Long-term LNG Contracts

Peter R. Hartley
George & Cynthia Mitchell Chair, Economics Department
Rice Scholar in Energy Economics, Center for Energy Studies,
James A. Baker III Institute for Public Policy
Rice University
and
BHP-Billiton Chair in the Business of Resources
University of Western Australia
Overview of talk

- Motivation: some recent developments in the LNG market
- Present a model of factors affecting the desirability of long-term LNG contracts in an uncertain environment
- We focus on how changes in the market environment affects
  - Contract terms
  - Project leverage
  - Spot trading activity
  - Overall profitability
- We then use these insights to make predictions about how the LNG market may continue to evolve
Increasing spot and short-term LNG trades: Atlantic Basin

Source: International Group of Liquefied Natural Gas Importers (GIIGNL)
Increasing spot and short-term LNG trades: Pacific Basin

Source: International Group of Liquefied Natural Gas Importers (GIIGNL)
Recent evolution of natural gas prices

Price data from Platts; LNG Oil-Index calculated
Other recent developments

- LNG swaps are increasingly used to exploit arbitrage opportunities
- Many regasification terminals are adding storage capacity to support arbitrage
- Expiration of some early long-term contracts has left spare capacity and without a need to finance large investments
  - Many have entered the short-term and spot market, not signed long-term contracts
- Many recent projects have featured contracts with greater volume flexibility, and less than 100% off-take commitments by buyers
- Following the EU restructuring directive of 1998 (promoting competition in EU gas markets), the EU Commission found destination clauses to be anti-competitive in 2001
  - Stimulated re-export of cargoes from Europe and increased destination flexibility
- Growth of “branded LNG,” where non-consuming buyers purchase LNG from multiple projects and sell to buyers under their own names
  - Example: BG, which has signed contracts with several suppliers
Effects of US developments on LNG trade

- The first few US terminals are proposing exports under a tolling arrangement
  - Cheniere signed a 20-year contract with Kogas that priced the feed gas at 115% of Henry Hub and paid Cheniere a $3/mmbtu liquefaction fee
  - Cheniere have a similar agreement with the Indian state transmission operator
  - Developers of the Freeport terminal also have signed a tolling agreement with BP, who will add the LNG to their global portfolio
- Many proposed facilities are smaller and more modular than traditional trains
  - For example, the Elba Island liquefaction terminal has modular liquefaction units with lower capacity and capital costs and output assigned to Shell’s global portfolio
  - Australian firm LNG Ltd has proposed a terminal in Lake Charles, LA, using a more energy efficient and less capital intensive process for producing LNG
- Future co-location of regasification and liquefaction facilities in the US with pipeline connections to a deep market will facilitate short-term arbitrage
Model: Benefits/Costs of Long-Term LNG Contracts

- Set up a representative LNG export project with partnering CCGT power stations
- Key idea: long term contract makes cash flows less volatile
  - Allows increased leverage, and reduces the cost of project finance
  - We assume the net benefits of debt are approximated by corporate tax benefits alone
- But the firms face a “value at risk” type of limitation on total debt
  - Denote the after-tax cash flow for particular values of demand ($\varepsilon$) and supply ($\xi$) shocks, and export net-back ($p_X$) and import ($p_M$) spot prices, by $C(\varepsilon, \xi, p_X, p_M)$
  - Let the total amount of debt finance be $B$ with after-tax interest cost $r_B(1-\tau)B$
  - We then require $\Pr[C(\varepsilon, \xi, p_X, p_M) < 0.1B + r_B(1-\tau)B] = 0.05$
- Contracts also may limit flexibility to exploit profitable trading opportunities
Some comments on related literature

- Paper builds on a literature, mostly based on the Williamson transaction-cost framework.
- Creti and Villeneuve survey noted Williamson’s key insight: durable transaction-specific investments expose parties to ex-post opportunistic behavior and strategic bargaining.
- A long-term contract is intermediate between spot trading and vertical integration.
- Fixing the terms of trade can give inefficient future trades as supply & demand fluctuate.
  - To mitigate this, contracts allow limited adjustments.
  - While quantity adjustments leave the other party with alternative avenues for making up lost profits, price adjustments are zero-sum.
- A take-or-pay clause helps lessen the efficiency losses resulting from the contract:
  - If value to buyer $v < \text{next best opportunity for seller $s$}$ it is efficient not to take, but if $s < v < y$ (contract price), then a take-or-pay of $y-s$ forces efficient trade.
  - This assumes that $v$ is the only source of variability; more generally a fixed price contract with a take-or-pay clause cannot deliver a first-best outcome.
- Commercial parties emphasize the risk sharing benefits of contracts, but this explanation of the efficiency benefits of take-or-pay clauses reduced academic interest in risk sharing.
Investment projects and market environment

- Demand shocks ($\varepsilon$) could result from plant outages, or changes in other fuel prices or electricity demand.
- Supply shocks ($\xi$) could result from plant outages, weather shocks, strikes, or shipping congestion.
- Demand shocks standard deviation is set at more than 5.7 times the supply shocks standard deviation.
- Since importer demand is $-\partial\Pi/\partial p$, the "consumer surplus" area under the input demand curve is the change in short run profit from a change in $p$.
- Since exporter supply is $\partial\Pi/\partial p$, the "producer surplus" area above the supply curve is the change in short run profit from a change in $p$. 

[Graph showing the relationship between price ($p$) and quantity ($q$) with demand and supply shocks.]
Spot market price distributions

• Import price: $p_M = p_X + \nu$, with \(\nu\) beta distributed, independently of \(p_X\)
• Beta distributions are symmetric with means zero, exponent 3.25
• Assume a large number of other potential suppliers and demanders so that spot prices at any time are unaffected by any trades made by the parties to the contract
Bilateral contract

- The bilateral long-term contract has the following features:
  - There is a contract price $p$ paid by the buyer at the importer’s location ($p-S$ paid at the exporter’s location) and contract volume $q$
  - The supplier is required to deliver $q$ unless both parties agree to a lesser amount
  - Importer taking $M < q$ when $p_X < p-S$ pays $(p-S-p_X)(q-M) = \varphi(q-M)$ to the exporter
    - The “take or pay” fee $\varphi$ compensates the exporter for any deficiency between the spot market and the contract price
  - The exporter can fulfill contracts with swaps or sell surplus production spot
  - The importer can sell contracted volume spot or supplement contracted volume with spot market purchases
- The contract terms $p$ and $q$ are chosen to maximize the sum of the expected NPV of profits of the importer and exporter
- The contract has to be incentive compatible in the sense that both parties obtain positive expected NPV and also prefer the contract outcome to what they could obtain under trade without a contract
Spot market trading regimes

- In addition to the contract solution, we examine two regimes where trading between the parties is not subject to any contract:
  - In the first, we have “full information”, where the parties know current actual demand and supply curves, all costs, and current spot prices at all times
  - In the second “partial information” regime, only the prevailing spot market prices are known when parties trade
- The partial information case is more realistic in the sense that if trading outcomes depend on detailed cost shocks and other private information, parties may have an incentive to hide that information to gain an advantage
  - For the contract to be incentive compatible, it has to be better than the outcome under the partial information regime for both parties
- Details of the trading strategies, including when it is desirable to make spot trades in the contract regime are presented in an appendix
Numerical experiments

- We examined the solution for the best contract, and the full information and partial information spot market solutions, for more than 75 spot market price distributions
  - $\mathbb{E}p_X = $8.75 or $9.25 per mmbtu, with $\sigma(p_X) = $0.82, $1.00 or $1.41
  - $\mathbb{E}p_M$ taking 4 values from $11.19–$12.50, and $\sigma(p_M)$ 18 values from $1.03–$1.71
  - Correlation between $p_X$ and $p_M$ averaged 0.72 and ranged from 0.55 to 0.89
  - Pr(ν<S) (where shipping cost $S=1.25) averaged .089, ranged from 0.0 to .296
- For some spot price distributions, the best incentive compatible contract gave $\mathbb{E}(NPV_X)<0$ and hence would not be feasible
  - In all these cases, the spot market solutions also gave $\mathbb{E}(NPV_X)<0$, so spot prices were too low to make the bilateral trade between these parties worthwhile
- The contract solution had $\mathbb{E}(NPV)>0$ for both parties in a few cases where the spot market no-contract solutions had $\mathbb{E}(NPV_X)<0$
  - In these cases, the investment projects would proceed under a contract, but would not be feasible without a contract
# Average values of key variables

<table>
<thead>
<tr>
<th></th>
<th>$8.75$</th>
<th>$9.25$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E(p_X)$</td>
<td>8.75</td>
<td>9.25</td>
</tr>
<tr>
<td>$E(v) = E(p_M) - E(p_X)$</td>
<td>2.4375</td>
<td>1.9375</td>
</tr>
<tr>
<td></td>
<td>3.25</td>
<td>2.4375</td>
</tr>
<tr>
<td></td>
<td>3.25</td>
<td>3.25</td>
</tr>
<tr>
<td>Number of distributions</td>
<td>12</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Contract price $p$ ($/mmbtu$)</td>
<td>10.68</td>
<td>10.90</td>
</tr>
<tr>
<td></td>
<td>10.97</td>
<td>11.10</td>
</tr>
<tr>
<td></td>
<td>11.42</td>
<td></td>
</tr>
<tr>
<td>Contract quantity $q$ ($10^6$ mmbtu/year)</td>
<td>223.09</td>
<td>230.90</td>
</tr>
<tr>
<td></td>
<td>229.59</td>
<td>234.57</td>
</tr>
<tr>
<td></td>
<td>239.35</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_X)$ under contract ($\text{$ m}$)</td>
<td>45.10</td>
<td>463.35</td>
</tr>
<tr>
<td></td>
<td>487.06</td>
<td>749.45</td>
</tr>
<tr>
<td></td>
<td>1260.92</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_X)$ full information ($\text{$ m}$)</td>
<td>−312.28</td>
<td>49.19</td>
</tr>
<tr>
<td></td>
<td>178.57</td>
<td>287.61</td>
</tr>
<tr>
<td></td>
<td>610.37</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_X)$ public information ($\text{$ m}$)</td>
<td>−434.10</td>
<td>39.87</td>
</tr>
<tr>
<td></td>
<td>105.19</td>
<td>338.46</td>
</tr>
<tr>
<td></td>
<td>865.71</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_M)$ under contract ($\text{$ m}$)</td>
<td>1547.12</td>
<td>1233.85</td>
</tr>
<tr>
<td></td>
<td>881.00</td>
<td>785.26</td>
</tr>
<tr>
<td></td>
<td>137.94</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_M)$ full information ($\text{$ m}$)</td>
<td>1662.83</td>
<td>1352.58</td>
</tr>
<tr>
<td></td>
<td>1121.91</td>
<td>1016.82</td>
</tr>
<tr>
<td></td>
<td>660.49</td>
<td></td>
</tr>
<tr>
<td>$E(NPV_M)$ public information ($\text{$ m}$)</td>
<td>1533.69</td>
<td>1205.90</td>
</tr>
<tr>
<td></td>
<td>792.61</td>
<td>731.30</td>
</tr>
<tr>
<td></td>
<td>55.10</td>
<td></td>
</tr>
<tr>
<td>$B_X$ under contract ($\text{$ m}$)</td>
<td>5176.72</td>
<td>5430.67</td>
</tr>
<tr>
<td></td>
<td>5490.05</td>
<td>5634.68</td>
</tr>
<tr>
<td></td>
<td>6004.37</td>
<td></td>
</tr>
<tr>
<td>$B_X$ full information ($\text{$ m}$)</td>
<td>3827.87</td>
<td>4135.53</td>
</tr>
<tr>
<td></td>
<td>4435.16</td>
<td>4375.31</td>
</tr>
<tr>
<td></td>
<td>4748.26</td>
<td></td>
</tr>
<tr>
<td>$B_X$ public information ($\text{$ m}$)</td>
<td>3612.66</td>
<td>3997.10</td>
</tr>
<tr>
<td></td>
<td>4016.04</td>
<td>4157.08</td>
</tr>
<tr>
<td></td>
<td>4492.09</td>
<td></td>
</tr>
<tr>
<td>$B_M$ under contract ($\text{$ m}$)</td>
<td>3162.26</td>
<td>2966.36</td>
</tr>
<tr>
<td></td>
<td>2785.63</td>
<td>2724.92</td>
</tr>
<tr>
<td></td>
<td>2308.40</td>
<td></td>
</tr>
<tr>
<td>$B_M$ full information ($\text{$ m}$)</td>
<td>3277.38</td>
<td>2917.39</td>
</tr>
<tr>
<td></td>
<td>3292.48</td>
<td>2875.80</td>
</tr>
<tr>
<td></td>
<td>2850.60</td>
<td></td>
</tr>
<tr>
<td>$B_M$ public information ($\text{$ m}$)</td>
<td>2620.52</td>
<td>2500.51</td>
</tr>
<tr>
<td></td>
<td>2350.06</td>
<td>2285.66</td>
</tr>
<tr>
<td></td>
<td>1982.46</td>
<td></td>
</tr>
<tr>
<td>Contract premium relative to $PI$</td>
<td>30.97%</td>
<td>26.54%</td>
</tr>
<tr>
<td></td>
<td>34.26%</td>
<td>30.18%</td>
</tr>
<tr>
<td></td>
<td>34.04%</td>
<td></td>
</tr>
<tr>
<td>Importer spot net purchases</td>
<td>50.12</td>
<td>53.34</td>
</tr>
<tr>
<td></td>
<td>15.96</td>
<td>27.07</td>
</tr>
<tr>
<td></td>
<td>1.10</td>
<td></td>
</tr>
<tr>
<td>Exporter spot net sales</td>
<td>28.48</td>
<td>42.86</td>
</tr>
<tr>
<td></td>
<td>9.83</td>
<td>26.63</td>
</tr>
<tr>
<td></td>
<td>11.66</td>
<td></td>
</tr>
</tbody>
</table>
Basic results on contract value

- The long-term contract makes both the exporter and importer strictly better off on average than the feasible spot market trading solution.
  - In the numerical examples, the combined surplus is about 30% higher.
- The main reason is that the contract allows the investment projects to carry more debt by stabilizing cash flows, and thereby to reduce the weighted average cost of finance.
- The benefits of extra debt exceed the final gains in net present value, implying there are partially offsetting losses from inefficient ex-post trades mandated by the contract terms.
- While contracts preclude some profitable trades, they also bestow an option value.
  - Both parties can use spot transactions to supplement long-term contract trades.
- Although the effect of changing uncertainty is not evident in the averages, we see later:
  - Spot price uncertainty critically affects the value of contracts versus spot trades.
  - Uncertainty in future demand and supply also influences the value of contracts.
Other effects of changes in mean spot prices

- An increase in both $p_X$ and $p_M$ holding the gap between them fixed amounts to a general increase in natural gas prices leaving the partners’ situations otherwise unchanged
  - The optimal contract price rises almost the full amount of the price increase
  - Bilateral trade becomes more desirable, so contract volume rises
  - Exporter net spot sales increase and importer net spot purchases decrease
  - Suppliers, whose costs are unrelated to the price increase, benefit substantially

- A reduction in the gap between $p_X$ and $p_M$ holding $p_X$ fixed decreases the spot prices available to the importer alone, leaving the opportunity cost for the exporter unchanged
  - Contract price and volume decrease, but by less than half the decreases when spot prices in general fall
  - Long-term contracts become less attractive, and spot trading by contracted parties increases as the value of embedded options to trade on spot markets goes up

- The contract premium is not much affected by the general level of spot market prices, but reducing the average spread between the spot prices noticeably reduces the premium
Contract premium over private information equilibrium

E(p_X) = 8.75, E(γ) = 1.9375

No feasible contracts

E(p_X) = 8.75, E(γ) = 2.4375

No feasible contracts

E(p_X) = 8.75, E(γ) = 3.25

E(p_X) = 9.25, E(γ) = 1.9375

Ruled out by arbitrage

E(p_X) = 9.25, E(γ) = 2.4375

E(p_X) = 9.25, E(γ) = 3.25
Extra debt under contract solutions
Gross spot trades relative to contract volumes

\[ E(p_X) = 8.75, E(\gamma) = 1.9375 \]

No feasible contracts

\[ E(p_X) = 8.75, E(\gamma) = 2.4375 \]

No feasible contracts

\[ E(p_X) = 8.75, E(\gamma) = 3.25 \]

\[ E(p_X) = 9.25, E(\gamma) = 1.9375 \]

Ruled out by arbitrage

\[ E(p_X) = 9.25, E(\gamma) = 2.4375 \]

\[ E(p_X) = 9.25, E(\gamma) = 3.25 \]
Key insights from variability changes

- Spot price variability produces variable cash flows, which reduces project debt capacity
  - This raises the advantage of contracts and increases contract volume
  - Conversely, lower spot price variability, resulting for example from higher supply/demand elasticity or more parties capturing price arbitrage opportunities, will erode the value of long term contracts
  - The contract premium varies much more with overall spot price variability than variability in the spread between them

- Changes in spot price variances (holding means fixed) non-linearly affect contract price and volume, ex-post trading inefficiencies and to a lesser extent spot market transactions
  - Options implicitly embedded in the contract are affected non-linearly, as are the values of any efficient ex-post trades precluded by the contract
  - Increased spot price variability also raises cash flow variability, thereby increasing the leverage benefits of the contract

- Additional debt under the contract is influenced much more by the overall variability of spot market prices than variability in the spread between exporter and importer prices
  - Also, changes in average spot prices or the average spread between exporter and importer spot prices do not have much of an effect on overall debt levels
Concluding comments

- As more countries import LNG, and more producers enter the market:
  - The average distance between any two potential trading partners will decline, cutting average price differences between buyers and sellers
  - The elasticity of supply or demand facing any one party will tend to increase
- Unconventional sources of supply also tend to raise supply elasticity, and a wider range of end-uses for natural gas likely will raise demand elasticity
- An increased number of intermediaries providing hub services and having access to storage will allow more effective price arbitrage further reducing price variability
- Accordingly, we would expect the variability of spot prices, and the gap between spot prices available to importers and netback prices available to exporters, to decline as market liquidity continues to rise
- Spot market trades from parties to contracts may also increase
- Growth in spot trading may reduce volumes under contract and raise spot market participation, further raising spot market liquidity
Appendix

Some technical details on the projects and their spot market environment, the numerical experiments and the results
Representative investment projects

- We consider a liquefaction plant of approximately 5 mtpy capacity
  - Since 1 tonne of LNG contains approximately 51.322 mmbtu, a 5 mtpy LNG plant would produce about $256.61 \times 10^6$ mmbtu per year
- For concreteness, we also assume that all the LNG will be used to fuel CCGT power generation plants
- Assume the following power plant physical parameters:
  - 400 MW capacity, operated at a 60% load factor
  - Heat rate of 6.43 mmbtu/MWh
- Output per plant = $400 \times 0.6 \times 8760 \times 10^{-6} = 2.1024$ TWh/year, which requires $13.518 \times 10^6$ mmbtu/year of natural gas
- Thus, 18 CCGT plants would consume $243.33 \times 10^6$ mmbtu per year
  - Gap of 5% would allow for losses in production, transport and regasification
  - Also, we allow for both parties to use spot markets for marginal trades
Liquefaction plant costs

From the regression line, capital cost for 5 mtpy plant = $9.119 billion

Annual operating cost (excluding cost of feed gas) of $0.28/mcf would give tax-deductible variable annual operating costs (assuming 1027 btu/mcf) of around $V_X = 0.2726 million per $10^6 mmbtu
Power plant and financing costs

- Using EIA data, a power plant capital cost of $1.003 million/MW and capacity of 400MW implies an investment cost of $401.2 million per plant, or $7.221 billion for 18 plants.
- Fixed O&M of $0.01462 million/MW implies $5.848 million fixed O&M per year per plant, or $105.264 million per year for 18 plants.
- Variable O&M (excluding fuel) of $3.11/MWh and a heat rate of 6.43 mmbtu/MWh imply annual non-fuel tax-deductible variable O&M of $0.4837 million/106 mmbtu.
- We use the adjusted present value approach to value cash flows on the projects.
  - Evaluate NPV of after-tax cash flows at the all-equity return and add the NPV of the tax savings due to debt.
  - Discount depreciation allowances at the nominal risk free rate.
  - All-equity return = 10%, bond yield = 5%, risk free rate = 3%.
- All projects are assumed to have a life of 25 years, with straight line depreciation for tax purposes.
- Corporate tax rate ($\tau$) is assumed to be 35% for all projects; annual fixed and variable O&M and fuel costs are fully tax-deductible as is interest on debt.
Shipping costs

- Take shipping costs $S$ to be $1.25/mmbtu
The full information spot trading regime

- If $p_X+S \geq p_M$ i.e. $-\nu \leq S$ importer and exporter each prefer spot market.
- When this is not the case, define prices $p_X$ for the exporter and $p_M$ for the importer such that supply equals demand and the price difference equals shipping cost $S$ plus variable O&M costs, $V_X+V_M$.
- We then have three cases:
  - $p_X-V_X \leq p_X$ and $p_M \leq p_M+V_M$ – both parties prefer bilateral trade.
  - $p_X-V_X \leq p_X$ and $p_X+S+V_M < p_M+V_M < p_M$ – importer prefers the spot market, which sets the price for the exporter.
    - Note we must have $p_M+V_M \geq p_M$ in case 3, since otherwise we obtain the contradiction $p_M > p_M+V_M > p_X+S+V_M > p_X+S+V_X+V_M$.
  - In case 2, the exporter may want to produce more at $p_M-S > p_X$ than the importer wants to buy at $p_M$, but any additional output must be sold spot at $p_X$.
  - In case 3, the importer may spot purchase at $p_M-V_M > p_X+S-V_M$. 

Appendix
Trading without a contract when only prices are known

- If \( \nu \leq S \) the importer and exporter both prefer to use spot markets
- When this is not the case, define “split the difference” prices
  \[ p_X = \frac{p_X + p_M - S}{2} \]
  for the exporter and
  \[ p_M = \frac{p_X + p_M + S}{2} \]
  for the importer
- Let \( M^D \) and \( X^S \) represent the demands and supplies at these prices
  - If \( M^D > X^S \), the importer must use spot market to satisfy extra demand if any
  - If \( M^D < X^S \), the exporter has to use the spot market for extra supply if any
  - If, by chance, \( p_X \) and \( p_M \) equate supply and demand from the two parties, no additional spot market transactions are desired
- As noted above, this option will be the only non-contract solution if parties cannot credibly convey the particular supply or demand shocks that they experience
Trading decisions under the contract

- If \( v \geq S \), i.e. \( p_M \geq p_X + S \), \( p_M + \varphi = p_M + p - S - p_X \geq p \) and the take-or-pay clause is irrelevant
  - Exporter will supply \( q \) at \( p \) and if importer demand is less than \( q \), the surplus will be sold spot, at a loss if \( p_X + S < p \)
  - Exporter and importer may supplement sales or purchases with spot market transactions

- If \( v < S \), i.e. \( p_M < p_X + S \), exercising the take or pay clause is preferable to taking \( q \) at \( p \)
  - However, if both \( p_X + S \geq p \) and \( S > v \), the exporter would prefer to fulfill the contract with a swap and make spot sales instead of sales under the contract
    - A swap satisfies importer demand at price \( p \) up to a maximum quantity of \( q \)
    - Importer and/or exporter may supplement bilateral trade with spot trades

- If \( p_M < p_X + S < p \), the importer will exercise the take or pay clause
  - Importer will pay \( \varphi q \) to the exporter and both parties will use spot markets
Optimal contract prices

- The contract prices $p$ ranged from $10.66–$11.50, with $E_p=$$11.03 and $\sigma(p) = 25\cent$
  - By comparison, the standard deviation of $E_{p_X}$ is $24\cent$ and of $E_{p_M}$ is $49\cent$
- An increase of $50\cent$ in $p_X$ (and $p_M$) increased the contract price (holding other variables fixed) about $45\cent$, and an increase of $50\cent$ in the gap $\nu = p_M - p_X$ increased $p$ about $20\cent$
  - Increased rent from higher spot prices is shared between the parties to the contract, but a general increase in prices benefits the supplier, while new entry that decreases the gap is more favorable for the importer
- The magnitudes of changes in $p$ in response to changes in the standard deviations of spot prices are similar to the response of $p$ to changes in $\nu$
  - Holding the means of the spot price distributions fixed, the $30$-$60\cent$ changes in standard deviations produced at most a $25\cent$ variation in optimal $p$
- Changes in the standard deviation of spot prices have non-linear effects:
  - Higher spot price variability provides more opportunities to take advantage of favorable spot market trades, but increases the cost of forgone profitable spot trades
  - Variability of spot market prices also raises variability of cash flows, thereby reducing the debt capacity of the investment projects and increasing the benefits of a contract
Contract prices ($/mmbtu)
Optimal contract volumes

- The contract volume averaged $232 \times 10^6 \text{ mmbtu/year}$, with a standard deviation of $5.6 \times 10^6 \text{ mmbtu/year}$ and a range from $220.2 - 241.8 \times 10^6 \text{ mmbtu/year}$
  - Recall that a 5 mtpa LNG plant would produce about $257 \times 10^6 \text{ mmbtu/year}$, while 18 CCGT plants would consume about $243 \times 10^6 \text{ mmbtu/year}$
- An increase of 50¢ in $E_{PX}$ (and $E_{PM}$) increased contract volume (holding other variables fixed) about $10^7 \text{ mmbtu/year}$, while an increase of 80¢ in the average gap $\nu = p_M - p_X$ between spot prices available to each party increased $q$ about $5 \times 10^6 \text{ mmbtu/year}$
  - Higher spot prices, and a bigger gap, make the bilateral trade more valuable
- Except when $E_{PX}=8.75$, $E_{\nu}=2.4375$, and for low $\sigma(p_X)$ when $E_{PX}=9.25$, $E_{\nu}=3.25$, an increase in the standard deviation $\sigma(p_X)$ of spot prices tends to reduce contract volume
- An increase in the standard deviation of the spot price gap $\nu$ tends to increase the contract volume at low levels of $E_{\nu}$ but reduce it at higher levels of $E_{\nu}$
- One explanation of the effects of spot price variability on contract volume appears to be that ex-post trading inefficiencies tend to be affected in the opposite way
Contract volumes ($10^6$ mmbtu/year)
Trading inefficiencies under contracts
The next three slides present results on spot market trading under the optimal contracts.

Both importer net spot market purchases and exporter net spot market sales increase substantially as the average gap $E\nu$ between spot prices available to importers and the netback price available to the exporter decreases.

Generally, reduced variability of the gap $\sigma(\nu)$ also decreases spot market transactions:

- Similarly, there is a tendency for reduced $\sigma(p_X)$ to reduce spot market transactions, but the effect is much weaker.
- The option to supplement contract trades with spot market transactions is exercised more when spot market prices are more variable.

Gross spot market transactions (regardless of sign or contracting party) tend to respond to changes in the spot market price distributions in a similar way to exporter net spot market sales.
Importer net spot purchases under contracts

\[ E(p_x) = 8.75, E(\gamma) = 1.9375 \]

No feasible contracts

\[ E(p_x) = 9.25, E(\gamma) = 1.9375 \]

Ruled out by arbitrage

\[ E(p_x) = 8.75, E(\gamma) = 2.4375 \]

No feasible contracts

\[ E(p_x) = 8.75, E(\gamma) = 3.25 \]

\[ E(p_x) = 9.25, E(\gamma) = 2.4375 \]

\[ E(p_x) = 9.25, E(\gamma) = 3.25 \]
Exporter net spot sales under contracts
Gross spot trades relative to contract volumes
Additional debt under the contract solutions

- The next slide shows that the contract solution allows the investment projects to be financed with additional debt.
  - For the parameter values we examined, debt under the contract solutions was on average 30% higher than debt under the private information spot market solutions.
- The additional debt is not very sensitive to the mean levels of the spot prices, but responds very strongly to the overall variability of spot market prices $\sigma(p_X)$.
  - This is consistent with the hypothesis that the contract allows more debt by stabilizing cash flows.
- Increases in the standard deviation of the gap $\sigma(\nu)$ also increase debt capacity under a contract, but the effect is somewhat weaker than increases in $\sigma(p_X)$.
Extra debt under contract solutions

---

No feasible contracts

Ruled out by arbitrage

---

E(\(p_X\)) = 8.75, E(\(\gamma\)) = 1.9375

E(\(p_X\)) = 8.75, E(\(\gamma\)) = 2.4375

E(\(p_X\)) = 8.75, E(\(\gamma\)) = 3.25

---

E(\(p_X\)) = 9.25, E(\(\gamma\)) = 1.9375

E(\(p_X\)) = 9.25, E(\(\gamma\)) = 2.4375

E(\(p_X\)) = 9.25, E(\(\gamma\)) = 3.25
Overall desirability of the contract solutions

- The next slide graphs the overall proportional difference in \( E(\text{NPV}_X + \text{NPV}_M) \) under the contract versus the partial information spot market solutions.

- \( E(\text{NPV}) \) of the exporter plus importer projects under the contract solution is:
  - 31% higher than the corresponding partial information spot market solution, and
  - 12% higher than the spot market solution using private as well as pubic information.

- The advantage of a contract is not much affected by the general level \( E(p_X) \) of spot market prices, but a reduction in the average gap \( E\nu \) noticeably reduces the benefits of a contract.
  - As we saw above, a reduction in the average gap \( E\nu \) also reduces contracted volume and increases spot market trading by parties to a contract.

- Key conclusion 1: A more liquid spot market that decreases the mean gap between importer and exporter netback prices decreases the relative superiority of the contract solution.

- A decrease in \( \sigma(p_X) \) also substantially reduces the benefits of a contract, but the effect of \( \sigma(\nu) \) is weak and generally more ambiguous.

- Key conclusion 2: A more liquid spot market that decreases spot price variability also decreases the relative superiority of the contract solution.
Contract premium over private information equilibrium

- For $E(p_X) = 8.75, E(\gamma) = 1.9375$:
  - No feasible contracts

- For $E(p_X) = 9.25, E(\gamma) = 1.9375$:
  - Ruled out by arbitrage

- For $E(p_X) = 8.75, E(\gamma) = 2.4375$:
  - No feasible contracts

- For $E(p_X) = 9.25, E(\gamma) = 2.4375$:
  - No feasible contracts

- For $E(p_X) = 8.75, E(\gamma) = 3.25$:
  - No feasible contracts

- For $E(p_X) = 9.25, E(\gamma) = 3.25$:
  - No feasible contracts
Total rent and rent shares under optimal contracts

- The next two slides summarize the effect of spot price distributions on total rent under the optimal contracts and its distribution between exporter and importer.
- The contract solutions yield average $E(NPV_X+NPV_M)$ of $1.488$ billion.
  - Recall the up-front investments were $9.119$ billion for $X$ and $7.221$ billion for $M$.
  - The contract thus yields a higher (real) rate of return than the assumed all-equity return = $10\%$, bond yield = $5\%$, risk free rate = $3\%$.
- Higher average spot prices $E(p_X)$ increase rent, while a larger gap $E\nu$ decreases it.
- Total rent also increases in $\sigma(p_X)$ and (almost everywhere) $\sigma(\nu)$.
- Average exporter share of the expected NPV under the contract was $44.6\%$.
  - It ranged from a minimum of $0.59\%$ to a maximum of $97.77\%$ and the standard deviation was $29.5\%$.
- The exporter share graphs resemble the graphs of the optimal contract price $p$.
- Increases in average spot market prices $E(p_X)$ and in the average gap $E\nu$ between importer and exporter prices raise the exporter share.
- Changes in spot price and price gap variances have ambiguous effects on rent share.
Total rent (sum of $E(\text{NPV})$) under contracts
Exporter rent share under contracts

\[ E(p_X) = 8.75, E(\gamma) = 1.9375 \]

No feasible contracts

\[ E(p_X) = 9.25, E(\gamma) = 1.9375 \]

Ruled out by arbitrage
Summary of the above results

- The contract solutions yield a higher joint E(NPV) for the project participants largely because they allow for higher debt levels
  - Inefficiencies arising from contract trades limiting the ability of parties to exploit spot market opportunities are not large, with changes in contract terms and supplemental spot market trades helping keep these under control
- Generally, a smaller gap between spot prices available to the exporter and the importer, and lower variability of spot market prices, reduces the advantages of the contract over spot market trades
- A reduction in the average difference between importer and exporter spot market prices also encourages substantially more spot market trading by parties to the contract
  - Increased spot market trading in turn should make investors less concerned about not having their trades covered by contracts
- On the other hand, a decrease in the variability of the gap between importer and exporter prices tends to decrease the amount of spot trading by parties to a contract