Optimal Capacity and Two-Part Pricing for Natural Gas Pipelines under Alternative Regulatory Constraints

by

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Introduction

• Natural gas → increasingly important primary energy resource in the U.S.
  – Recent increases in domestic supplies from advances in extraction technology
  – Steady rise in demand (mostly from electricity generation sector) due to increased public concern over carbon emissions

• Linkages between NG supply and demand centers fundamentally limited by the capacity of the pipeline transmission network
  – Insufficient capacity over certain routes results in bottlenecks & congestion
  – Systematic and measurable effects on transportation costs
  – Wedges between NG spot prices at any two nodes on network
  – Reduced market integration
  – Negative welfare effects
Introduction

• Federal regulation of interstate NG pipelines
  – Administered by the Federal Energy Regulatory Commission (FERC)
  – Has moved considerably toward a liberalized market structure over past two decades
  – Maintains some important controls over rate-setting behavior
  – Specifically, regulate interstate pipeline using a rate-of-return framework

• Broad intent of paper: illuminate potential interactions between
  – FERC’s regulatory framework for interstate NG pipelines
  – Pipeline capacity and transportation markets
  – NG spot market

• Results suggest these interactions may suppress investment in pipeline capacity
  – Implies exacerbation of congestion issues, undermined efficiency
Pipeline Market Structure

Pipeline
- Assumed to be local monopoly
- Sells ‘firm’ capacity contracts in primary market
- Charges two-part tariff: ‘reservation charge’ per unit contracted capacity and ‘usage charge’ per unit utilized (i.e. per unit gas shipped)

Gas Traders
- Competitive
- Purchase firm capacity contracts in primary market
- Transact gas or release unused capacity in the secondary market
- Charge secondary market ‘transportation charge’ per unit gas shipped

Gas Shippers
- Competitive
- Purchase released capacity from or ship gas via traders
- Pay secondary market transportation charge per unit shipped
- Sellers sell gas for spot price at point of sale
- Buyers buy gas for spot price at point of delivery
- Difference is equal to secondary market transportation charge

Two-part tariff regulated by FERC using rate-of-return framework

Primary market - capacity -

Secondary market - transportation -

Transportation charge unregulated, inversely related to available capacity

Gas traders’ demand for firm capacity affects capacity and pricing decisions of pipeline.

Uncertainty over demand for shipping affects traders’ demand for firm capacity.
Overview

• Previous papers (Marmer et al., 2007; Brown & Yücel, 2008) have asserted:
  – ROR-regulated primary + unregulated secondary → diversion of scarcity rents (i.e. *wealth transfers*) away from pipeline to firm capacity holders
  – Price controls prevent firm customers from offering higher tariffs to the pipeline
  – Negatively impacts pipeline’s incentive to install sufficient capacity where needed, which exacerbates congestion
  – What evidence do we have in support of these assertions? Very little.

• Extend rich literature on optimal capacity and two-part pricing to account for unique structure of the NG pipeline market.
  – Key assumption: secondary market demand is stochastic
  – Compare optimality conditions under three regulatory alternatives:
    1. Unregulated monopoly
    2. Ramsey second-best social optimum
    3. Rate-of-return
  – Parameterize and solve numerically
Review: Two-Part Tariff

- Improves pricing efficiency for public utilities with large fixed costs
  - Standard MC pricing results in deficit to firm
  - Two-part tariff an efficient means of covering this loss when transfers not possible (Coase, 1946)

- Consists of access fee + usage fee
  - Example: Pay a $10 cover (access fee) to get into the bar (which helps to pay for the band), then pay the bartender per drink (usage fee)

- Monopolistically optimal two-part tariff with a uniform access fee
  - Oi (1971): “Disneyland dilemma” model
  - Feldstein (1972): examined associated welfare loss
  - Sherman & Visscher (1981): under ROR, trade-off between reductions in access fee (increase customer base) and usage fee (increase output)
  - Vogelsang (1989, 2001): incentive-based two-part tariff as a price-cap index provides firm with sufficient incentive to expand when congestion costs exceed expansion costs
Review: Capacity

- **Averch & Johnson (1962):** an ROR-regulated monopoly firm will employ a higher amount of capital than it would if unregulated (the A-J effect)
  - Over-capitalizes because its cost of capital is less than the market cost

- **Demand uncertainty affects the optimal investment in capacity**
  - Boiteaux (1949): The peak-load pricing & capacity problem
  - Williamson (1966): Peak-load problem with indivisibilities in plant expansion
  - Bailey (1972): Peak-load problem under alternative regulatory constraints
  - Meyer (1975): Optimal pricing & capacity with stochastic demand

- **Sherman & Visscher (1978):** Ramsey second-best pricing & optimal capacity with stochastic demand
  - Ramsey pricing: maximizes social welfare subject to break-even constraint for firm
  - Probability that in any period demand may exceed capacity $\rightarrow$ minimize “expected forgone profits” (opportunity cost of not investing in greater capacity)
Theoretical Model

- Model template: two-hub, one-pipeline network (Cremer & Laffont, 2002)
  - \( d_{j,t} \) (\( j = 1,2 \)) is local demand
  - \( q_{j,t} \) is local supply (inelastic)
  - Flow from Hub 1 to Hub 2, \( y_{t} \), is strictly unidirectional
  - Capacity of the pipeline is \( K \)
  - For simplicity, assume no storage available
Theoretical Model

- Fundamental underlying relationships
  - Flow balance
    \[ d_{1,t} = q_1 - y_t \quad d_{2,t} = q_2 + y_t \]
  - Secondary market transportation charge from H1 to H2, \( \tau_t \), is a decreasing function of available capacity, \( k_t^a = K - y_t \)
    \[ \tau_t = \tau_t(k_t^a), \text{ where } \tau_t'(k_t^a) < 0 \]
  - Arbitrage condition: spot price differential equal to transportation charge
    \[ p_{1,t} = p_{2,t} - \tau_t(k_t^a) \]
Theoretical Model

* Step 1: Derive optimal firm capacity reservation for a representative trader facing uncertain demand for transportation services
  - Shipping quantity demanded is log-normally distributed
  - Firm capacity is the sole factor of production for the trader to produce the output of transportation services
  - Profit maximization yields trader i's factor demand function for firm capacity
  - Sum over $N$ traders yields aggregate firm capacity demand function

* Trader $i = 1, ..., N$ chooses capacity reservation in period $t$, $k_{i,t}$, to maximize an expected profit function.

$$
\pi_i^e = (\tau^e - P^u) \left\{ y_i^e - \int_{k_{i,t}}^{\infty} [y_{i,t} - k_{i,t}] f_i(y_{i,t}) dy_{i,t} \right\} - P^r k_{i,t}
$$

- expected variable profit per unit shipped
- expected shipping quantity demanded
- expected shipping demand in excess of reserved capacity
- total reservation charge
Theoretical Model

- **Key concept:** objective function includes *minimization of expected opportunity cost* of insufficient capacity

  \[
  \text{expected opportunity cost} = (\text{exp. variable profit per unit}) \times (\text{exp. demand in excess of capacity})
  \]

- **Solution to FOC represents trader }i{\text{'s demand for firm capacity**
  - After simplification:

  \[
  (\tau^e - P^u) \left[ 1 - F_i(k^*_{i,t}) \right] = P^r \quad \Rightarrow \quad k^*_{i,t} = \psi_{i,t}(P^r, P^u; K, y^e_i, \sigma_i)
  \]

- **A trader’s firm capacity demand is a function of**
  - *Reservation charge*, \( P^r \), where \( \partial k^*_{i,t} / \partial P^r < 0 \)
  - *Usage charge*, \( P^u \), where \( \partial k^*_{i,t} / \partial P^u < 0 \)
  - *Maximum capacity* of the pipeline, \( K \), where \( \partial k^*_{i,t} / \partial K < 0 \)
  - Parameters of his demand distribution, \( y^e_i, \sigma_i \), where \( \partial k^*_{i,t} / \partial y^e_i > 0 \) and \( \partial k^*_{i,t} / \partial \sigma_i < 0 \)

- **Aggregate firm capacity demand:** \( \sum_i \psi_i(P^r, P^u, K) = \psi(P^r, P^u, K) \)
Theoretical Model

Regulatory Alternative #1: *Unconstrained Monopoly*

- Pipeline maximizes profit by choosing reservation charge \((P^r)\), usage charge \((P^u)\), maximum capacity, \((K)\)

\[
\max_{\{P^r, P^u, K\}} \pi^e_{pl} = (P^u - v(K)) \left\{ y^e - \int_{K}^{\infty} (y_t - K)g(y_t)dy_t \right\} + P^r \psi(P^r, P^u, K) - C(K)
\]

- Subject to reservation demand constraint (capacity must at least meet aggregate reservation demand)

\[
s.t. \quad K \geq \psi(P^r, P^u, K)
\]
Theoretical Model

Regulatory Alternative #2: *Ramsey Second-Best Social Optimum*

- **Welfare maximization** subject to **break-even constraint** for pipeline firm
  - Must account for the economic welfare of all affected parties: pipeline, traders, buyers & sellers in the *spot markets* at the two hubs connected by the pipeline
  - Pipeline’s capacity has an *external effect* on economic welfare at the two hubs
Theoretical Model

Regulatory Alternative #2: *Ramsey Second-Best Social Optimum*

- Regulator’s objective choose reservation charge, usage charge, capacity to maximize expected social welfare

\[ \max_{\{p^r, p^u, K\}} SW^e = CS_1(p_1^e) + CS_2(p_2^e) + PS_1(p_1^e) + PS_2(p_2^e) + \sum_i \pi_i^e + \pi_{pl}^e \]

\[ \text{s.t. } \pi_{pl}^e \geq 0 \]

- Reservation demand constraint
- Break-even constraint
- Flow balance identities
- Arbitrage condition
Theoretical Model

Regulatory Alternative #3: *Rate-of-Return*

- Based on FERC’s actual rate-setting mechanism for interstate pipelines
  - Determined by calculating pipeline’s *cost of service* (a.k.a. revenue requirement)
  - Allowed ROR is calculated as a *weighted-average cost of capital*
  - All *fixed costs* (includes labor) allocated to the *reservation charge*
  - All *variable costs* (fuel needed to run compressors) allocated to the *usage charge*

- Key feature: *usage charge* set equal to the *marginal cost of shipping gas*
  \[ P^u = v(K) \]
  - Implies the pipeline’s *expected variable profit* and *expected opportunity cost* are zero!

\[
\pi_p = (P^u - v(K)) \left\{ y^e - \int_K^{\infty} (y_t - K) g(y_t) dy_t \right\} + P^r \psi(P^r, P^u, K) - C(K)
\]

entire term equals zero
Theoretical Model

Regulatory Alternative #3: Rate-of-Return

- Pipeline’s profits are realized solely through capacity reservation
  - Constrained to an allowed ROR on capacity cost, $C(K)$

\[
\max_{\{P_r, K\}} \pi_{pl}^e = P_r \psi(P_r, P_u, K) - C(K)
\]

- ROR constraint
  \[ s.t. \quad \pi_{pl}^e \leq rC(K) \]

- Reservation demand constraint
  \[ K \geq \psi(P_r, P_u, K) \]

- Usage charge equals MC
  \[ P_u = \nu(K) \]
Summary of Methodology

- Begins with theoretical derivation of optimality conditions (not presented today due to time constraint)
- FOC’s too complex to solve analytically → solve numerically
  - Assign explicit functional forms
  - Parameterize
  - Assume $N = 10$ (relatively) identical traders
  - Code into GAMS
  - Solve for optimal two-part tariff and capacity under each regulatory alternative

- To examine effect of uncertainty, compare *four distributional cases*:
  - Hold the aggregate mean constant across all four

<table>
<thead>
<tr>
<th></th>
<th>Case 1 (LL)</th>
<th>Case 2 (LH)</th>
<th>Case 3 (HL)</th>
<th>Case 4 (HH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variances of individual traders’ transportation demands</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Correlation between individual traders’ transportation demands</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>
Numerical Implementation

Characteristics of Each Distributional Case

<table>
<thead>
<tr>
<th></th>
<th>Case 1 (LL)</th>
<th>Case 2 (LH)</th>
<th>Case 3 (HL)</th>
<th>Case 4 (HH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical trader’s expected shipping</td>
<td>1.606</td>
<td>1.606</td>
<td>1.606</td>
<td>1.606</td>
</tr>
<tr>
<td>quantity* ( y^e_{i,t} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Typical standard deviation of</td>
<td>2.078</td>
<td>2.005</td>
<td>5.529</td>
<td>5.095</td>
</tr>
<tr>
<td>( y^e_{i,t} )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Correlation between any two traders’</td>
<td>0.4</td>
<td>0.7</td>
<td>0.4</td>
<td>0.7</td>
</tr>
<tr>
<td>actual shipping quantities</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected aggregate expected</td>
<td>16.06</td>
<td>16.06</td>
<td>16.06</td>
<td>16.06</td>
</tr>
<tr>
<td>shipping quantity** ( y^e_t )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of ( y^e_t )</td>
<td>10.495</td>
<td>12.742</td>
<td>26.997</td>
<td>29.465</td>
</tr>
</tbody>
</table>

Volumetric parameters expressed in units of 100,000 MMBtu/day

*Individual shipping demands log-normally distributed

**Aggregate shipping demand inverse-gamma distributed
### Numerical Implementation

#### Case 1 (LL) solution

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unregulated</th>
<th>Rate-of-Return Regulation</th>
<th>Second-Best Social Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trader 1 Capacity Reservation, $k_1$</td>
<td>0.447</td>
<td>0.758</td>
<td>0.913</td>
</tr>
<tr>
<td>Trader 2 Capacity Reservation, $k_2$</td>
<td>0.444</td>
<td>0.741</td>
<td>0.887</td>
</tr>
<tr>
<td>Trader 3 Capacity Reservation, $k_3$</td>
<td>0.465</td>
<td>0.771</td>
<td>0.921</td>
</tr>
<tr>
<td>Trader 4 Capacity Reservation, $k_4$</td>
<td>0.435</td>
<td>0.727</td>
<td>0.87</td>
</tr>
<tr>
<td>Trader 5 Capacity Reservation, $k_5$</td>
<td>0.464</td>
<td>0.764</td>
<td>0.91</td>
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<tr>
<td>Trader 6 Capacity Reservation, $k_6$</td>
<td>0.452</td>
<td>0.752</td>
<td>0.9</td>
</tr>
<tr>
<td>Trader 7 Capacity Reservation, $k_7$</td>
<td>0.436</td>
<td>0.735</td>
<td>0.882</td>
</tr>
<tr>
<td>Trader 8 Capacity Reservation, $k_8$</td>
<td>0.443</td>
<td>0.737</td>
<td>0.882</td>
</tr>
<tr>
<td>Trader 9 Capacity Reservation, $k_9$</td>
<td>0.454</td>
<td>0.743</td>
<td>0.884</td>
</tr>
<tr>
<td>Trader 10 Capacity Reservation, $k_{10}$</td>
<td>0.433</td>
<td>0.717</td>
<td>0.856</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Second-Best Social Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate Capacity Reservation, $\sum_i k_i$</td>
<td>4.471</td>
<td>7.446</td>
<td>8.904</td>
</tr>
<tr>
<td>Maximum Capacity of Pipeline</td>
<td>4.471</td>
<td>7.446</td>
<td>8.904</td>
</tr>
<tr>
<td>Reservation Charge ($/MMBtu$)</td>
<td>0.84</td>
<td>0.523</td>
<td>0.423</td>
</tr>
<tr>
<td>Usage Charge ($/MMBtu$)</td>
<td>0</td>
<td>0.02</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<th>Rate-of-Return Regulation</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Hub 1 Exp. Equilibrium Spot Price ($/MMBtu$)</td>
<td>3.932</td>
<td>4.123</td>
<td>4.216</td>
</tr>
<tr>
<td>Exp. Basis Differential ($/MMBtu$)</td>
<td>1.068</td>
<td>0.877</td>
<td>0.784</td>
</tr>
<tr>
<td>Exp. Social Welfare ($100,000's$)</td>
<td>205.738</td>
<td>211.768</td>
<td>214.743</td>
</tr>
</tbody>
</table>
# Numerical Implementation

## Case 2 (LH) solution

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unregulated Monopoly</th>
<th>Rate-of-Return Regulation</th>
<th>Second-Best Social Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trader 1 Capacity Reservation, $k_1$</td>
<td>0.422</td>
<td>0.706</td>
<td>0.859</td>
</tr>
<tr>
<td>Trader 2 Capacity Reservation, $k_2$</td>
<td>0.44</td>
<td>0.726</td>
<td>0.878</td>
</tr>
<tr>
<td>Trader 3 Capacity Reservation, $k_3$</td>
<td>0.431</td>
<td>0.715</td>
<td>0.867</td>
</tr>
<tr>
<td>Trader 4 Capacity Reservation, $k_4$</td>
<td>0.444</td>
<td>0.734</td>
<td>0.889</td>
</tr>
<tr>
<td>Trader 5 Capacity Reservation, $k_5$</td>
<td>0.429</td>
<td>0.716</td>
<td>0.871</td>
</tr>
<tr>
<td>Trader 6 Capacity Reservation, $k_6$</td>
<td>0.436</td>
<td>0.718</td>
<td>0.868</td>
</tr>
<tr>
<td>Trader 7 Capacity Reservation, $k_7$</td>
<td>0.435</td>
<td>0.729</td>
<td>0.888</td>
</tr>
<tr>
<td>Trader 8 Capacity Reservation, $k_8$</td>
<td>0.443</td>
<td>0.732</td>
<td>0.887</td>
</tr>
<tr>
<td>Trader 9 Capacity Reservation, $k_9$</td>
<td>0.43</td>
<td>0.718</td>
<td>0.874</td>
</tr>
<tr>
<td>Trader 10 Capacity Reservation, $k_{10}$</td>
<td>0.428</td>
<td>0.721</td>
<td>0.88</td>
</tr>
</tbody>
</table>

| Aggregate Capacity Reservation, $\sum_i k_i$ | 4.338 | 7.216 | 8.761 |

| Maximum Capacity of Pipeline | 4.338 | 7.216 | 8.761 |
| Reservation Charge ($/MMBtu$) | 0.845 | 0.535 | 0.429 |
| Usage Charge ($/MMBtu$) | 0 | 0.021 | 0 |

| Hub 1 Exp. Equilibrium Spot Price ($/MMBtu$) | 3.924 | 4.108 | 4.207 |
| Exp. Basis Differential ($/MMBtu$) | 1.076 | 0.892 | 0.793 |
| Exp. Social Welfare ($100,000's$) | 204.713 | 210.495 | 213.639 |
## Numerical Implementation

### Case 3 (HL) solution

<table>
<thead>
<tr>
<th>Variable</th>
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<th>Rate-of-Return Regulation</th>
<th>Second-Best Social Optimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trader 1 Capacity Reservation, $k_1$</td>
<td>0.23</td>
<td>0.266</td>
<td>0.593</td>
</tr>
<tr>
<td>Trader 2 Capacity Reservation, $k_2$</td>
<td>0.185</td>
<td>0.214</td>
<td>0.468</td>
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<tr>
<td>Trader 3 Capacity Reservation, $k_3$</td>
<td>0.171</td>
<td>0.197</td>
<td>0.426</td>
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<tr>
<td>Trader 4 Capacity Reservation, $k_4$</td>
<td>0.135</td>
<td>0.156</td>
<td>0.34</td>
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<tr>
<td>Trader 5 Capacity Reservation, $k_5$</td>
<td>0.134</td>
<td>0.155</td>
<td>0.342</td>
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<tr>
<td>Trader 6 Capacity Reservation, $k_6$</td>
<td>0.125</td>
<td>0.144</td>
<td>0.316</td>
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<tr>
<td>Trader 7 Capacity Reservation, $k_7$</td>
<td>0.116</td>
<td>0.135</td>
<td>0.306</td>
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<tr>
<td>Trader 8 Capacity Reservation, $k_8$</td>
<td>0.104</td>
<td>0.121</td>
<td>0.274</td>
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<tr>
<td>Trader 9 Capacity Reservation, $k_9$</td>
<td>0.1</td>
<td>0.116</td>
<td>0.252</td>
</tr>
<tr>
<td>Trader 10 Capacity Reservation, $k_{10}$</td>
<td>0.095</td>
<td>0.11</td>
<td>0.247</td>
</tr>
</tbody>
</table>

| Aggregate Capacity Reservation, $\sum_i k_i$ | 1.396 | 1.615 | 3.566 |

<table>
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<tbody>
<tr>
<td>Maximum Capacity of Pipeline</td>
<td>1.396</td>
<td>1.615</td>
<td>3.566</td>
</tr>
<tr>
<td>Reservation Charge ($/MMBtu$)</td>
<td>0.85</td>
<td>0.678</td>
<td>0.313</td>
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<tr>
<td>Usage Charge ($/MMBtu$)</td>
<td>0</td>
<td>0.195</td>
<td>0.465</td>
</tr>
</tbody>
</table>

| Hub 1 Exp. Equilibrium Spot Price ($/MMBtu$) | 3.735 | 3.749 | 3.874 |
| Exp. Basis Differential ($/MMBtu$) | 1.265 | 1.251 | 1.126 |
| Exp. Social Welfare ($100,000's$) | 189.786 | 191.113 | 194.874 |
## Numerical Implementation

### Case 4 (HH) solution

<table>
<thead>
<tr>
<th>Variable</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Trader 1 Capacity Reservation, $k_1$</td>
<td>0.227</td>
<td>0.266</td>
<td>0.578</td>
</tr>
<tr>
<td>Trader 2 Capacity Reservation, $k_2$</td>
<td>0.18</td>
<td>0.212</td>
<td>0.464</td>
</tr>
<tr>
<td>Trader 3 Capacity Reservation, $k_3$</td>
<td>0.149</td>
<td>0.175</td>
<td>0.385</td>
</tr>
<tr>
<td>Trader 4 Capacity Reservation, $k_4$</td>
<td>0.142</td>
<td>0.168</td>
<td>0.371</td>
</tr>
<tr>
<td>Trader 5 Capacity Reservation, $k_5$</td>
<td>0.134</td>
<td>0.158</td>
<td>0.35</td>
</tr>
<tr>
<td>Trader 6 Capacity Reservation, $k_6$</td>
<td>0.136</td>
<td>0.159</td>
<td>0.343</td>
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<tr>
<td>Trader 7 Capacity Reservation, $k_7$</td>
<td>0.119</td>
<td>0.14</td>
<td>0.307</td>
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<td>Trader 8 Capacity Reservation, $k_8$</td>
<td>0.116</td>
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<td>Trader 9 Capacity Reservation, $k_9$</td>
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<td>Trader 10 Capacity Reservation, $k_{10}$</td>
<td>0.105</td>
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<tr>
<td>Aggregate Capacity Reservation, $\sum_i k_i$</td>
<td>1.414</td>
<td>1.664</td>
<td>3.648</td>
</tr>
<tr>
<td>Maximum Capacity of Pipeline</td>
<td>1.414</td>
<td>1.664</td>
<td>3.648</td>
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<tr>
<td>Reservation Charge ($/MMBtu$)</td>
<td>0.862</td>
<td>0.689</td>
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<td>Usage Charge ($/MMBtu$)</td>
<td>0</td>
<td>0.187</td>
<td>0.473</td>
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<tr>
<td>Hub 1 Exp. Equilibrium Spot Price ($/MMBtu$)</td>
<td>3.737</td>
<td>3.753</td>
<td>3.88</td>
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<tr>
<td>Exp. Basis Differential ($/MMBtu$)</td>
<td>1.263</td>
<td>1.247</td>
<td>1.12</td>
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<tr>
<td>Exp. Social Welfare ($100,000's$)</td>
<td>190.91</td>
<td>192.001</td>
<td>195.991</td>
</tr>
</tbody>
</table>
Results

• “Bumper sticker” summary of main result:

\[
\begin{align*}
\text{unregulated monopoly capacity} & < \text{capacity under ROR} < \text{socially optimal capacity}
\end{align*}
\]

• ROR capacity \textit{closer} to unregulated monopoly capacity when \textit{uncertainty} in the secondary market is \textit{greater}

\[
\begin{align*}
\text{greater uncertainty in secondary market} & \rightarrow \text{reduces primary market demand for capacity} & \rightarrow \text{reduces optimal capacity choice of pipeline}
\end{align*}
\]

Secondary market uncertainty leads to an \textit{attenuation} of the classic Averch-Johnson effect.

• Evidence of potential \textit{wealth transfers} from pipeline to firm capacity owners under ROR in high uncertainty cases
  – Pipeline has positive accounting profits under welfare maximization, which shift to primary capacity owners under ROR
Discussion

Distribution of Individual Shipping Quantity, $f_i(y_i)$
vs. Optimal Capacity Reservation, $k_i$

Trader 8 from Case 1 (LL)

$y_8^e = 1.58$
$std. dev. = 1.92$
$k_8^m = 0.443$
$k_8^r = 0.737$
$k_8^{so} = 0.882$
Discussion

Distribution of Individual Shipping Quantity, $f_i(y_i)$

vs. Optimal Capacity Reservation, $k_i$

Trader 7 from Case 3 (HL)

$y_7^e = 1.58$

$\text{std. dev.} = 6.01$

$k_i^m = 0.116$

$k_i^r = 0.135$

$k_i^{so} = 0.306$
Results

Distribution of Aggregate Shipping Demand, $g(y)$
vs. Optimal Capacity of Pipeline, $K$

Case 1 (LL)
$y^e = 16.06$
$std. dev. = 10.495$
$K^m = 4.471$
$K^r = 7.446$
$K^{so} = 8.904$
Results

Distribution of Aggregate Shipping Demand, $g(y)$ vs. Optimal Capacity of Pipeline, $K$

Case 2 (LH)

$y^e = 16.06$
$\text{std. dev.} = 12.742$
$K^m = 4.338$
$K^r = 7.216$
$K^{so} = 8.761$
Results

Distribution of Aggregate Shipping Demand, $g(y)$
vs. Optimal Capacity of Pipeline, $K$

Case 3 (HL)
$y^e = 16.06$
$\text{std. dev.} = 26.977$
$K^m = 1.396$
$K^r = 1.615$
$K^{so} = 3.566$
Results

Distribution of Aggregate Shipping Demand, $g(y)$
vs. Optimal Capacity of Pipeline, $K$

Case 4 (HH)
$y^e = 16.06$
$std. dev. = 29.465$
$K^m = 1.414$
$K^r = 1.664$
$K^{so} = 3.648$
Discussion

What’s driving this pattern of changes in the solution across regulatory alternatives and distributional cases?

1. *Individual* traders’ *uncertainty* over shipping demand
   - Greater uncertainty lowers each individual trader’s capacity reservation demand, lowering the pipeline’s optimal capacity

2. Relative *pricing structure* under ROR vs. Ramsey second-best
   - ROR is more rigid than Ramsey
   - With ROR the usage charge must equal to the MC to the pipeline of shipping a unit of gas → reservation charge must remain high → with high uncertainty firm capacity demand cannot be stimulated by reduction in the reservation charge
   - With Ramsey pricing, the reservation charge can be lowered when uncertainty is high to stimulate firm capacity demand, with the difference being made up for by an increase in the usage charge (traders pay less to reserve capacity, but more to actually use it)

3. Inclusion/omission of *external effect of capacity* on *economic welfare* (consumer & producer surpluses) *at* the two *hubs*
   - Greater capacity reduces the secondary market transportation charge, which positively impacts economic welfare at the two hubs
   - Accounted for by Ramsey pricing rule, not by ROR
Discussion

What about the transfers from the pipeline to the firm capacity owners?

• Must distinguish between **economic profits** and **accounting profits**
  
  – Accounting profits (for traders and pipeline) do not include the expected opportunity cost of insufficient capacity
  
  – This is an economic cost only, not an actual cost incurred from producing output
  
  – Omit integral term from traders’ and pipeline’s profit functions to get accounting profits (i.e. **scarcity rents** accruing to constrained capacity)

<table>
<thead>
<tr>
<th>Regulatory Case</th>
<th>Unregulated Monopoly</th>
<th>Rate-of-Return Regulation</th>
<th>Social Optimum</th>
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<tbody>
<tr>
<td><strong>in $100,000’s</strong></td>
<td>Economic Profit</td>
<td>Accounting Profit</td>
<td>Economic Profit</td>
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<td>Low Variance - Low Correlation</td>
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<tr>
<td>Pipeline</td>
<td>0.712</td>
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<tr>
<td>Pipeline</td>
<td>0.084</td>
<td>-3.404</td>
<td>0.119</td>
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</tbody>
</table>
Some Implications

- **ROR** regulation *suppresses* the *optimal capacity* of the pipeline relative to what is socially optimal.
  - Provides the pipeline with the *least flexibility* in setting prices, adversely affecting investment in capacity.

- Performs more poorly when uncertainty is higher
  - 1.4% welfare loss in low uncertainty cases
  - 2.0% welfare loss in high uncertainty cases

- Lends weight to the attractiveness of *incentive-based* mechanisms
  - Price- and revenue-cap mechanisms allow *more flexibility* in rate structure, motivate operators to *improve efficiency* (Guthrie, 2006; Joskow, 2008).
  - Generally more complicated than ROR

- If costs of transitioning to an incentive-based scheme are too high, ROR pricing may need to be augmented by policies designed to *reduce secondary market uncertainty*. 
Recap

• Transportation demand *uncertainty* plays a central role in capacity reservation decisions of a pipeline’s firm customers
• As uncertainty increases, ROR regulation *distorts* optimality conditions that determine *pricing* & maximum *capacity* of pipeline
• Results in a situation where capacity is increasingly *sub-optimal* as secondary market uncertainty increases
  – Attenuation of the Averch-Johnson effect: with higher uncertainty, capacity is closer to unregulated monopoly outcome than to Ramsey second-best social optimum
• Total *social welfare* is *lower* under ROR in all solutions
  – ROR does not account for the economic welfare of consumers & producers at the hubs connected by the pipeline
• Evidence of potential *wealth transfers* from pipeline to firm capacity owners in high uncertainty cases
• Strong implications for regulation of pipelines serving routes characterized by high stochasticity of demand in secondary market