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Shale: Well Behavior, Demand Response and Exports

Based on the BIPP Center for Energy Studies publications:
"Panel Analysis of Barnett Shale Production"
"US LNG Exports: Truth and Consequence"
SENR Testimony Feb 12, 2013

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April 15, 2013

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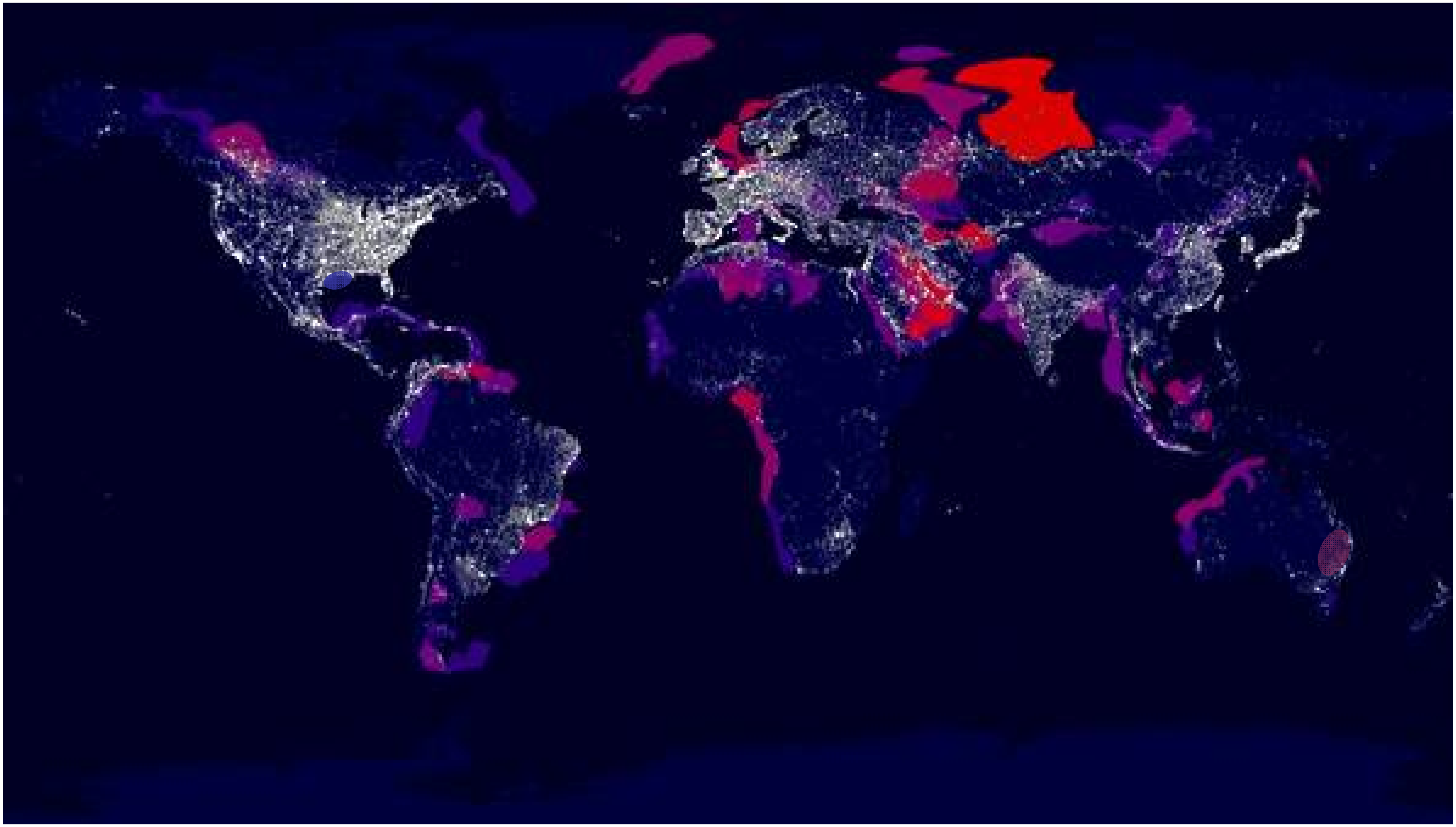
The "50,000 Foot" view in 2000: LNG is coming to North America



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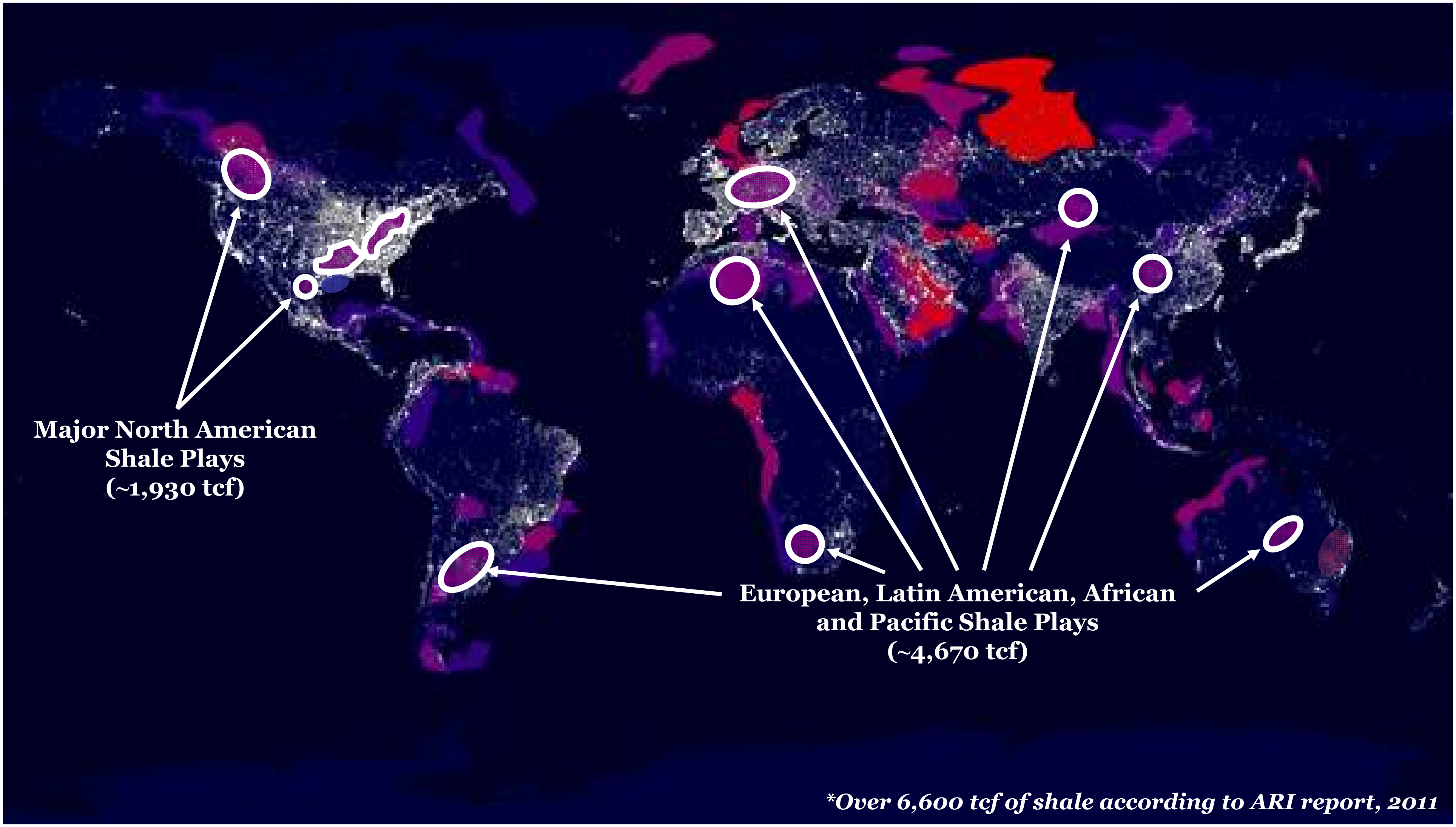
The difference a decade makes: Over 6,600 tcf of technically recoverable shale*



Far-reaching implications of shale gas

- Expansion of production from US shale plays has rendered the utilization of LNG import capacity in the US very low.
- **It has also had an impact on the relative price of oil and gas, and**
- **… it has raised the possibility of US LNG exports.**
  - Domestic price impacts are a central concern, but will not likely be large given domestic elasticity of supply.
  - Recent work by Hartley and Medlock (2012) indicate this apparent opportunity may be highly contingent on the value of the US dollar.
- 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 long term increases in price.
  - Greater supply elasticity also pressures traditional pricing paradigms.

Modeling Well Decline in Shale Gas Plays

"Panel Analysis of Well Production History in the Barnett Shale"

Purpose

- The primary purpose of the empirical analysis is to test the statistical validity of the proposed methodology (REI) for modeling well production.
- The REI method proposes production, denoted $q_{t,i}$, can be modeled as

$$q_{t,i} = \frac{k \cdot REI_i}{t_i^{0.5}}$$

- The above equation can be transformed into

$$\ln q_{t,i} = \ln\left(k \cdot REI_i\right) + \rho \ln t_i$$

- where the term $\ln\left(k \cdot REI_i\right)$ is well-specific. Moreover, we can test whether or not $\rho = -0.5$.

Estimation

- Estimation is done using longitudinal monthly production data for over 16,500 wells drilled in the Barnett shale covering 1990 through 2011.
- We include the well's production history, as well as a set of variables to indicate the geological characteristics of the shale at the well's location. We also include variable to indicate the size of the operator, the year of first production, whether or not the well has been refractured, and the average price of the 12 month strip of futures.
- We estimate the following equation

$$
\begin{aligned}
\ln q_{t,i} = u_i + \alpha \ln t_i + \delta \ln q_{t-1,i} + \beta \ln p_{NYMEX,t} \\
+ a_1 porosity_i + a_2 top_i + a_3 TM_i + a_4 TOC_i + a_5 thickness_i \\
+ a_6 phih_i + a_7 pressure_i + a_8 bg_i \\
+ b_1 oper_{sm,i} + b_2 oper_{med,i} + b_3 length_i + b_4 vintage_i
\end{aligned}
$$

- where u_i is a well-specific term that can be modeled as either fixed or random. It turns out that u_i is treated as random, meaning the other included variables capture the systematic variation between wells.

Variable Definitions

- for well *i*
  - t_i denotes the time period since initial production
  - $p_{NYMEX,t}$ is the average of the 12 month strip of NYMEX futures prices,
  - $poros_i$ denotes the effective porosity of the reservoir,
  - top_i denotes the depth to the top of the shale,
  - TM_i denotes thermal maturity of the shale resource,
  - TOC_i denotes total organic carbon,
  - $thick_i$ denotes the shale thickness after accounting for the limestone intrusion,
  - Φh_i denotes effective porosity multiplied by thickness,
  - $press_i$ is the reservoir pressure,
  - bg_i denotes the gas formation volume factor,
  - $oper_{sm,i}$ and $oper_{med,i}$ are indicator variables denoting operator size, and
  - $length_i$ is the length of the lateral in horizontal wells
  - $vintage_i$ denotes the first year of production.

Estimation Results

Variable	Parm	Vertical	Horizontal
lnt	α	-0.155***	-0.180***
		(0.00137)	(0.00191)
lnq_{t-i}	δ	0.689***	0.641***
		(0.00127)	(0.00129)
$lnp_{NYMEX,t}$	β	0.106***	0.0302***
		(0.00266)	(0.00469)
poros	a_1	14.52***	7.708***
		(0.934)	(0.672)
top	a_2	-0.00013***	-0.00018***
		(2.04e-05)	(1.44e-05)
TM	a_3	0.583***	0.325***
		(0.0253)	(0.0164)
TOC	a_4	0.0696***	0.0148***
		(0.00503)	(0.00411)
thick	a_5	0.0006***	0.00144***
		(0.0002)	(0.00012)
Φh	a_6	-0.00577**	-0.00497**
		(0.00269)	(0.00219)

Variable	Parm	Vertical	Horizontal
press	a_7	-0.00025***	-0.00041***
		(3.89e-05)	(2.64e-05)
bg	a_8	-9.9922	-115.1***
		(16.4667)	(14.81)
$oper_{sm,i}$	b_1	-0.224***	-0.0835***
		(0.0062)	(0.0064)
$oper_{med,i}$	b_2	-0.147***	-0.0539***
		(0.0067)	(0.00444)
$length_i$	b_3	2.51e-05	8.58e-05***
		(1.96e-05)	(1.96e-06)
$vintage_i$	b_4	-0.0152***	0.00210**
		(0.00085)	(0.00132)
R^2		0.807	0.693
Observations		360,039	405,326
Sample Size		3,839	11,645

Note: Standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1

Implications

- The equation estimated represents a state-transition equation. Thus, the production profile of any well is path dependent, and by definition, depends on production in the previous period. Because of this, we should expect autocorrelation in the residuals if we impose the restriction $\delta = 0$. By specifying the model as such, we want to test the hypothesis that $\rho = -0.5$, where $\rho = \alpha/(1 - \delta)$.
- It turns out that we cannot reject the hypothesis that $\rho = -0.5$ in either vertical or horizontal wells. In fact, we have

  Horizontal: $\rho = -0.501$

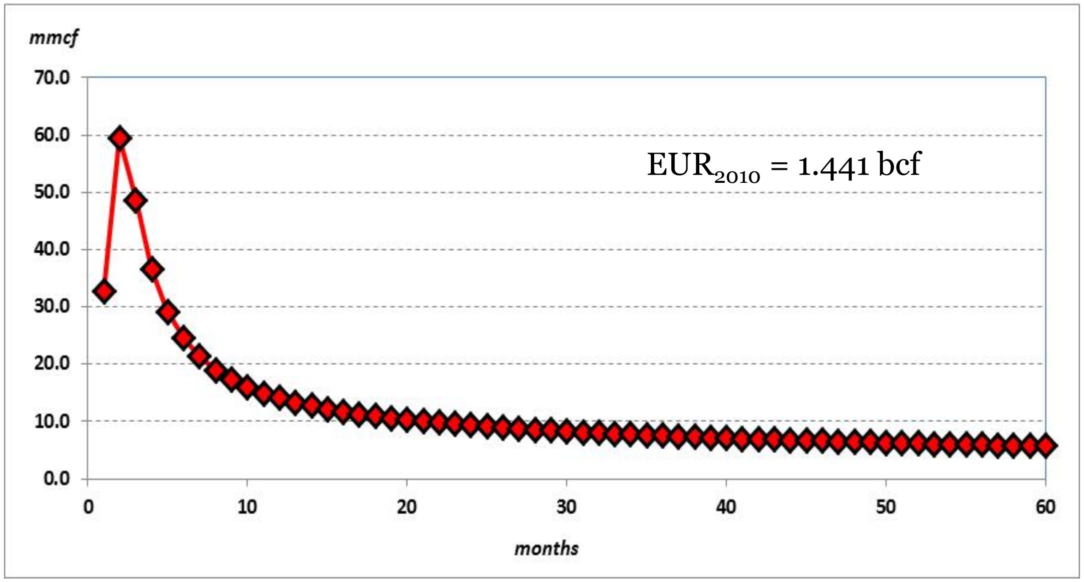
  Vertical: $\rho = -0.499$
- So, the data supports using the *REI* measure as a valid description of well performance in the Barnett shale.
- Note that the decline profile so modeled is approximated by a hyperbolic decline model where "*b*" can be fit or numerically approximated.

Simulation

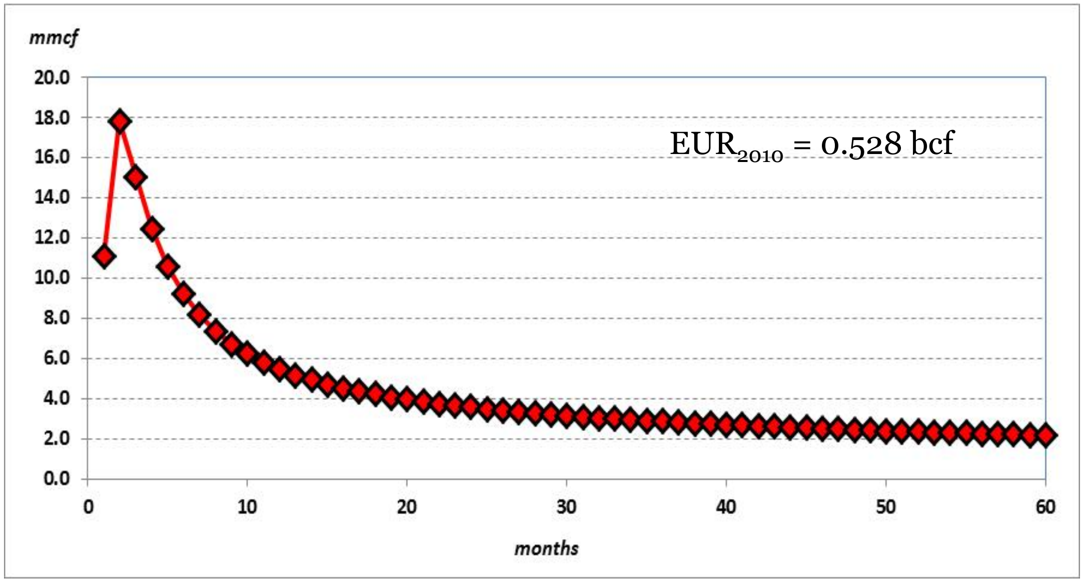
Sample Average Values

Variables	Vertical	Horizontal
top	-6365.55	-5921.97
TM	1.2835	1.3079
TOC	3.3685	2.9627
thick	291.394	285.121
perfzon	462.73	2293.47
phih	18.6864	17.0353
bg	0.0045	0.0049
press	3662.24	3376.41
poros	0.0641	0.0589
length	427.09	2876.64
price	4.00	4.00

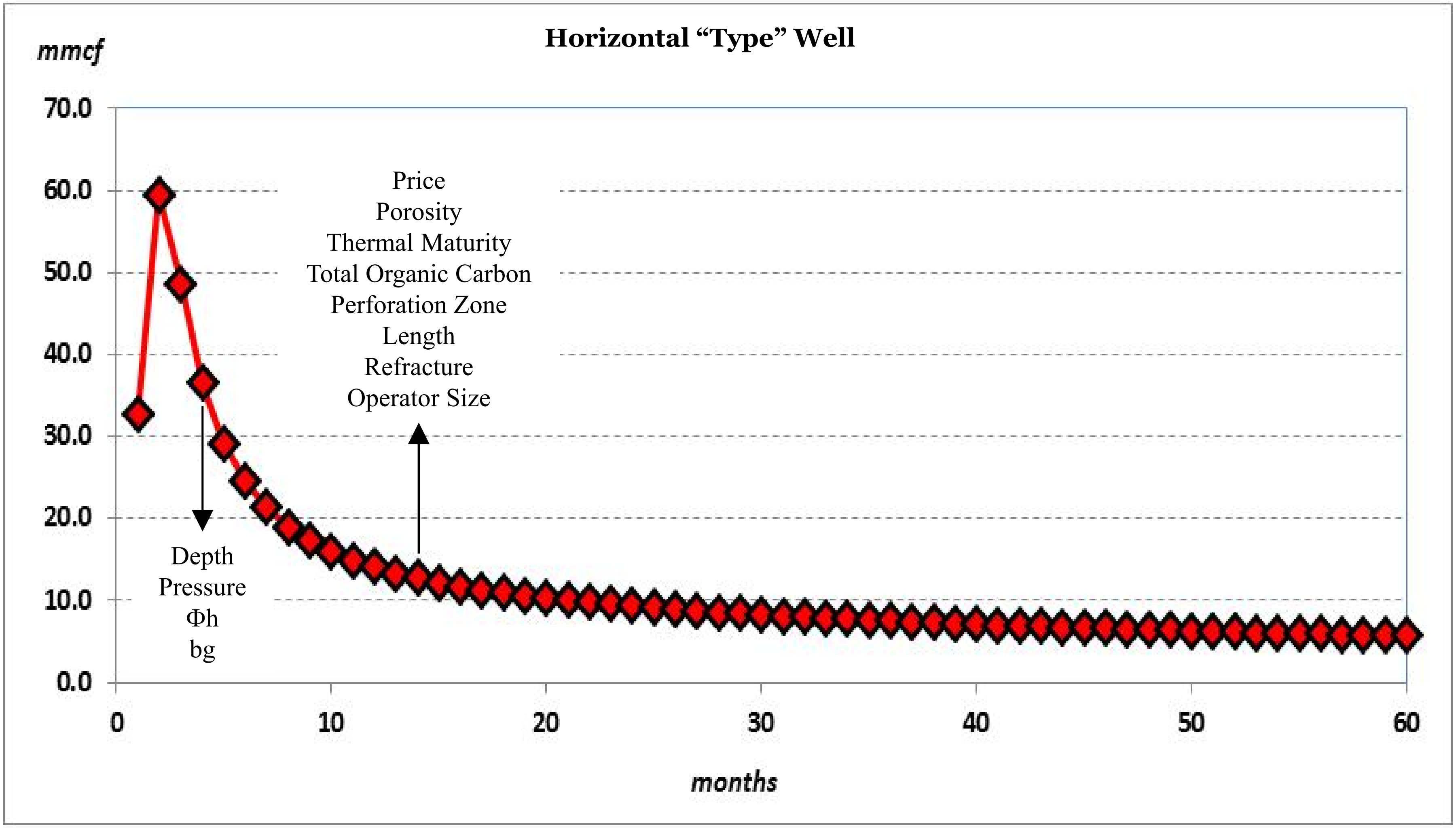
Fitted Horizontal "Type" Well



Fitted Vertical "Type" Well

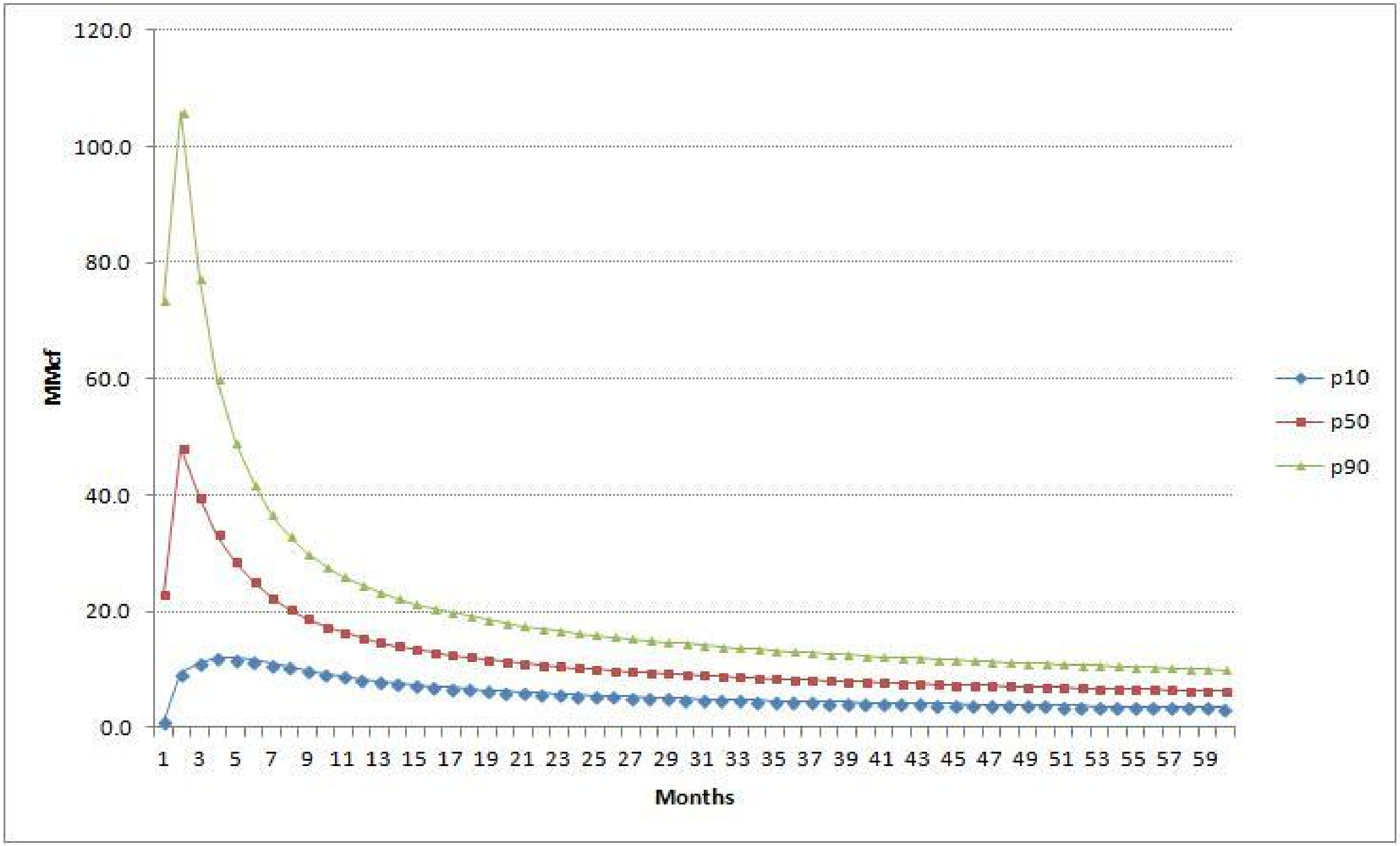


Marginal Effects of Geology and Other Parameters on Production



A Range of Outcomes are Possible

- Just varying IP, we see EURs from 0.85 bcf to 2.53 bcf, which indicates a range of well productivity and hence profitability in horizontal wells.

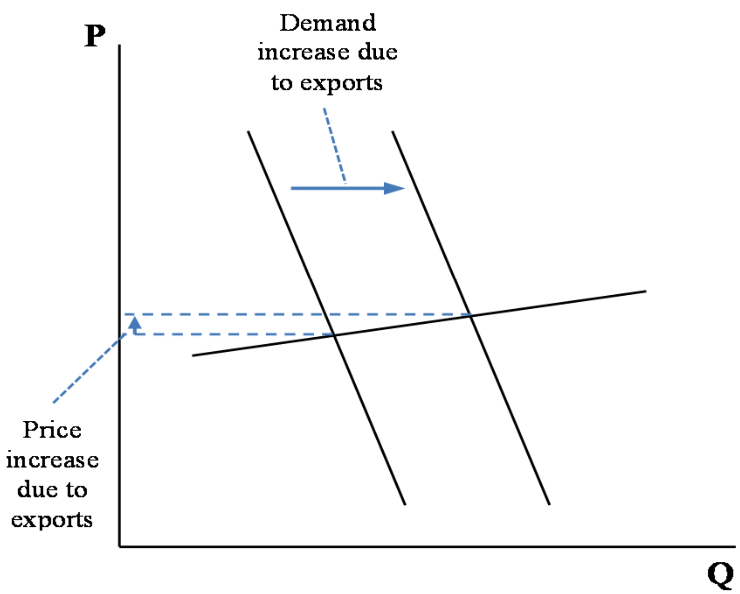


Demand Response and The Prospect of US LNG Exports

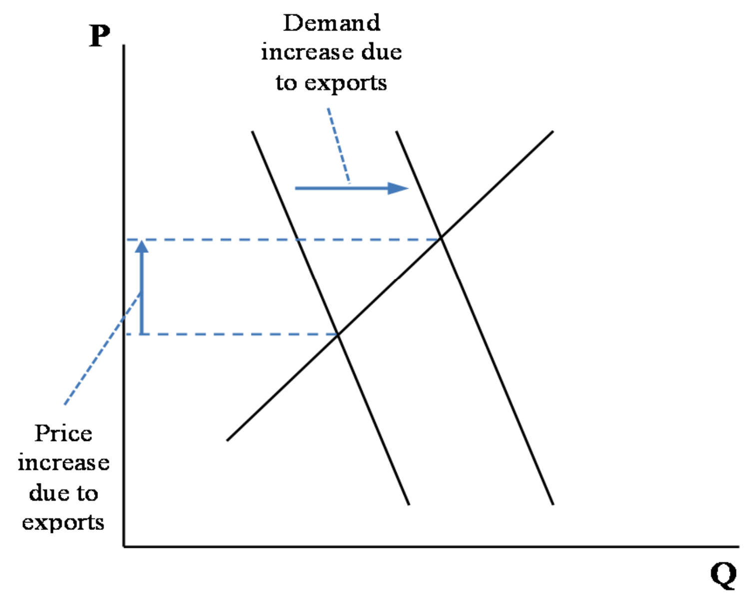
Domestic Price Impacts of US LNG Exports

- Common claim: US price will increase substantially
  - Only true if US domestic supply is highly inelastic (pictured below) and foreign supply is highly elastic (not pictured). This claim is unlikely.

The Elasticity of Domestic Supply and the Impact of Exports on Price



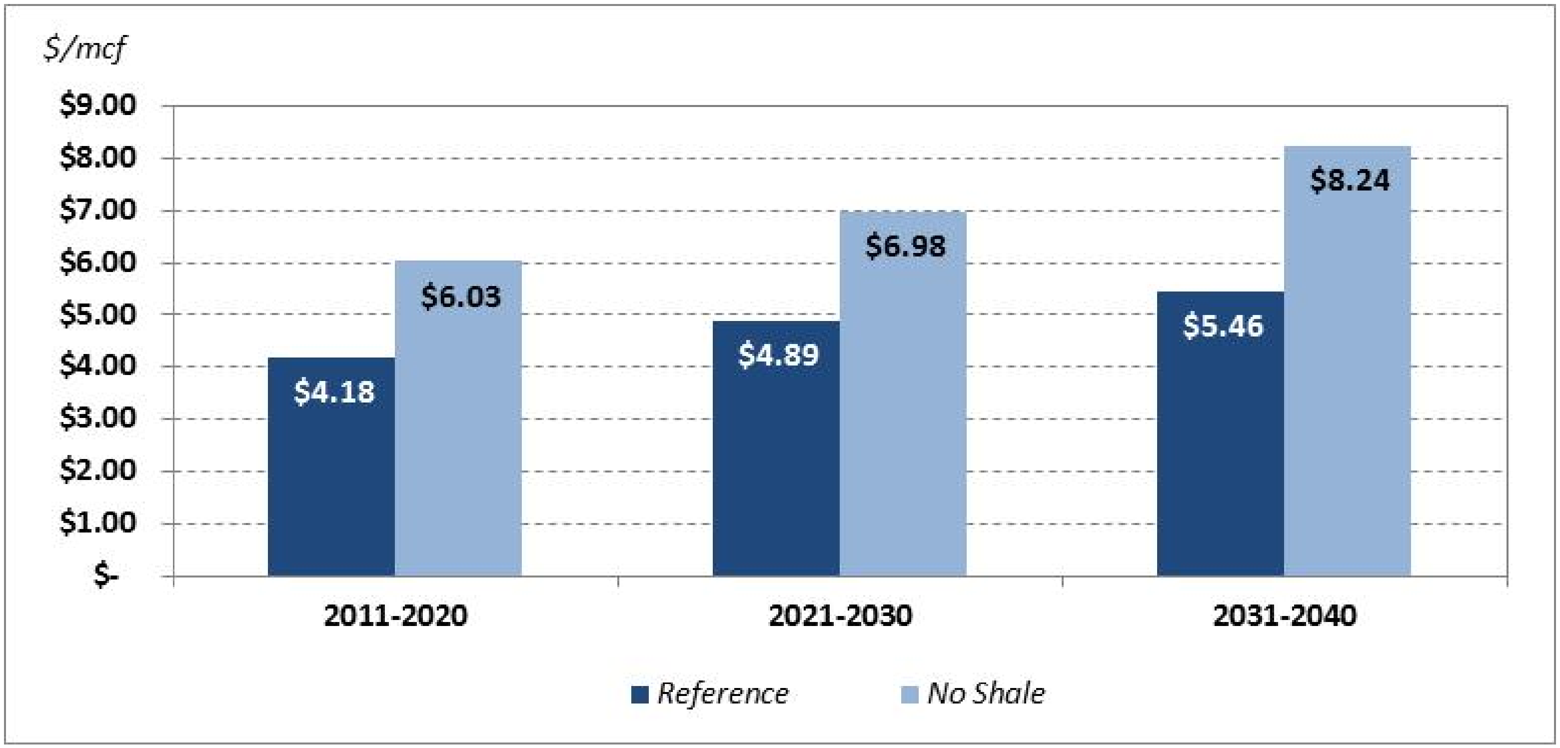
Case 1: Supply elastic



Case 2: Supply inelastic

Impact of Shale on Henry Hub, 2011-2040

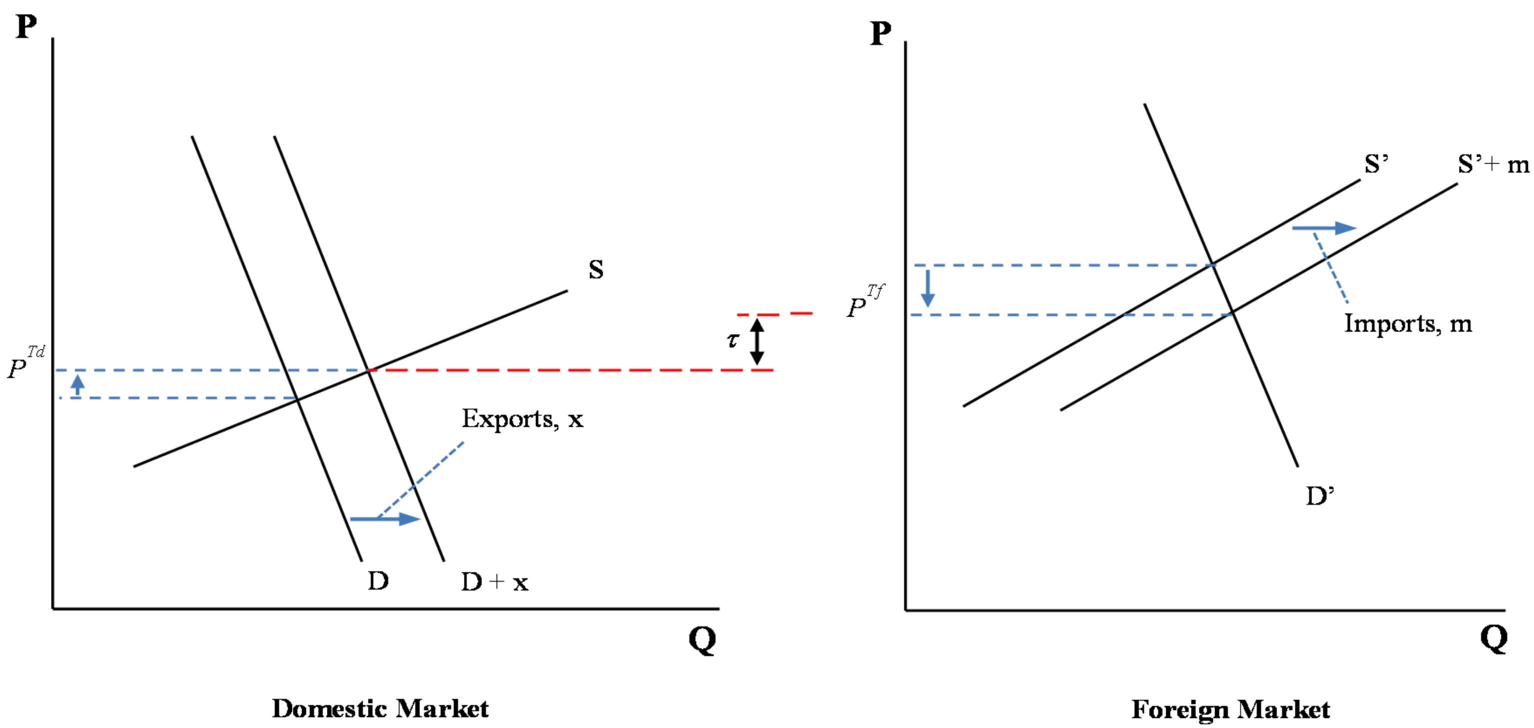
- The domestic supply curve is much more elastic as a result of shale gas developments. Domestic ***long run*** elasticity*
  - with shale = 1.52; without = 0.29.



* - Results derived from the Rice World Gas Trade Model (RWGTM). The RWGTM was developed by Ken Medlock and Peter Hartley at Rice University using the MarketBuilder software provided by Deloitte MarketPoint .

Price Impacts of US LNG Exports: Introducing the Foreign Market Response

- When trade between two markets is introduced, price in each adjusts. The adjustments will depend on the relative elasticities of supply and demand.

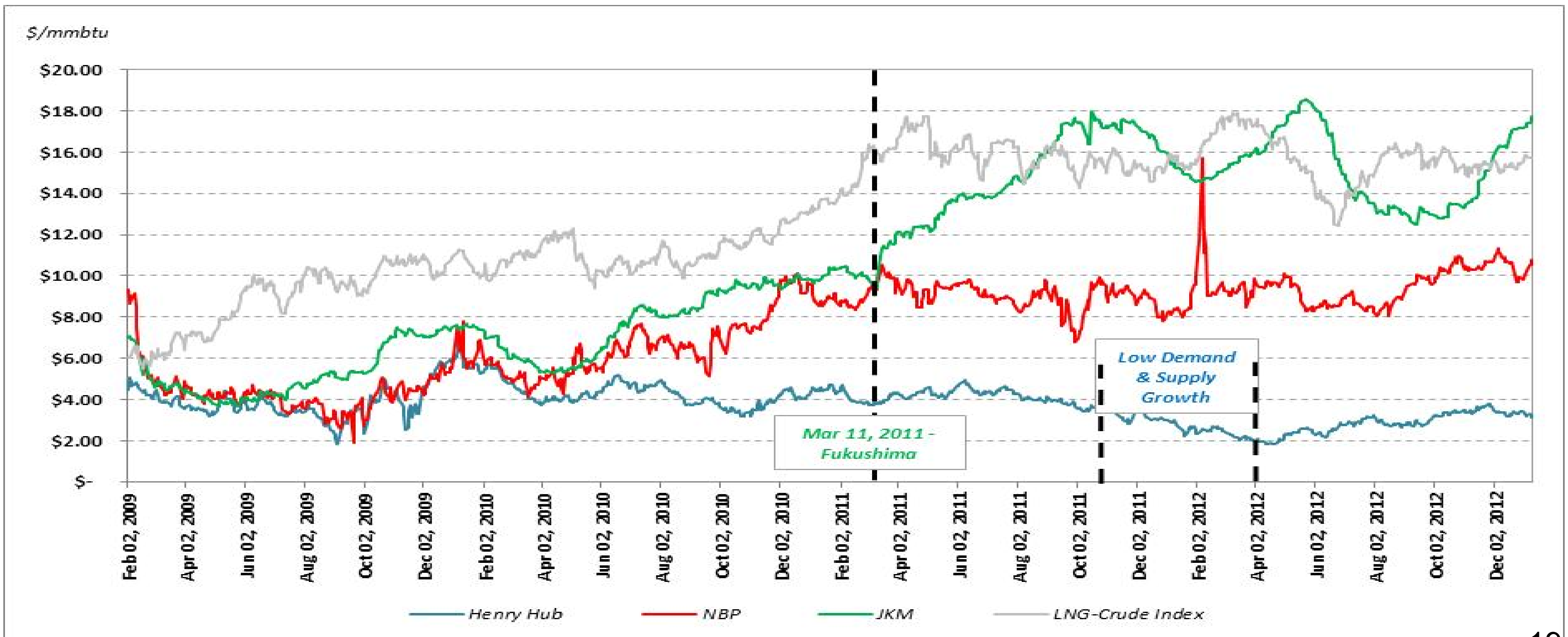


The Impact of US LNG Exports

- Lots of attention given to current international spot price, but several factors are often ignored, such as
  - short term capacity constraints, which are important when considering where we are today,
  - domestic market interactions with markets abroad, and
  - a weak US dollar.
- "Spot" price of natural gas in Asia changed after Fukushima.
- US LNG exports could put significant downward pressure on international price.
  - In 2011, LNG trade totaled about 32 bcfd. Current US filings total over 29 bcfd.
- Effects of international trade are contingent on both domestic and foreign elasticities of supply and demand.

International Prices

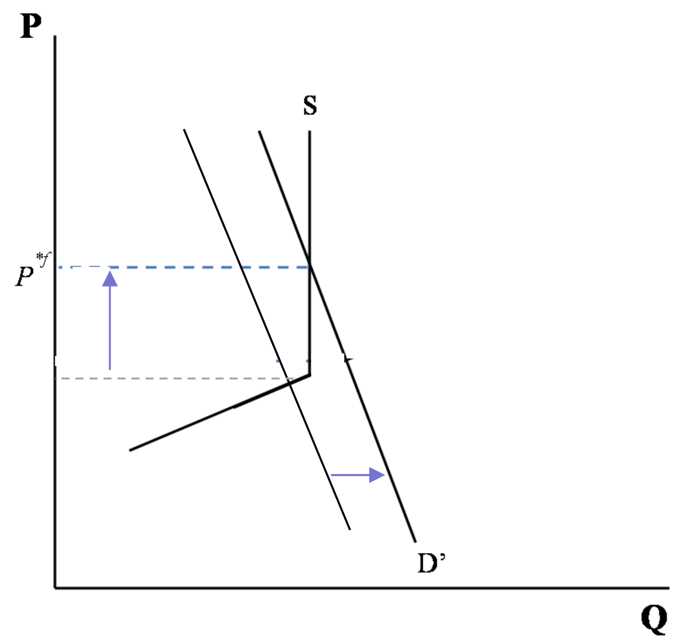
- Will the change in regional natural gas price relationships since March 2011 persist?
  - Unexpected demand shocks have had an influence.
  - It is reasonable to expect that US price will rise to reflect marginal cost and JKM premium will subside with relief of deliverability constraint



Price data from Platts; LNG Oil-Index author's calculation

The Short Term

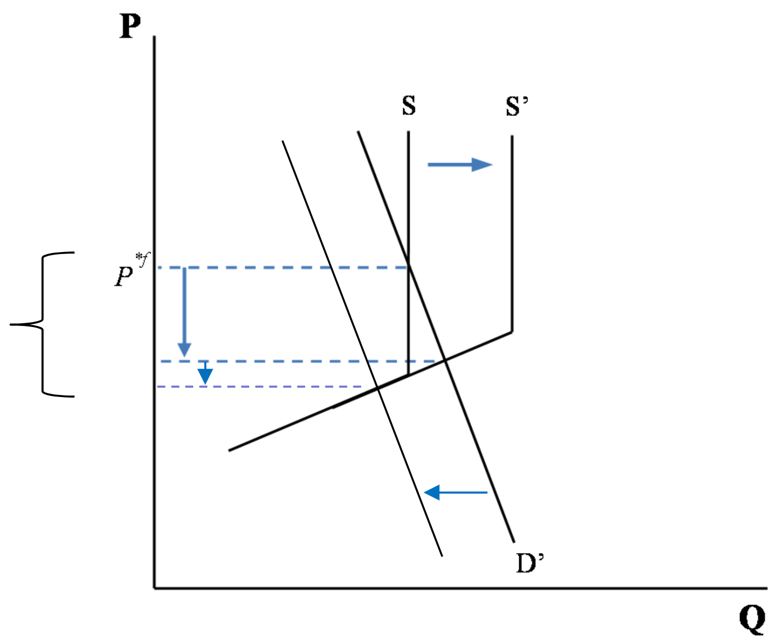
- A wide divergence in price is exactly what we should expect to see if the ability to deliver is constrained…
  - Increased Japanese demand for natural gas in the wake of Fukushima is an *unexpected* demand shock. These sorts of shocks stress delivery capability and create rents in the marketplace.



Moving past the short term

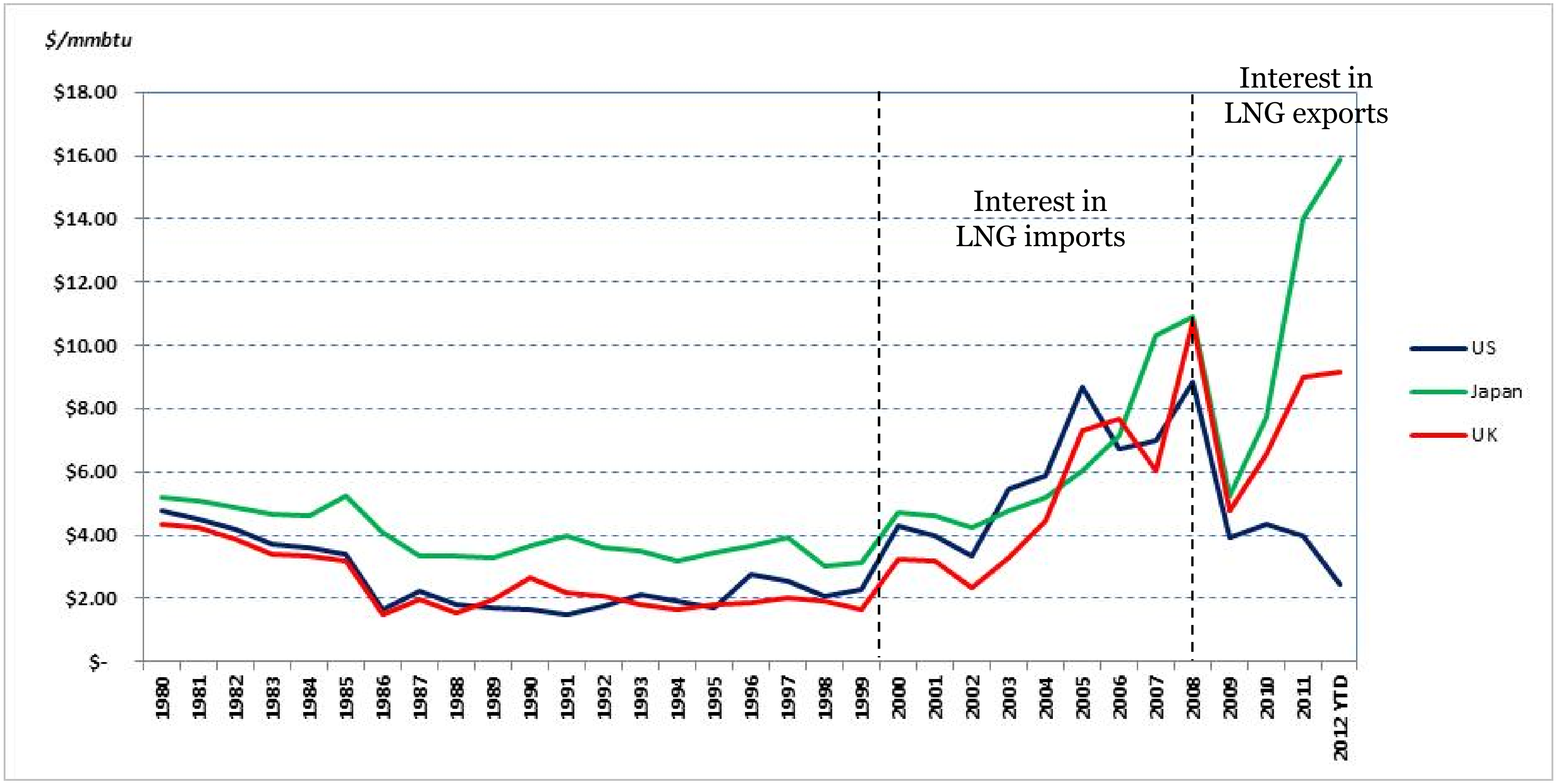
- Alleviating the deliverability constraint will have a large impact on international prices.
  - US exports could put downward pressure on international price.
  - This will be exacerbated by (a) demand reductions and (b) other supplies (for example, China shale, East Africa, Australia, Russia) .

The extent is highly uncertain, but the direction is not…



A Longer Term View of Prices

- The recent divergence is new… but can it persist? Or, is it a result of short term constraints?

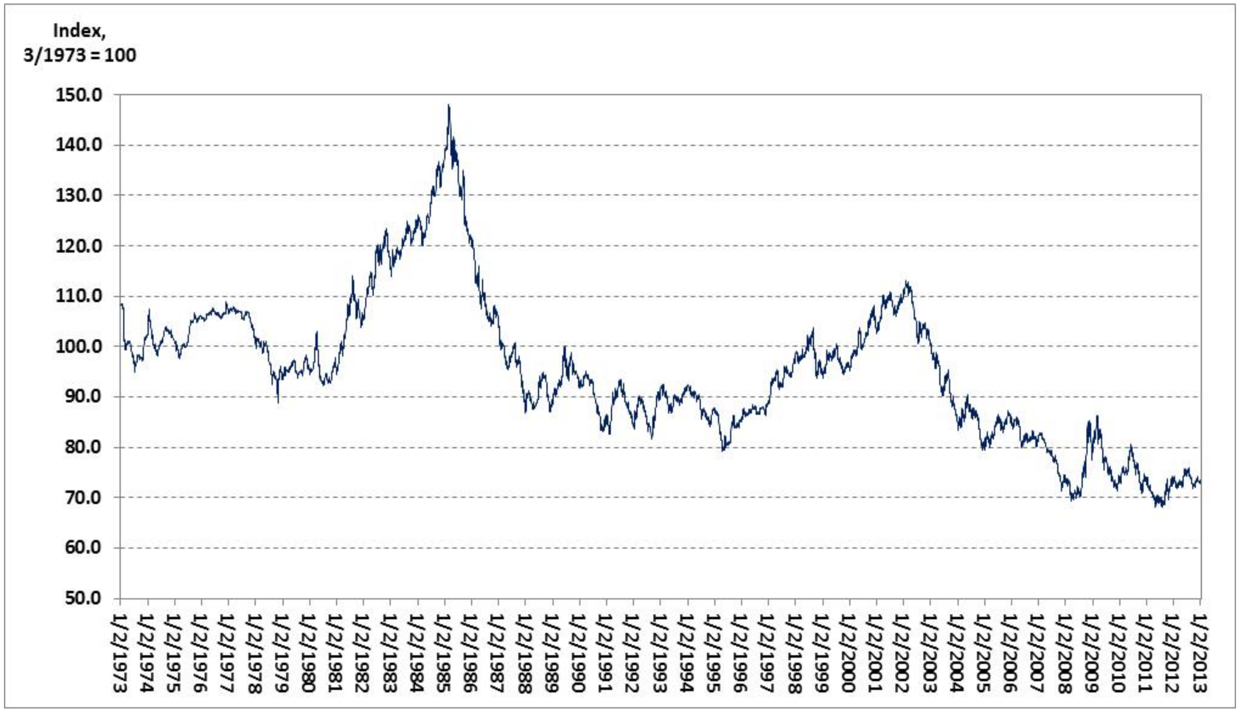


Sources: Compiled from Platts, IEA, EIA

Exchange Rate Effects

- Other factors that are important to the issue are the exchange rate, the role of liquidity in pricing paradigms, and foreign supply developments.
  - Exchange rate impacts: $P_{US} - P_{UK} \cdot XR \cdot HR = arb\ value$

Trade-Weighted Value of US $, Major Currencies (Daily, Jan 1973 – Jan 2013)

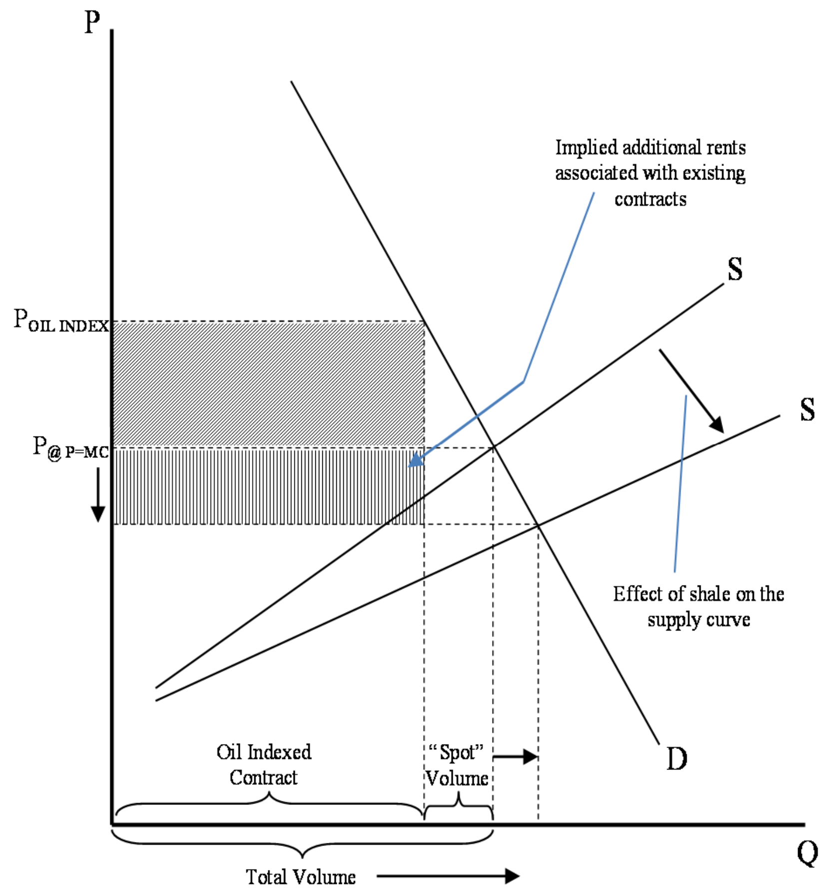


Source: US Federal Reserve Bank

Contracts and Liquidity

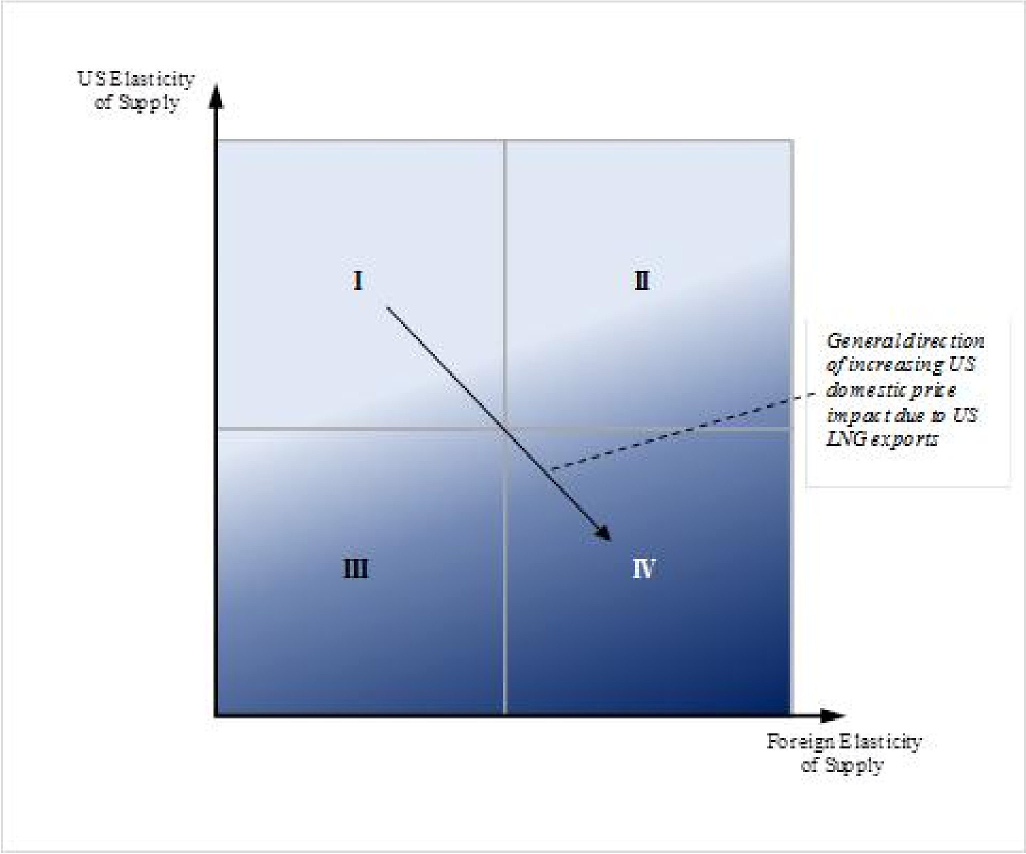
- Absent storage and physical liquidity, oil indexation provides an element of price certainty.
- Oil indexation is a form of price discrimination
  - (1) Firm must be able to distinguish consumers and prevent resale.
  - (2) Different consumers have different elasticity of demand.
- Increased ability to trade between suppliers and consumers (physical liquidity) violates condition (1).
  - This will happen in a liberalized market, or as LNG trade grows, or as hubs emerge in end-use markets.

The Supply Curve Effect of Shale and Implications for Price



The Marginal Profitability of Trade

- To understand what a license to export means for actual exports, we must examine the incidence on price of trade. Unfortunately, most analyses have focused on the US only. This ignores the interaction between the US domestic market and the market abroad.



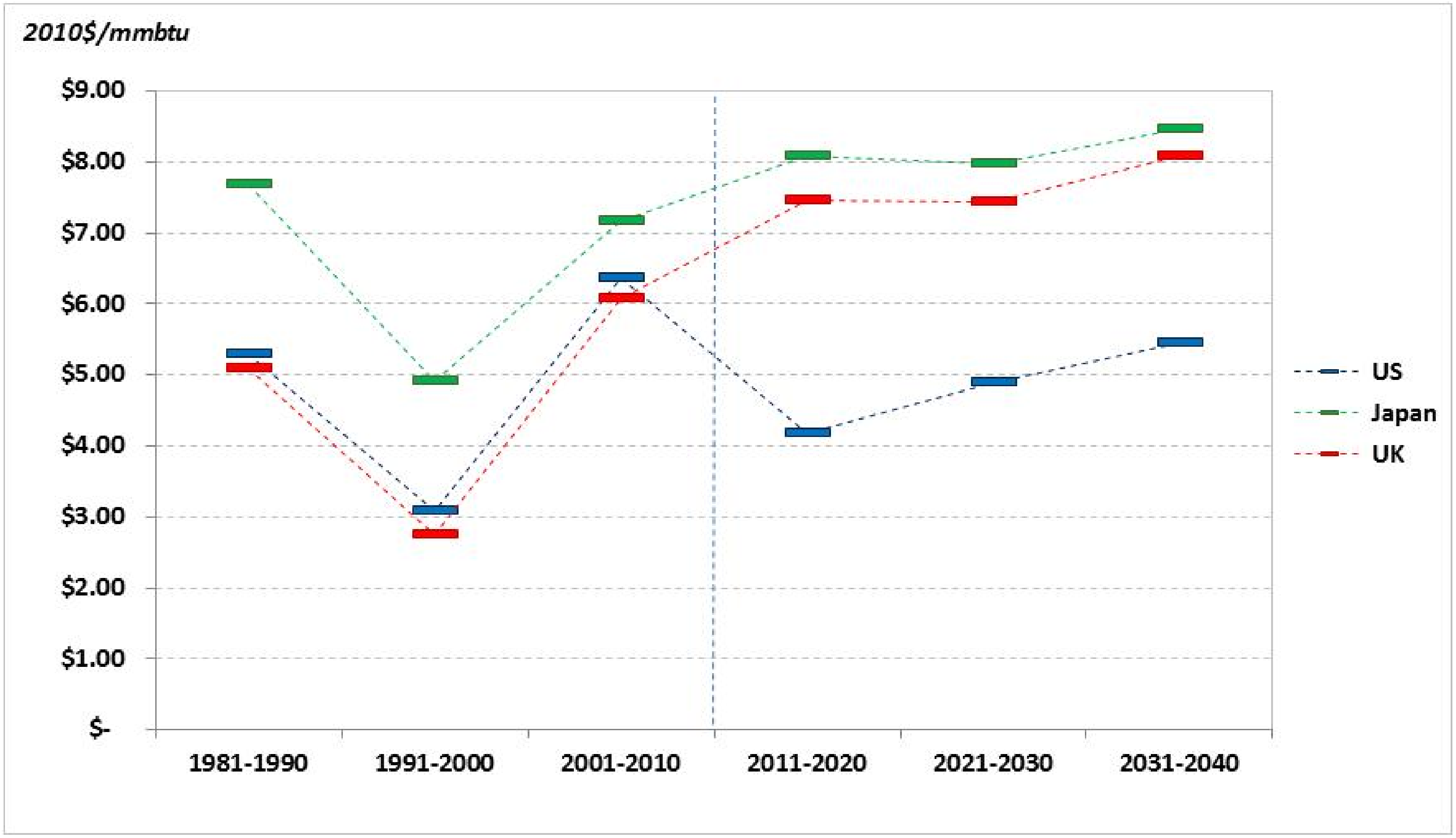
Results from the RWGTM: Case of US Gulf Coast LNG Arbitrage, 2011-2040

- Modeling indicates the current arbitrage value may be transitory. In fact, the positive export margin tends to disappear after 2015.
- The timing is highly dependent on nukes in Japan and LNG in Australia.
- Even so, substantial changes to the table values indicate the result is robust.

	2011	2011-2020	2021-2030	2031-2040
Feed gas cost ($/mcf)	$ 3.80	$ 3.98	$ 4.69	$ 5.26
Liquefaction ($/mcf)	$ 2.92	$ 2.92	$ 2.92	$ 2.92
Transport cost ($/mcf)				
UK	$ 1.07	$ 1.07	$ 1.07	$ 1.07
Japan	$ 2.15	$ 2.15	$ 2.15	$ 2.15
Landed cost ($/mcf)				
UK	$ 7.79	$ 7.97	$ 8.67	$ 9.25
Japan	$ 8.87	$ 9.05	$ 9.75	$ 10.33
Market price ($/mcf)				
NBP	$ 8.93	$ 7.47	$ 7.44	$ 8.09
JKM	$ 13.86	$ 8.08	$ 7.98	$ 8.46
Export Margin ($/mcf)				
UK	$ 1.14	$ (0.49)	$ (1.23)	$ (1.16)
Japan	$ 4.99	$ (0.96)	$ (1.77)	$ (1.87)

How do the RWGTM results compare to history?

- Henry Hub remains below the relationship that persisted historically, although the Asia price and NBP grow slightly closer.



Sources: Compiled from Platts, IEA, EIA and RWGTM

Viability of US LNG Exports

- Current arbitrage value is high, but there is risk
  - Price impact in foreign market could be significant
    - Relative supply and demand elasticities matter.
  - Risk of foreign supply developments
    - Asia can be served by pipeline supplies from Russia, Central Asia, and South Asia, by LNG from the Middle East, Africa, Australia, Asia-Pacific, North America, and by local supplies.
  - Exchange rate risk is present
    - Recent paper by Hartley and Medlock (2012) indicates exchange rates are important in the crude oil-natural gas price differential when (i) there is limited capability for direct arbitrage and (ii) fuel-switching is limited. So, oil-indexed flows are potentially exposed.
    - Gas-indexed trades are also exposed. Foreign gas is traded in own currencies, so exchange rates effect the arbitrage opportunity.
  - Higher supply elasticity challenges pricing paradigms

Viability of US LNG Exports (cont.)

- Export capacity will be built on the expectation that current rents from arbitrage will "pay" for the upfront fixed cost.
  - But, once the fixed cost is sunk, operation no longer hinges on the payment to capital. It is possible that some terminals will not earn the *ex-ante* required rate of return, contingent on the off-take agreement.
- US LNG export capacity could be used for seasonal arbitrage. While the annual load factor would be lower in this circumstance, if seasonal price differences among the regional markets are sufficient, US exports would be profitable.
- LNG exports from the US will link global markets to storage in the US. By providing this link, liquidity benefits could spill over and contribute to very different market paradigm.
- LNG project success could hinge on who bears risk in contractual relationships.

Questions/Comments

Appendix:
The Oil-Gas Price Relationship

The Oil-Gas Price Relationship

- In the US, crude oil and natural gas prices have diverged from each other.
- Shale gas developments have contributed to this…
  - Increased available supply and contributed to storage overhang
  - Driven fuel substitution in power generation sector diminishing the margin of substitution with residual fuel oil
- Recent work by Hartley and Medlock (2012) indicate the price relationship is highly contingent on the value of the US dollar.
  - One commodity is fully fungible while the other is a non-traded good
  - Both commodities are potential substitutes for one another
  - Arbitrage between prices occurs de facto through fuel switching, unless the ability to switch is absent.
  - In this case, the exchange rate becomes the point of arbitrage between the commodities, meaning the exchange rate will be important in determining the price relationship.
  - Importantly, we also show that if fuel switching capability is present, the exchange rate effect is negligible.

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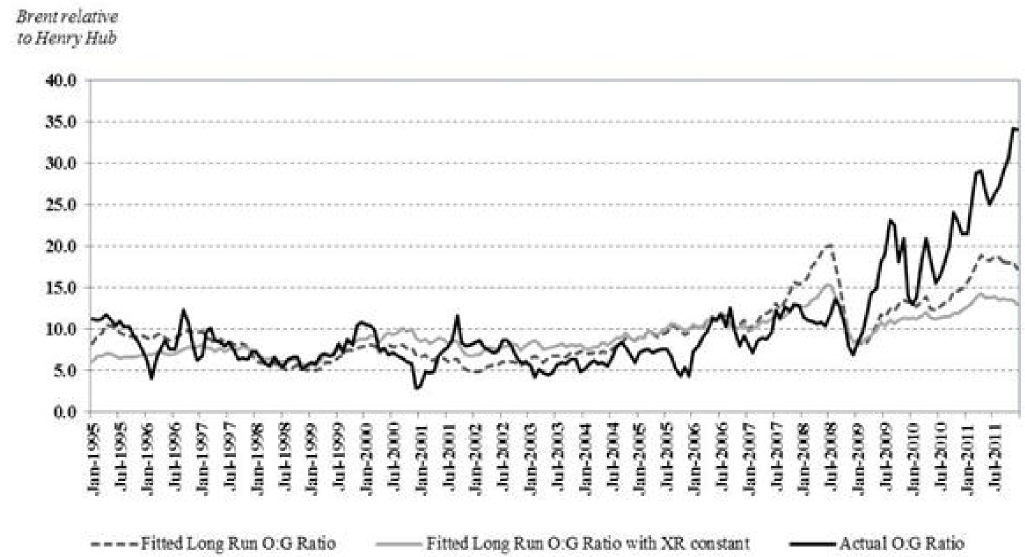
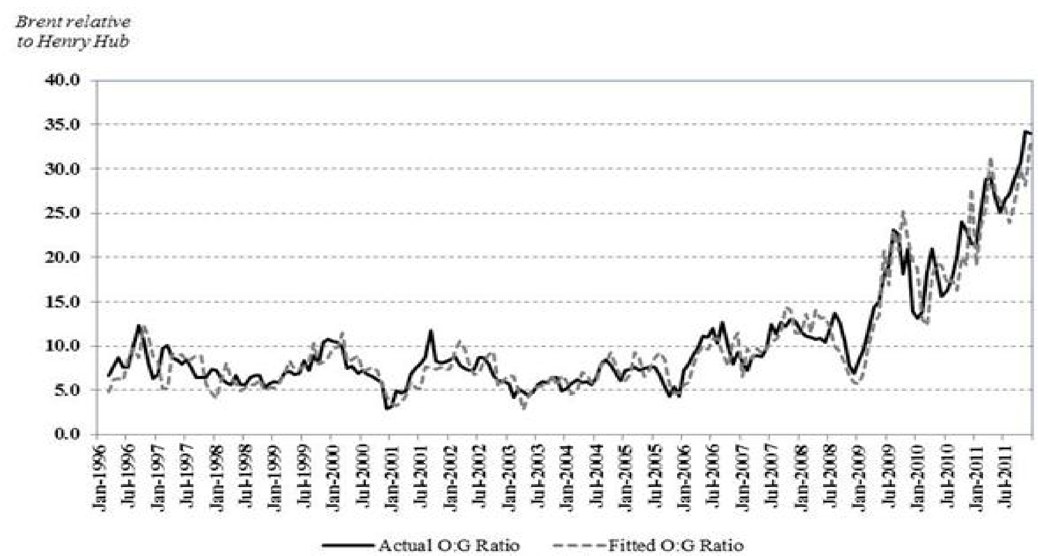
The Oil-Gas Price Relationship (cont.)

- The long run relationship and the impact of the exchange rate, up to 40% of drift is explained by XR movements.



- Accounting for transitory factors explains the remainder of drift.
  - In the very recent history, warm winter and continued production growth combined to push storage well above normal ranges



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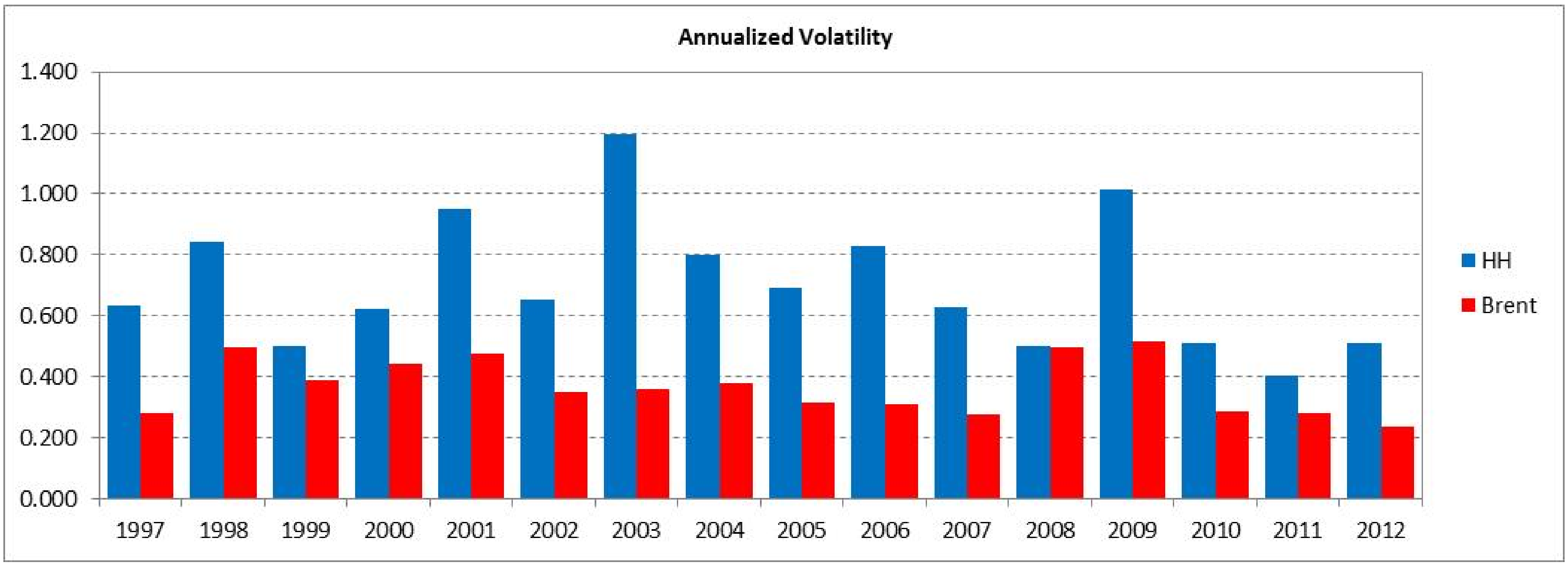
What about Price Volatility?

- Common claim: If we allow LNG exports we will import oil price volatility.
- The premise here is that crude oil is more volatile than natural gas. Is it?



- Economic theory predicts this. The more fungible (or tradable) a commodity is, the lower its price volatility, all else equal.
- Is the term being misused? (Volatility vs. forecast accuracy?)