The Impacts of the Natural Gas Shale Boom on U.S. Energy Security

The Rice World Gas Trade Model: A Discussion of the Reference Case (Unconstrained) Results

prepared by:

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December 29, 2010

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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 Altos:
  - 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 highly dependent on data availability and existing gas delivery 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.

\[
\begin{align*}
\ln q_{\text{com},i,t} &= \alpha_i - 0.154 \ln p_{ng,i,t} + 0.039 \ln p_{ho,i,t} + 0.160 \ln y_t + 0.290 \ln hdd_t - 0.033 \ln cdd_t + 0.176 \ln pop_t + 0.758 \ln q_{\text{com},i,t-1} \\
\ln q_{\text{res},i,t} &= \alpha_i - 0.201 \ln p_{ng,i,t} + 0.049 \ln p_{ho,i,t} + 0.117 \ln y_t + 0.405 \ln hdd_t - 0.007 \ln cdd_t + 0.312 \ln pop_t + 0.683 \ln q_{\text{res},i,t-1} \\
\ln q_{\text{ind},i,t} &= \alpha_i - 0.071 \ln p_{ng,i,t} + 0.330 \ln \text{manuf}_{i,t} + 0.202 \ln hdd_t + 0.047 \ln cdd_t + 0.780 \ln q_{\text{ind},i,t-1} \\
\ln q_{\text{pwr},i,t} &= \alpha_i - 0.442 \ln p_{ng,i,t} + 0.238 \ln p_{fo,i,t} + 0.102 \ln p_{coal,i,t} + 1.089 \ln \text{elecgen}_{i,t} + 0.189 \ln \text{renew}_{i,t} \\
&\quad - 0.511 \ln hdd_t + 0.339 \ln cdd_t + 0.716 \ln q_{\text{pwr},i,t-1}
\end{align*}
\]
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: \( \varepsilon_{\theta,p} = 0.043 \ln \theta_{ng,i,t} \). 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 generic curve. 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.

![Per Capita GDP vs Growth Rate Graph](image-url)
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 120 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
- ... 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...
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.
The RWGTM: Infrastructure (cont.)

- A brief focus on LNG costs
  - These are generally generic with regard to region.

<table>
<thead>
<tr>
<th>Sample Capital Cost for Liquefaction</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 (Queensland)</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.
What does the “shale revolution” mean?
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 in primarily in Asia.
- Many investments were made to expand LNG potential to North America in particular
  - At one point, 47 terminals were in the permitting phase.
  - Since 2000, 2 terminals were re-commissioned and expanded (Cove Point and Elba); 9 others were constructed.
  - In 2000, import capacity was just over 2 bcf/d; It now stands at just over 17.4 bcf/d.
  - By 2012, it could reach 20 bcf/d.
- A similar story in Europe
  - In 2000, capacity was just over 7 bcf/d; It is now over 14.5 bcf/d.
  - By 2012, it could exceed 17 bcf/d.
- Shale gas developments have since turned expectations upside-down

North American LNG Terminals

Office of Energy Projects
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 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.
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.
Shale is everywhere, and it has significant implications for global energy markets

Major North American Shale Plays

European and Pacific Shale Plays
(Limited data available publicly)
North American Shale Gas

- Shale is distributed in many locations, some traditional producing areas but others are in the heart of market areas.
- Supply potential in BC, in particular, has pushed the idea of LNG exports targeting the Asian market
  - Asia is an oil-indexed market.
  - Competing projects include pipelines from Russia and the Caspian States, as well as LNG from other locations.
  - BC is a basis disadvantaged market, but selling to Asia could provide much more value to developers.
- For those regions not accustomed to seeing robust natural gas development, regulatory conflicts are being realized.
North American Shale (cont.)

• 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

• Resource assessment is large. Our work at BIPP indicates a technically recoverable resource of 686 tcf.

• Point: We learn more as time passes!
North American Resources in a Global Context

- North American resources are large, but must be placed in a global context.
  - FSU and Middle East (pictured for comparison) are larger and generally less costly. However, access and transportation costs make North American resources preferential in the short-to-medium term.
  - Cost reductions and higher recoverable resource estimates benefit the US supply picture.
Rest of World Shale Gas

- There is tremendous uncertainty about shale resources outside of North America.
- To be certain, the estimates of resource in place are very large, and location is a premium with regard to prevailing market prices and energy security benefit.
- 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.

<table>
<thead>
<tr>
<th></th>
<th>Mean Technically Recoverable Resource (tcf)</th>
<th>Breakeven Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>40.0</td>
<td>$5.75</td>
</tr>
<tr>
<td>Germany</td>
<td>30.0</td>
<td>$5.50</td>
</tr>
<tr>
<td>Poland</td>
<td>120.0</td>
<td>$5.25</td>
</tr>
<tr>
<td>Sweden</td>
<td>30.0</td>
<td>$6.00</td>
</tr>
<tr>
<td>China</td>
<td>45.0</td>
<td>$5.00</td>
</tr>
<tr>
<td>Australia</td>
<td>50.0</td>
<td>$4.00</td>
</tr>
<tr>
<td>Total non-North America</td>
<td>315.0</td>
<td></td>
</tr>
</tbody>
</table>

Note, ongoing work will likely add assessments for technically recoverable resource in Croatia, Denmark, France, Hungary, Netherlands, Ukraine, and the United Kingdom. Estimates are currently too preliminary to be presented in this case.
The Global Shale Gas Resource

- Knowledge of the shale resource is not new
  - Rogner (1997) estimated over 16,000 tcf of shale gas resource in-place globally
  - Only a very small fraction (<10%) of this was deemed to be technically recoverable and even less so economically.

- Only recently have innovations made this resource accessible
  - Shale developments have been focused largely in North America where high prices have encouraged cost-reducing innovations.
  - IEA recently estimated about 40% of the estimates resource in-place by Rogner (1997) will ultimately be technically recoverable.
  - Recent assessment by Advanced Resources International (2010) notes a greater resource in-place estimate than Rogner (1997), with most of the addition coming in North America and Europe.

- We learn as we advance in this play!

<table>
<thead>
<tr>
<th>Region</th>
<th>Resource In-Place (tcf)</th>
<th>Resource In-Place (tcm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America</td>
<td>3,842</td>
<td>109</td>
</tr>
<tr>
<td>Latin America</td>
<td>2,117</td>
<td>60</td>
</tr>
<tr>
<td>Europe</td>
<td>549</td>
<td>15</td>
</tr>
<tr>
<td>Former USSR</td>
<td>627</td>
<td>18</td>
</tr>
<tr>
<td>China and India</td>
<td>3,528</td>
<td>100</td>
</tr>
<tr>
<td>Australasia</td>
<td>2,313</td>
<td>66</td>
</tr>
<tr>
<td>MENA</td>
<td>2,548</td>
<td>72</td>
</tr>
<tr>
<td>Other</td>
<td>588</td>
<td>17</td>
</tr>
<tr>
<td>Total</td>
<td>16,112</td>
<td>457</td>
</tr>
</tbody>
</table>
European Shale Gas

- In depth studies are underway, with on-going independent analysis of shale potential in Austria, Sweden, Poland, Romania, and Germany
  - Rogner (1997) estimates
    - In-place: 549 tcf
    - Technically recoverable: No Data
  - ARI estimates (2010)
    - In-place: 1000 tcf
    - Technically recoverable: 140 tcf
      - Alum Shale (Sweden), Silurian Shale (Poland), Mikulov Shale (Austria)
  - Europe also has an additional 35 tcf of technically recoverable CBM resource located primarily in Western European countries and Poland.
  - Quote from ARI report: “Our preliminary estimate for the gas resource endowment for Western and Eastern Europe, which we anticipate to grow with time and new data, is already twice Rogner’s estimate of 549 Tcf (15.6 Tcm).”
Asia/Pacific Shale and CBM

- Limited data availability
- Rogner (1997) estimates
  - China/India In-place: 3,530 tcf
  - Technically recoverable: No Data
- China and the U.S. Department of Energy have recently entered into a “U.S.-China Shale Gas Resource Initiative” to support gas shale development in China.
- CBM potential in the Asia-Pacific Region is large and generally better known (ARI, 2010).
  - Indonesia: 450 tcf (in-place)
    50 tcf (technically recoverable)
  - China: 1,270 tcf (in-place)
    100 tcf (technically recoverable)
  - India: 90 tcf (in-place)
    20 tcf (technically recoverable)
  - Australia: 1,000 tcf (in-place)
    120 tcf (technically recoverable)

Source: Graphics from ARI (2010)
Reference Case
Allows economics to drive outcomes. No political constraints are modeled, and no bilateral relationships are superimposed.
North American Shale Production
Composition of U.S. Production

- US shale production grows to about 50% of total production by 2040.
- Canadian shale production grows to about 1/3 of total output by 2040 (not pictured). This offsets declines in other resources as total production remains fairly flat.
Impact of Shale Production outside North America

- European shale production grows to about 25% of total production by 2040. China shale production is a smaller portion, accounting for about 8% of total production by 2040 (not pictured). While this is not as strong as North America, it does offset the need for increased imports from Russia, North Africa, and 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.
Global Gas Trade: LNG vs. Pipeline and Market Connectedness

- Globally, LNG growth is strong, reaching about 50% of total international natural gas trade by the early 2030s. This is driven largely by demand in Asia.
- Previously disconnected regional markets become linked.
LNG Imports to Europe

- 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.
LNG Imports to Asia

- Strong demand growth creates a much needed sink for LNG supplies.
  - China leads in LNG import growth despite growth in pipeline imports and supplies from domestic unconventional sources.
LNG Imports by Region

- LNG Imports by Region – putting the US in a global context
  - Most LNG import growth is in Asia, particularly in China and India.
  - There are strong increases in Mexico, Europe and South America as well.
  - The United States and Canada remain very minor LNG importers, with US LNG imports growing to the size of South Korea’s by the late 2030s.
LNG Exports by Country

- LNG Exports by Country
  - Substantial growth from the Middle East, Australia, Nigeria and Venezuela
  - Qatar, Australia, Nigeria and Iran are the four largest LNG exporters in 2040, and, collectively, account for 60% of global LNG exports.
Select Regional Prices

- Prices tend to rise over time as lower cost supplies are depleted.
- Prices tend to move together as LNG growth increasingly connects markets, meaning gas markets are increasingly connected. Note this occurs despite lack of LNG trade into the US because arbitrage opportunity forces equilibrium.
- Europe emerges as the highest priced market, averaging about $0.50 over Henry Hub through the 2030s.
Comments on Gas Market Globalization
Hartley and Medlock (2006) demonstrate that local shocks will be transmitted across previously disconnected regional markets more easily as LNG trade expands.

This begs the question, “Will increased LNG trade leave the US increasingly exposed to international market fluctuations?”

- If so, we can also ask, “Is globalization welfare improving?”

Hartley and Medlock (2006, 2008, 2009) demonstrates that growth in LNG trade implies growth in physical liquidity, i.e. - supply options are expanded. This provides a means of dealing with unexpected shocks.

- Example 1: Europe dealing with a Russian cut-off of supplies
- Example 2: Market flexibility in the event of a US hurricane disruption
Brito and Hartley (2007) also show that growth in physical liquidity also limits the ability of a single supplier to price above marginal cost.

Of course, other important questions are motivated in the context of globalization of gas markets, such as

- What is the likelihood of a cartel emerging?
- What is the effect of environmental policy aimed at reducing CO2 emissions?
  - or even New Source Performance Standards in the US?
- What is the effect of policy that limits access to resources?
- What is the effect of the expansion of shale gas production?
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.
- 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).
  - This will happen in a liberalized market or as LNG trade grows.
- Evidence of a weaker ability to price discriminate is emerging in Europe.
  - Recent changes in contractual terms
The Role of Shale Gas

- Expansion of production from shale plays has rendered the utilization of LNG import capacity in the US very low.
- Moreover, Hartley and Medlock (2010) indicate that, in the aggregate, average annual capacity utilization of US LNG regasification terminals may not exceed 20% until the 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 is more of a manufacturing process 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.