from produced water; ecological concerns related to land use and reclamation; etc.

• A stable regulatory environment that fosters responsible development of domestic resources is critical to achieving the potential benefits presented by shale.
Some Specifics on Shale in the RWGTM
Defining the Resource

• It is an incorrect representation to simply characterize recent estimates of shale gas in North America as “reserves”. It is important to understand what these assessments are actually estimating.

• Shale gas-in-place (GIP) numbers are large. *Cost* and *technology* define accessibility.

• **We use estimates of technically recoverable resource and define development cost curves for each assessment.**

**Resource in Place**
Resource endowment. Lots of uncertainty, but we can never get beyond this ultimate number.

**Technically Recoverable Resource**
This is the number that is being assessed. Lots of uncertainty, but experience has shown this number generally grows over time.

**Economically Recoverable Resource**
This will grow with decreasing costs and rising prices, but is bound by technology.

**Proved Reserves**
Connected and ready to produce.
Shale in The United States: An Evolving State of Knowledge

- In 2003, the NPC used an assessment of 38 tcf of technically recoverable shale gas in its study of the North American gas market.
- In 2005, most estimates placed the resource at about 140 tcf.
- Recent estimates are much higher
    - Survey of producers yielded 840 tcf with the majority of the additional resource in the Marcellus and Haynesville shales.
  - (2011) ARI estimate of over 900 tcf.
- Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 637 tcf.
- Point: We learn more as time passes!
# US Shale in the RWGTM

- As knowledge continues to advance, more shale plays may become commercial targets and greater proportions of shale resources may become technically feasible.
- Developers also become better at identifying optimal drill sites... Barnett is a good case in point.

<table>
<thead>
<tr>
<th>Shale Play</th>
<th>Mean Technically Recoverable Resource (tcf)</th>
<th>Breakeven Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antrim</td>
<td>13.2</td>
<td>$5.50</td>
</tr>
<tr>
<td>Devonian/Ohio</td>
<td>220.4</td>
<td></td>
</tr>
<tr>
<td>Utica</td>
<td>5.4</td>
<td>$6.25</td>
</tr>
<tr>
<td>Marcellus</td>
<td>185.0</td>
<td></td>
</tr>
<tr>
<td>Marcellus Tier 1</td>
<td>46.3</td>
<td>$4.00</td>
</tr>
<tr>
<td>Marcellus Tier 2</td>
<td>64.8</td>
<td>$5.25</td>
</tr>
<tr>
<td>Marcellus Tier 3</td>
<td>74.0</td>
<td>$6.50</td>
</tr>
<tr>
<td>NW Ohio</td>
<td>2.7</td>
<td>$6.75</td>
</tr>
<tr>
<td>Devonian Siltstone and Shale</td>
<td>1.3</td>
<td>$6.75</td>
</tr>
<tr>
<td>Catskill Sandstones</td>
<td>11.7</td>
<td>$6.75</td>
</tr>
<tr>
<td>Berea Sandstones</td>
<td>6.8</td>
<td>$6.75</td>
</tr>
<tr>
<td>Big Sandy</td>
<td>6.3</td>
<td>$6.00</td>
</tr>
<tr>
<td>Nora/Haysi</td>
<td>1.2</td>
<td>$6.25</td>
</tr>
<tr>
<td>New Albany</td>
<td>3.8</td>
<td>$7.00</td>
</tr>
<tr>
<td>Floyd/Chatanooga</td>
<td>4.3</td>
<td>$6.00</td>
</tr>
<tr>
<td>Haynesville</td>
<td>160.0</td>
<td></td>
</tr>
<tr>
<td>Haynesville Tier 1</td>
<td>32.0</td>
<td>$4.00</td>
</tr>
<tr>
<td>Haynesville Tier 2</td>
<td>56.0</td>
<td>$5.00</td>
</tr>
<tr>
<td>Haynesville Tier 3</td>
<td>72.0</td>
<td>$6.25</td>
</tr>
<tr>
<td>Fayetteville</td>
<td>36.0</td>
<td>$4.25</td>
</tr>
<tr>
<td>Woodford Arkoma</td>
<td>8.0</td>
<td>$4.50</td>
</tr>
<tr>
<td>Woodford Ardmore</td>
<td>4.2</td>
<td>$5.75</td>
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<tr>
<td>Barnett</td>
<td>58.0</td>
<td></td>
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<tr>
<td>Barnett Tier 1</td>
<td>30.0</td>
<td>$4.00</td>
</tr>
<tr>
<td>Barnett Tier 2</td>
<td>28.0</td>
<td>$5.50</td>
</tr>
<tr>
<td>Barnett and Woodford</td>
<td>35.4</td>
<td>$6.50</td>
</tr>
<tr>
<td>Eagle Ford</td>
<td>42.0</td>
<td>$-</td>
</tr>
<tr>
<td>Eagle Ford Tier 1</td>
<td>22.0</td>
<td>$3.75</td>
</tr>
<tr>
<td>Eagle Ford Tier 2</td>
<td>20.0</td>
<td>$5.25</td>
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<tr>
<td>Palo Duro</td>
<td>4.7</td>
<td>$6.25</td>
</tr>
<tr>
<td>Lewis</td>
<td>10.2</td>
<td>$6.25</td>
</tr>
<tr>
<td>Bakken</td>
<td>1.8</td>
<td>$4.50</td>
</tr>
<tr>
<td>Niobrara</td>
<td>1.3</td>
<td>$6.50</td>
</tr>
<tr>
<td>Hilliard/Baxter/Mancos</td>
<td>11.8</td>
<td>$6.50</td>
</tr>
<tr>
<td>Paradox/Uinta</td>
<td>13.5</td>
<td>$6.50</td>
</tr>
<tr>
<td>Mowry</td>
<td>8.5</td>
<td>$6.50</td>
</tr>
</tbody>
</table>

Total US Shale: 637.0

Source: Energy Information Administration based on data from various published studies. Updated: May 28, 2009.
Rest of World (RoW) Shale: Little Data and Lots of Uncertainty

- There is uncertainty about shale resources outside of North America.
- The estimates of resource in-place are very large, and location is a premium in many instances.
- However, accessibility is critical. Not only do cost and technology matter, but market structure and government policy is equally as important.

  Arguably, if the current market structure in the United States did not exist, the shale gas boom would not have occurred. This is due to the fact that the small producers who initiated the proof of concept had little to no risk of accessing markets from very small production projects. A market in which capacity rights are not unbundled from facility ownership does not foster entry by small producers.
## RoW Shale in the RWGTM

- As knowledge continues to advance, more shale plays may become commercial targets.
- The RWGTM *currently* only allows 800 tcf of recoverable resource outside the U.S., meaning we allow only a fraction of the recent ARI technical assessment to be commercial.

<table>
<thead>
<tr>
<th>Region</th>
<th>Mean Technically Recoverable Resource (tcf)</th>
<th>Breakeven Price</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CANADA</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horn River</td>
<td>90.0</td>
<td></td>
</tr>
<tr>
<td>Horn River Tier 1</td>
<td>50.0</td>
<td>$ 4.50</td>
</tr>
<tr>
<td>Horn River Tier 2</td>
<td>40.0</td>
<td>$ 5.25</td>
</tr>
<tr>
<td>Montney</td>
<td>65.0</td>
<td></td>
</tr>
<tr>
<td>Montney Tier 1</td>
<td>25.0</td>
<td>$ 4.75</td>
</tr>
<tr>
<td>Montney Tier 2</td>
<td>40.0</td>
<td>$ 5.50</td>
</tr>
<tr>
<td>Utica</td>
<td>10.0</td>
<td>$ 6.50</td>
</tr>
<tr>
<td><strong>MEXICO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burgos Basin</td>
<td>90.0</td>
<td></td>
</tr>
<tr>
<td>Burgos Tier 1</td>
<td>20.0</td>
<td>$ 5.75</td>
</tr>
<tr>
<td>Burgos Tier 2</td>
<td>30.0</td>
<td>$ 6.75</td>
</tr>
<tr>
<td>Burgos Tier 3</td>
<td>40.0</td>
<td>$ 8.00</td>
</tr>
<tr>
<td>Sabinas Basin</td>
<td>20.0</td>
<td>$ 7.25</td>
</tr>
<tr>
<td>Tampico Basin</td>
<td>25.0</td>
<td>$ 7.00</td>
</tr>
<tr>
<td><strong>EUROPE</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Austria</td>
<td>40.0</td>
<td>$ 6.25</td>
</tr>
<tr>
<td>Germany</td>
<td>30.0</td>
<td>$ 6.25</td>
</tr>
<tr>
<td>Poland</td>
<td>120.0</td>
<td></td>
</tr>
<tr>
<td>Silurian Tier 1</td>
<td>45.0</td>
<td>$ 6.00</td>
</tr>
<tr>
<td>Silurian Tier 2</td>
<td>75.0</td>
<td>$ 7.25</td>
</tr>
<tr>
<td>Sweden</td>
<td>30.0</td>
<td>$ 6.50</td>
</tr>
<tr>
<td><strong>MEXICO</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>230.0</td>
<td></td>
</tr>
<tr>
<td>Sichuan/Jianghan</td>
<td>45.0</td>
<td>$ 6.50</td>
</tr>
<tr>
<td>Ordos</td>
<td>35.0</td>
<td>$ 5.75</td>
</tr>
<tr>
<td>Tarim/Junggar/Tuja</td>
<td>120.0</td>
<td>$ 7.25</td>
</tr>
<tr>
<td>Songliao</td>
<td>30.0</td>
<td>$ 6.00</td>
</tr>
<tr>
<td>Australia</td>
<td>50.0</td>
<td>$ 4.50</td>
</tr>
<tr>
<td><strong>Total non-U.S.</strong></td>
<td><strong>800.0</strong></td>
<td></td>
</tr>
</tbody>
</table>
Scenario Analysis
Three Scenarios were considered...

Reference Case
The Reference Case posits a scenario in which all known global shale gas resources can be developed, given prevailing commercial technologies and open tendering practices. This scenario includes all global shale resources that are currently identified in Europe and Asia and thereby present a full picture of the current expectations for changing geopolitical and market implications of development of shale gas resources.

Scenario 2
Under this scenario, shale developments in North America are limited to the Barnett, Woodford, and Fayetteville shale plays. Furthermore, under this scenario, no shale gas outside of North America is open for development. This scenario is a counterfactual aimed to demonstrate what the world would look like if shale gas developments did not progress to the levels currently under way.

Scenario 3
In this scenario, specific U.S. shale plays located north of Virginia are blocked from development by environmental and/or other political, fiscal, or regulatory factors. Commercial investment in all other U.S., Canadian, and other global shale gas is permitted in the scenario. While it is possible that environmental obstacles may, at some point, also impact development of resources in other countries, this scenario focuses solely on the consequences of limiting U.S. Middle Atlantic resource development to highlight the U.S. energy security implications of such policy choices.

The comments that follow focus on comparisons of the Reference Case and Scenario 2.
Reference Case:
Global Supply by Super Region, 1990-2040

- Middle East production grows to meet demand growth in both the Middle East and Russia. By 2040, the Middle East accounts for 20% of global supply.
Global Supply by Super Region, 1990-2040 (cont.)

- **Scenario 2 delta to Reference Case**: Scenario 2 sees global dependence on the Middle East grow to 27% by 2040.
U.S.
Reference Case: Composition of U.S. Production, 2010-2040

- U.S. shale gas production exceeds 50% of total production by 2030.
- Canadian shale gas production grows to 1/3 of total output by the mid-2030’s (not pictured).
The lack of shale production leaves domestic supply severely diminished as long term declines in other basins dominate the overall trend.

Scenario 2
Reference Case:
North American Shale Production, 2010-2040
Reference Case:
U.S. LNG Imports, 2010-2040

- Very low re-gas terminal capacity utilization through 2040.
U.S. LNG Imports (cont.)

- Absent shale resources, U.S. LNG imports rise substantially.

Scenario 2 delta to Reference Case
Henry Hub Price, 2010-2040

• Prices tend to rise over time as lower cost supplies are depleted. But, abundant shale gas resources render the domestic supply curve to be relatively flat.

• Scenario 2 is a sensitivity that shows no Shale development

• Scenario 3 is a sensitivity that shows no Shale in the Mid-Atlantic region
Rest of World
Reference Case: Shale Production in Europe, 2010-2040

- European shale production grows to about 35% of total production by 2040. While this is not as strong as North America, it does offset the need for increased imports from Russia, North Africa, and as LNG. In fact, the impact of shale growth in Europe is tilted toward offsetting Russian imports, but it also lowers North Sea production at the margin, as well as other sources of imports.
Reference Case: European LNG Imports, 2010-2040

- Growth in LNG is an important source of diversification to Europe. Indigenous shale gas opportunities abate this to some extent. However, shale production does not grow as strongly as in North America, so LNG imports in Europe rise. Note that strong growth in North America, by displacement, influences European LNG.
No Shale Case: European LNG Imports, 2010-2040

- Without shale development, the US draw on global LNG results in a reduction in LNG imports to Europe relative to the reference case. The shortfall is made up primarily with stronger Russian imports and lower demand growth.
Russian opportunities to Europe are diminishing as a result of shale production growth and Europe’s increased pull on LNG.

The market share of Russia in non-FSU Europe falls to just over 13% by 2040, while it rises then stabilizes at just over 12% in Northeast Asia.
• Absent shale, Russian exports are substantially higher, with a significant impact on flows to Europe.

• The market share of Russia in non-FSU Europe stabilizes at about 19% by 2040, and around 16% in Northeast Asia. Note that Russian market share in both regions is higher.
**Iranian Supply Disposition**

- **Reference Case:**
  Most Iranian production is consumed domestically, but longer term, exports begin to grow.

- **Scenario 2 delta to Reference Case:**
  LNG exports from Iran are significantly higher. This results from the greater global pull on Iranian resources in the absence of shale gas.
• Shale gas production in China grows to about 15% of the domestic market, but LNG is by far the largest single source of natural gas supply to China out to 2040.

• Water will likely play a major role in Chinese shale production endeavors, as indicated by the fact that known shale plays are coincident with regions where water stress is already high.
Reference Case: LNG Imports to Asia 2010-2040

- Strong demand growth creates the largest global sink for LNG supplies.
  - China leads in LNG import growth despite growth in both pipeline imports and supplies from domestic unconventional sources.
No Shale Case:
LNG Imports to Asia 2010-2040

- Strong demand growth still creates the largest global sink for LNG supplies, but the competition from North American imports is evident.
  - Only Chinese LNG imports grow in this scenario. Displacement makes pipeline supplies from Iran to India more viable, and higher prices generally reduce demand relative to the Reference Case.
Reference Case: 
LNG Exports by Country, 2010-2040

- Substantial long term growth from the Middle East, Australia, and Venezuela. Qatar and Australia are the largest LNG exporters through 2040, and, collectively, account for over 35% of global LNG exports.
No Shale Case: LNG Exports by Country, 2010-2040

- Growth in Qatar, Nigeria, Venezuela and Iran are all much higher. The lack of shale in the U.S. favors LNG suppliers in or near the Atlantic basin.

Scenario 2 delta to Reference Case
An Important Role for Shale Gas

• Expansion of production from shale plays has rendered the utilization of LNG import capacity in the US very low.

• Moreover, in the aggregate, average annual capacity utilization of US LNG regasification terminals may not approach 15% until the late 2030s.

• Current and potential future expansion of shale gas in the US, Europe and Asia effectively makes the *global* natural gas supply curve more elastic.
  - This mitigates the potential for sustained increases in price.
  - To the extent that shale gas production can be more price responsive (through completion delays, for example) than production from other natural gas plays, the idea of “just-in-time” production could also simulate the traditional role of storage. Thus, shale gas production may also limit seasonal volatility to some extent.
  - Greater supply elasticity also puts pressure on traditional pricing paradigms.
Appendix
U.S. LNG Exports
LNG Exports: North America in a Global Context

- North American resources are large, but must be placed in a global context.
  - Multiple forces are at work: cost reduction and exchange rate movements.
  - Former Soviet Union (FSU) and Middle East (pictured for comparison) are larger and generally less costly. Access, transportation costs and the value of the dollar make North American resources preferential in the short-to-medium term in North America.

Cost reductions and higher recoverable resource estimates benefit the US supply picture.

A weak US$ lifts $-denominated costs outside of the US, which makes exports look attractive.
Two recent working papers indicate the exchange rate plays an important role in the determination of:

- The spread between oil and US gas prices (Medlock and Hartley (2011))

Key Points:

- Exchange Rate (XR) is vital to the stability of the relationship.
- Dynamic adjustment is sensitive to seasonal factors.

Example: The cointegrating (or long run equilibrium) relationship between crude oil and natural gas prices for different US$ values.

<table>
<thead>
<tr>
<th>XR (US$ vs Major Cur)</th>
<th>HH ($/mmbtu)</th>
<th>Oil Price ($/bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td></td>
<td>88.715</td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>102.941</td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>74.490</td>
</tr>
<tr>
<td>current</td>
<td></td>
<td>69.764</td>
</tr>
</tbody>
</table>

Actual HH $4.55

Implication: LNG exports are at least partly an exchange rate arb. This begs the question, “What happens to the oil-gas price ratio if the US$ strengthens?”
Oil Indexation, Liquidity, and the Role of Shale Gas
The Role of Oil Indexation

- Absent storage and physical liquidity, oil indexation provides an element of price certainty.

- Oil indexation is a form of price discrimination
  1. Firm must be able to distinguish consumers and prevent resale.
  2. Different consumers have different elasticity of demand.
  3. Both conditions are met in Europe and Asia, but not in North America.

- Lack of transport differentials in Europe is evidence of discrimination.

- Increased ability to trade between suppliers and consumers (physical liquidity) violates condition (1).
  1. This will happen in a liberalized market or as LNG trade grows.

- Evidence of a weaker ability to price discriminate is emerging in Europe.
  1. Recent changes in contractual terms
The Rice World Gas Trade Model
The RWGTM

- The Rice World Gas Trade Model (RWGTM) has been developed to examine potential futures for global natural gas, and to quantify the impacts of geopolitical influences on the development of a global natural gas market.
- The model predicts regional prices, regional supplies and demands and inter-regional flows.
- Regions are defined at the country and sub-country level, with extensive representation of transportation infrastructure.
- The model is non-stochastic, but it allows analysis of many different scenarios. Geopolitical influences can alter otherwise economic outcomes.
- The model is constructed using the MarketBuilder software from Deloitte MarketPoint, Inc.
  - Dynamic spatial general equilibrium linked through time by Hotelling-type optimization of resource extraction.
  - Capacity expansions are determined by current and future prices along with capital costs of expansion, operating and maintenance costs of new and existing capacity, and revenues resulting from future outputs and prices.
The RWGTM: Demand

- Over 290 regions.
  - Regional detail is dependent on data availability and existing infrastructure.
- Demand is estimated directly for US...
  - United States (residential, commercial, power and industrial sectors)
    - Sub-state detail is substantial (for example, 10 regions in Texas) and is based on data from the Economic Census and the location of power plants.
    - Demand functions estimated using longitudinal state level data.

\[
\begin{align*}
\ln q_{\text{com},i,t} &= \alpha_i - 0.154 \ln p_{\text{ng},i,t} + 0.039 \ln p_{\text{ho},i,t} + 0.160 \ln y_t + 0.290 \ln \text{hdd}_{i,t} - 0.033 \ln \text{cdd}_{i,t} + 0.176 \ln \text{pop}_{i,t} + 0.758 \ln q_{\text{com},i,t-1} \\
\text{Commercial} \\
\ln q_{\text{res},i,t} &= \alpha_i - 0.201 \ln p_{\text{ng},i,t} + 0.049 \ln p_{\text{ho},i,t} + 0.117 \ln y_t + 0.405 \ln \text{hdd}_{i,t} - 0.007 \ln \text{cdd}_{i,t} + 0.312 \ln \text{pop}_{i,t} + 0.683 \ln q_{\text{res},i,t-1} \\
\text{Residential} \\
\ln q_{\text{ind},i,t} &= \alpha_i - 0.071 \ln p_{\text{ng},i,t} + 0.330 \ln \text{manuf}_{i,t} + 0.202 \ln \text{hdd}_{i,t} + 0.047 \ln \text{cdd}_{i,t} + 0.780 \ln q_{\text{ind},i,t-1} \\
\text{Industrial} \\
\ln q_{\text{pwr},i,t} &= \alpha_i - 0.442 \ln p_{\text{ng},i,t} + 0.238 \ln p_{\text{fao},i,t} + 0.102 \ln p_{\text{coal},i,t} + 1.089 \ln \text{elecgen}_{i,t} - 0.189 \ln \text{renew}_{i,t} \\
&\quad - 0.511 \ln \text{hdd}_{i,t} + 0.339 \ln \text{cdd}_{i,t} + 0.716 \ln q_{\text{pwr},i,t-1}
\end{align*}
\]

Power Generation
The RWGTM: Demand (cont.)

- ... but demand is estimated indirectly for RoW.
  - Rest of World (Power Gen, Direct Use, EOR)
    - Energy intensity is estimated as a function of per capita income and energy price using panel data for over 70 countries from 1970-2007.

\[
\ln \left( \frac{E}{Y} \right)_{i,t} = \alpha_i - 0.086 \ln y_{i,t} - 0.012 \ln p_{i,t} + 0.834 \ln \left( \frac{E}{Y} \right)_{i,t-1}
\]

- Natural gas share is estimated as a function of GDP per capita, own price, oil price, installed thermal capacity, and the extent to which the country imports energy

\[
\ln \left( \ln \theta_{ng,i,t} \right) = \alpha_i + 0.068 \ln \left( \frac{E}{Y} \right)_{i,t} + 0.043 \ln p_{ng,i,t} - 0.028 \ln p_{oil,i,t} - 0.041 \ln thermcap_i + 0.098 \ln entrade_{i,t} + 0.767 \ln \left( \ln \theta_{ng,i,t} \right)
\]

Note, the natural gas share equation is in double log form, which bounds the share between 0 and 1 (when forecasting). The sign of the estimated coefficients are opposite the sign of the elasticity. In fact, the own price elasticity is given as: \( e_{\theta,p} = 0.043 \ln \theta_{ng,i,t} \). So, the price elasticity is decreasing in natural gas share, ranging between -3.064 and -0.049 across all countries. This feature captures rigidities associated with capital deployment.
The estimated relationship between energy intensity and per capita GDP reveals that energy intensity generally decreases with rising incomes (see Medlock and Soligo, *Energy Journal* 2001).

The graphic indicates a path for a generic country. The level of energy intensity for individual countries will vary depending on a number of factors, but each will exhibit a similar pattern.

The forecast path for energy intensity is then multiplied by the projected GDP per capita to reveal a forecast path for per capita energy demand. Population projections are then taken from the UN median case to reveal total energy demand.
The RWGTM: Demand (cont.)

- Economic growth is based on conditional convergence a long run growth path that is based on historical US and UK growth rates (dating back into the 1800s) at various levels of per capita income. The long run growth path is estimated using a piecewise linear spline knot regression.

- Countries converge to the long run growth path at a rate estimated using an unbalanced panel across all countries spanning multiple years.
The RWGTM: Demand (cont.)

- Recent economic and financial crisis is incorporated. We use the IMF economic outlook for growth through 2015 for all countries. Beyond 2015, growth is governed by the model of conditional convergence. All GDP estimates are in $2005PPP.

Note, the graphics depict real growth of per capita GDP in PPP terms. These growth estimates will differ from growth estimates of GDP per capita converted using nominal exchange rates to the extent the PPP exchange rate changes. Accordingly, in PPP terms, Chinese per capita income in roughly 60% of US per capita income by 2030, compared to 28% currently. This results due to the conditional convergence feature of the long run growth model.
The RWGTM: Supply

• Over 135 regions

• Natural gas resources are represented as...
  – Conventional, CBM and Shale in North America, China, Europe and Australia, and conventional gas deposits in the rest of the world. Recent ARI assessment of shale around the world is being studied for incorporation.

• ... in three categories
  – proved reserves (Oil & Gas Journal estimates)
  – growth in known reserves (P-50 USGS and NPC 2003 estimates)
  – undiscovered resource (P-50 USGS and NPC 2003 estimates)
    – Note: resource assessments are supplemented by regional offices if available.

• North American cost-of-supply estimates are econometrically related to play-level geological characteristics and applied globally to generate costs for all regions of the world.
  – Long run costs increase with depletion.
  – Short run adjustment costs limit the “rush to drill” phenomenon.
  – We allow technological change to reduce mining costs longer term
The RWGTM: Supply (cont.)

- Selected examples: Regional marginal cost of supply curves...
A Comment on Development Costs

- We often discuss “breakeven costs”, but it is important to put this into context...
- The cost environment is critical to understanding what prices will be. For example, F&D costs in the 1990s yield long run prices in the $3-$4 range.

![Graph showing real well cost, KLEMS, and real oil price index from 1980 to 2009. The graph indicates that real cost going forward is roughly equal to costs in 1982, 2004/05, 2009.]
The RWGTM: Infrastructure

- Required return on investment varies by region and type of project (using ICRG and World Bank data)
- Detailed transportation network
  - Pipelines aggregated into corridors where appropriate.
  - Capital costs based on analysis of over 100 pipeline projects relating project cost to various factors.
  - Tariffs based on posted data, where available, and rate-of-return recovery.
  - LNG is represented as a hub-and-spoke network, reflecting the assumption that capacity swaps will occur when profitable.
  - LNG shipping rates based on lease rates and voyage time.
- For all capital investments in both the upstream and midstream, we allow for existing and potential pipeline links, then “let the model decide” optimal current and future capacity utilization.
A brief focus on LNG costs

These are generally generic with regard to region.

<table>
<thead>
<tr>
<th>Region</th>
<th>Capex ($/mcf)</th>
<th>Capex ($/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>12.8934</td>
<td>620.2</td>
</tr>
<tr>
<td>Australia (Qld)</td>
<td>9.0988</td>
<td>437.7</td>
</tr>
<tr>
<td>Atlantic</td>
<td>7.7854</td>
<td>374.5</td>
</tr>
<tr>
<td>Pacific</td>
<td>9.0988</td>
<td>437.7</td>
</tr>
<tr>
<td>Middle East</td>
<td>8.4784</td>
<td>407.8</td>
</tr>
<tr>
<td>Arctic</td>
<td>18.2287</td>
<td>876.8</td>
</tr>
</tbody>
</table>

A facility must earn a minimum return to capital prior to the model choosing to build it. Hence, construction is based on current and future prices, as well as construction costs and financial parameters defining things such as tax rates and the required rates of return to debt and equity.