A Rolling Horizon Approach for Mixed Complementarity Modeling with Endogenous Probabilities: Application to Natural Gas Markets

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WASHINGTON, DC

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Outline

1. Natural Gas Markets/Renewables: Brief Overview Including Energy Security Issues
2. Rolling Horizon Model
3. Illustrative Numerical Results
4. Summary and Conclusions

Brief Overview of Natural Gas Markets

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Selected Aspects of Energy Security/Insecurity: Focus on Natural Gas

- Physical Security
  - Natural gas (LNG) shipments and pirates
- Supply/Demand Security
  - Russian natural gas demand security issues
  - European natural gas supply diversity, how to achieve supply diversity including U.S. exports of LNG to Europe and Asia
- Environmental/Energy Efficiency Programs Security
- Want models that take into account
  - Stochasticity
  - Learning by the players in response to changing market conditions e.g., energy insecurity
  - Market equilibrium aspects
- Rolling horizon mixed complementarity problems (MCPs)

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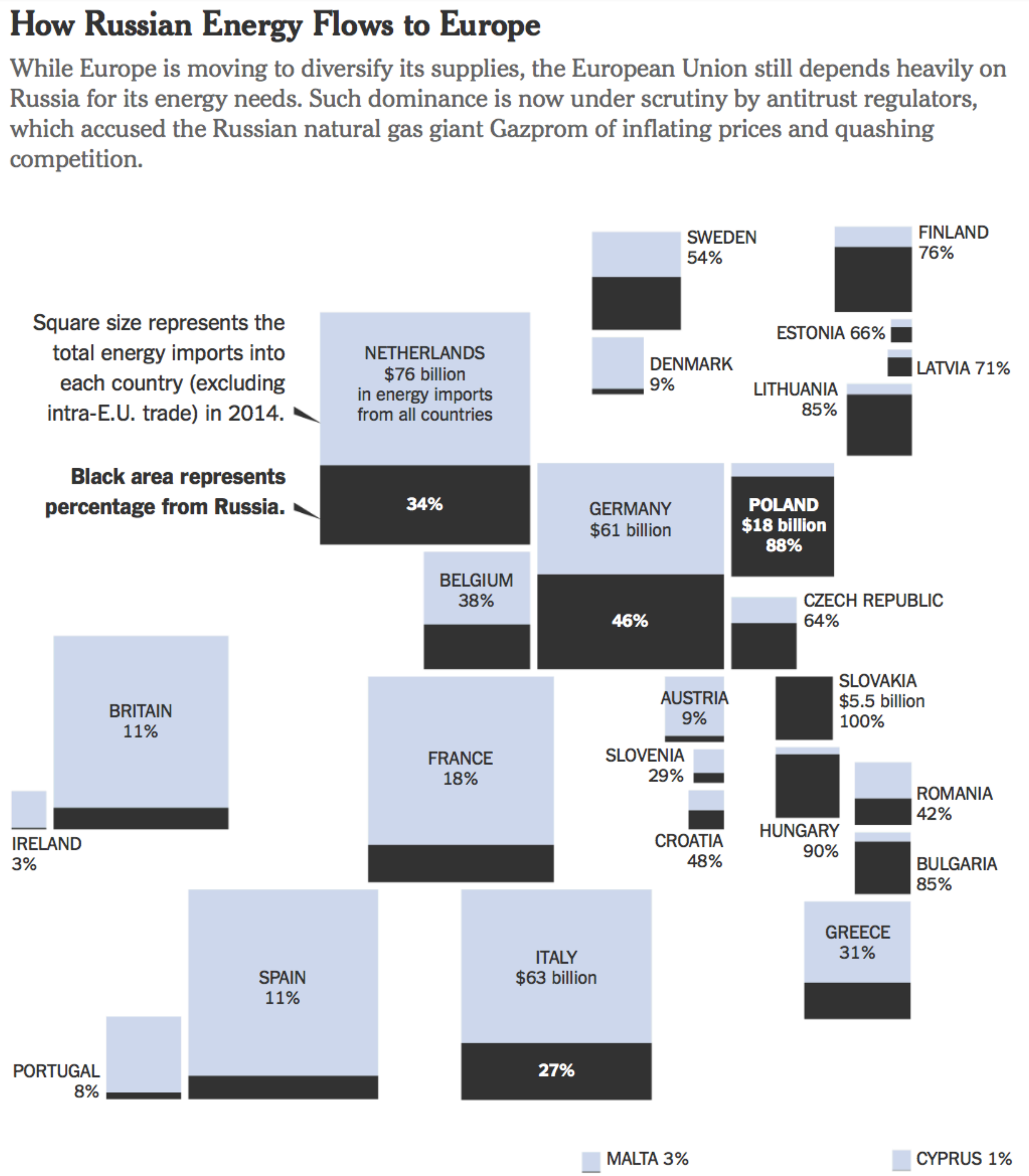
Natural Gas and Renewables

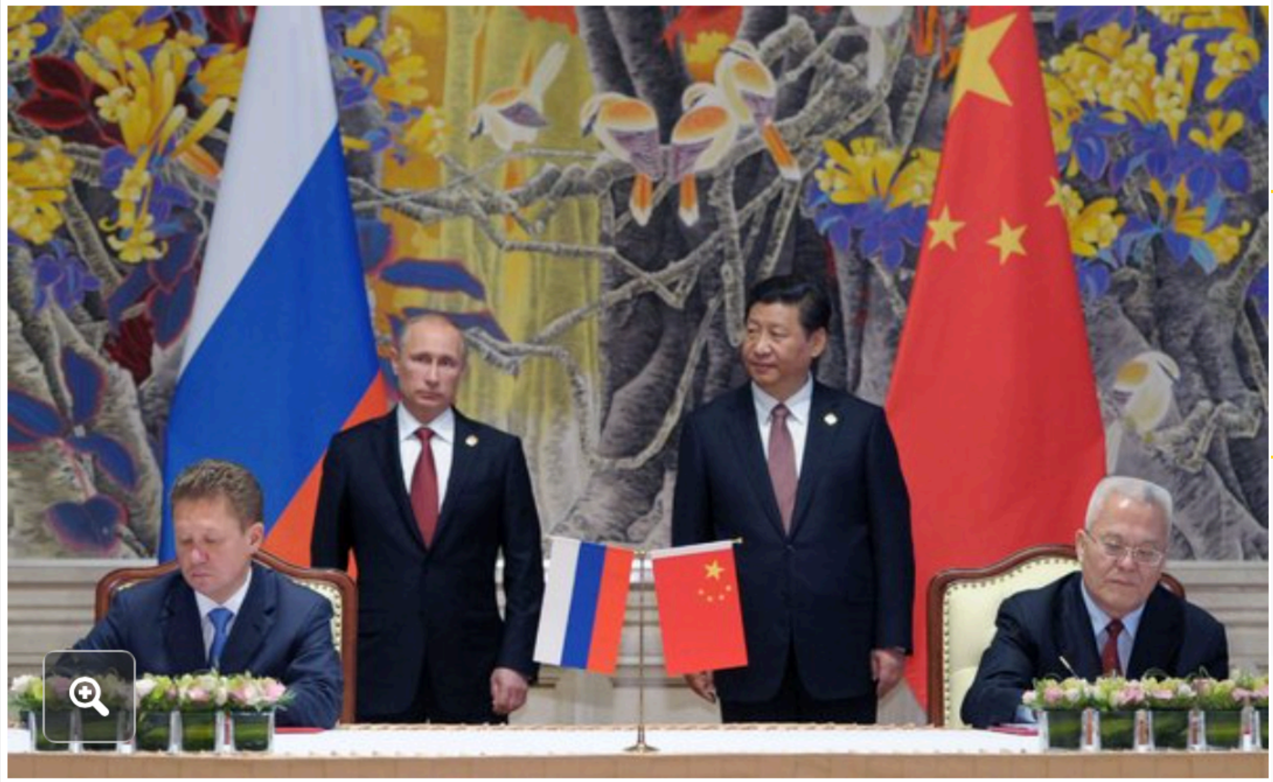
- Many countries striving to reduce greenhouse gases in light of climate change issues
- Main renewables in many places: intermittent wind and solar (also biomass)
- May still need a fossil fuel back-up (at least in the "short-term")
- Natural gas much cleaner than coal and other hydrocarbons– thus the rising importance of this fuel

Russia, Europe and Natural Gas Demand Insecurity: Looking West



Russia, China and Natural Gas Demand Insecurity: Looking East

- Last year, Gazprom made deals to supply gas to China for 30 years from Siberia, two new pipelines
- Eventually China could get more Russian gas than Germany (largest customer at present)
- Gazprom -$50 billion commitment to build a new pipeline to China that will take years to produce profits, Chinese financing is slow to happen



Vladimir V. Putin, second from left, stood next to President Xi Jinping of China at last May's signing of a gas deal in Shanghai. Pool photo by Alexey Druginyn

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Energy-Environmental Security: Earthquakes from Waste Disposal Wells?

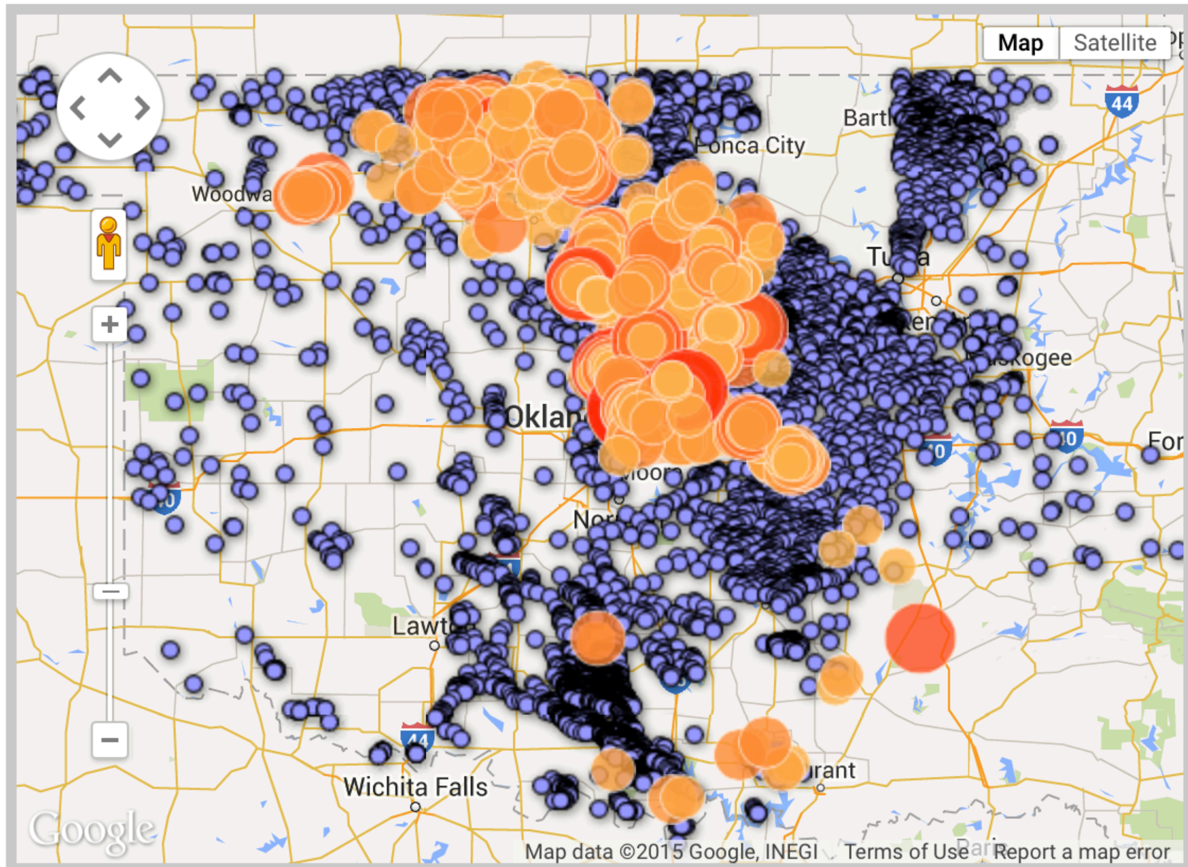
- In past decades, Oklahomans had about 1.5 earthquakes > magnitude 3.0 in an average year.
- Since a boom in oil and gas exploration (mid-2000s) 585 quakes of 3.0 or greater last year
- More than any state except Alaska on track for more than 900 such tremors this year

http://www.nytimes.com/2015/04/22/us/oklahoma-acknowledges-wastewater-from-oil-and-gas-wells-as-major-cause-of-quakes.html?smprod=nytcore-iphone&smid=nytcore-iphone-share

http://earthquakes.ok.gov/what-we-know/earthquake-map/

EARTHQUAKES IN OKLAHOMA

EARTHQUAKE MAP



Note: Only Earthquakes with a magnitude of 3.0 and higher are displayed.

- [x] Earthquakes - Past 7 days
- [x] Earthquakes - 2015 (YTD)
- [x] Earthquakes - 2014
- [x] Earthquakes - 2013
- [x] Earthquakes - 2012
- [ ] Earthquakes - 2011
- [ ] Earthquakes - 2010
- [ ] Earthquakes - 2000 through 2009
- [ ] Earthquakes - 1990 through 1999
- [ ] Earthquakes - 1980 through 1989
- [x] Waste Water Disposal Wells

Rolling-Horizon Model for Natural Gas Market Equilibrium

- Each player solves a stochastic optimization problem, put all the KKT conditions together from each player's problem +market-clearing conditions= stochastic mixed complementarity problem (MCP)
- RH model: solving a sequence of stochastic MCPs, one for each roll (time period)
- Only partial foresight as to future demand (or other stochastic elements)
- Players choose decisions variables but can also compete in things like adjusting probabilities of demand scenarios
- More closely matches real markets than perfect foresight where all time periods solved for at the same time (energy security aspect)

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Players Use Data Strategically

$$\min_{x_{p,s}} \sum_{s} PROB_p^s\left(X^P; X^{-P}\right) f_{ps}\left(X^P; X^{-P}\right)$$

$$s.t.\ X^P \in S_p\left(X^P; X^{-P}\right)$$

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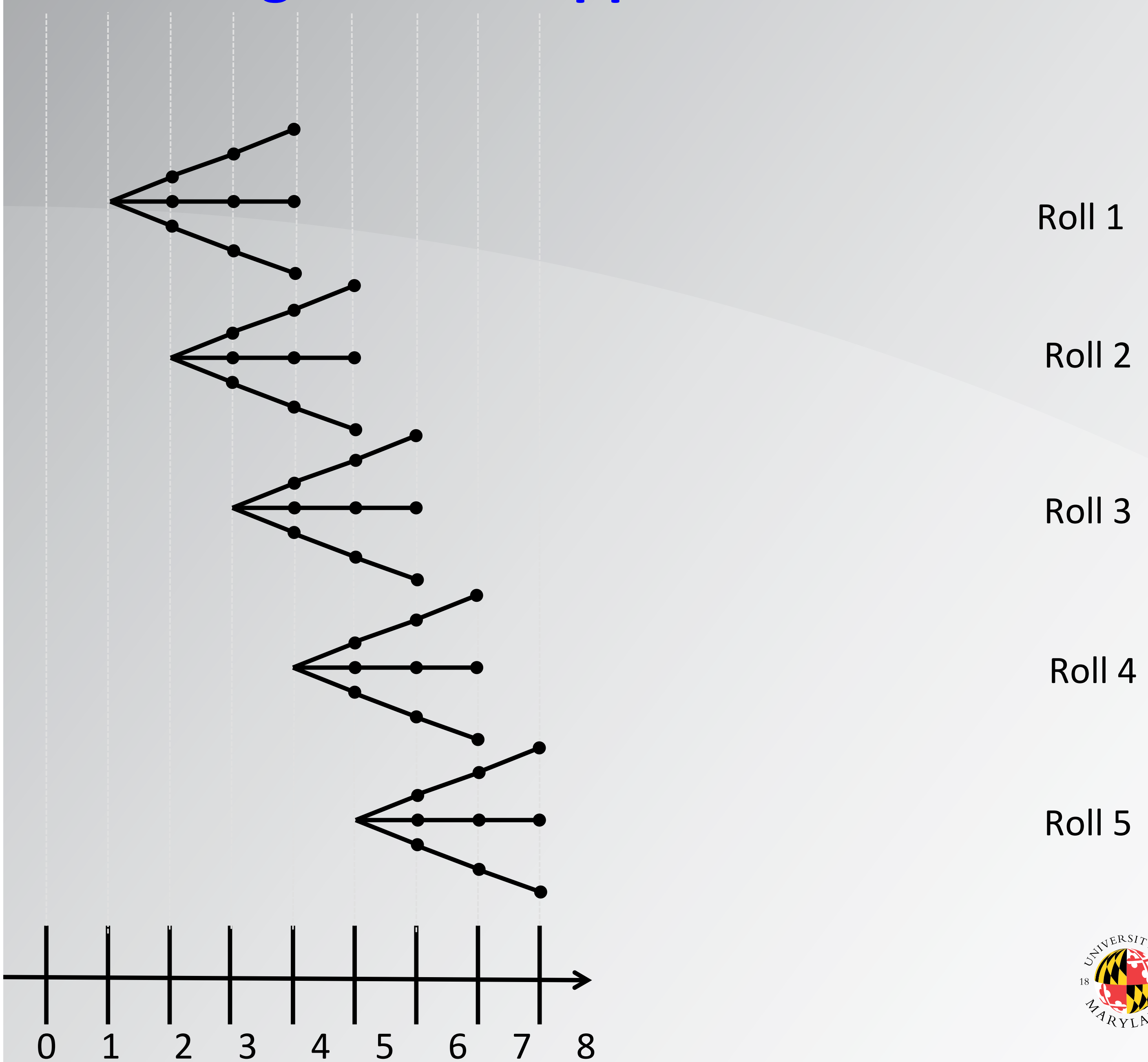
Rolling Horizon Approach: Stochastic Demand Tree



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Rolling-Horizon Modeling Advantages

- RH model vs. perfect foresight modeling
- RH model's ability to have endogenous probabilities
  - Market players learn in between rolls
  - Endogenous probabilities (i.e., scenario tree can change depending on previous roll's results and learning)
- RH computational advantage (for large scenario trees)
- Value of the rolling horizon (VoRH)

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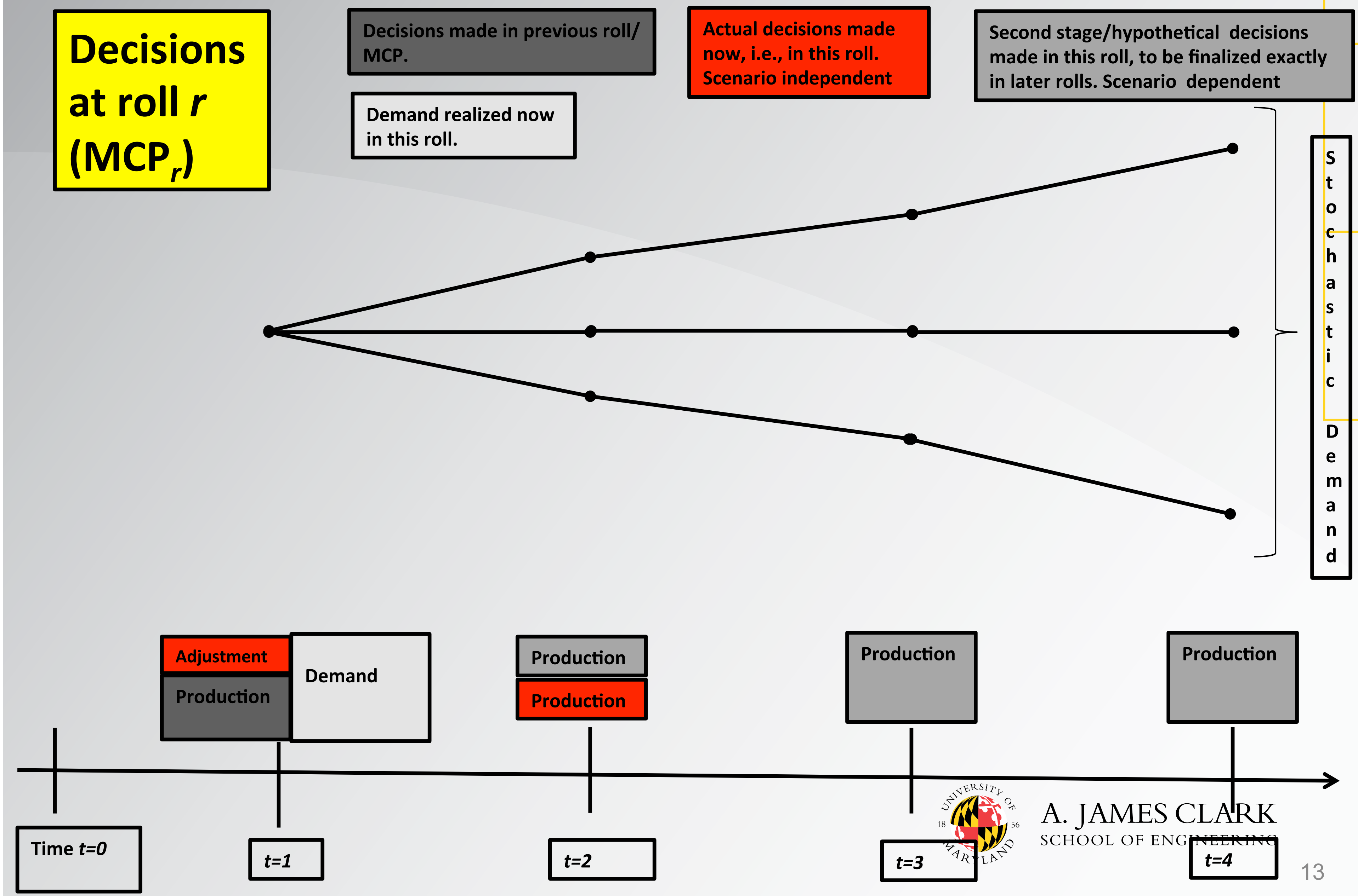
Model: Rolling Horizon of Stochastic Demand Tree



Computational Advantages

Table 19: Minimum, Median and Maximum CPU time (in seconds) associated with Perfect Foresight model with scenario obtained from the fast forward selection scenario-reduction algorithm.

No. of Scenarios	Model Variables	Min CPU	Median CPU	Max CPU
3	5095	0.2	0.21	0.22
10	16547	1.93	2.03	7.71
50	81987	270.41	7468.91	17632.71
100	163787	> 21600	> 21600	> 21600

Rolling-Horizon Model: VoRH

- H is a function whose zero matches the MCP solution, parameterized by perfect foresight solution
- Plug in rolling-horizon solution to see how far off from zero you get, the resulting norm is VoRH

Definition: The value of the rolling horizon (VoRH) for problem (12) is defined as

$$\inf_{\left(\overline{x}^{rh},\overline{y}^{rh}\right)\in SOL^{rh}} \left\{ \sup_{\left(\overline{x}^{pf},\overline{y}^{pf}\right)\in SOL^{pf}} \left\| H_{\left(\overline{x}^{pf},\overline{y}^{pf}\right)}\left(\overline{x}^{rh},\overline{y}^{rh}\right)\right\| \right\} \qquad (15)$$

where $\left\| H_{\left(\overline{x}^{pf},\overline{y}^{pf}\right)}\left(\overline{x}^{pf},\overline{y}^{pf}\right)\right\| = 0.$

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Model: multi-player model

- Gas producers
  - choose sales, production, injection/extraction and flows through pipeline
  - so as to maximize their sales less
    - production costs
    - storage costs
    - pipeline costs
    - cost of adjustments/ recourse costs
  - subject to:
    - production constraints
    - storage constraints
    - adjustment constraints

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Model: producer's objective function

$$
\begin{aligned}
\max_{sales^*_{pmtr}, prod^*_{pmtr}, flows^{*,prod}_{patr}, inj^*_{pmtr}, xtr^*_{pmtr}} \sum_m \sum_{t=r}^{r+H-1} & D_t DAYS_t \Big\{ E_{s(r)} \Big[\pi^s_{mtr} sales^s_{pmtr} \\
& - C^{production}_{pmtr}(prod^s_{pmtr}) \\
& - \sum_{a \in A(p)} (\tau^{REG}_{at} + \tau^s_{atr}) flows^{s,prod}_{patr} - C^{storage}_{pmtr}(inj^s_{pmtr}, xtr^s_{pmtr}) \Big] \Big\} \\
& - D_{t=r} DAYS_{t=r} \Big(RU^{prod}_{pmr} prod^{adj+}_{pm(t=r)r} + RO^{prod}_{pmr} prod^{adj-}_{pm(t=r)r} \\
& + RU^{sales}_{pmr} sales^{adj+}_{pm(t=r)r} + RO^{sales}_{pmr} sales^{adj-}_{pm(t=r)r} \\
& + RU^{inj}_{pmr} inj^{adj+}_{pm(t=r)r} + RO^{inj}_{pmr} inj^{adj-}_{pm(t=r)r} \\
& + RU^{xtr}_{pmr} xtr^{adj+}_{pm(t=r)r} + RO^{xtr}_{pmr} xtr^{adj-}_{pm(t=r)r} \\
& + \sum_{a \in A(p)} (RU^{flows}_{par} flows^{adj+,prod}_{pa(t=r)r} + RO^{flows}_{par} flows^{adj-,prod}_{pa(t=r)r}) \Big) \\
& - D_{t=r+1} DAYS_{t=r+1} E_{s(r)} \Big[RU^{prod}_{pmr} prod^{SS+,s}_{pm(t=r+1)r} \\
& + RO^{prod}_{pmr} prod^{SS-,s}_{pm(t=r+1)r} \\
& + RU^{sales}_{pmr} sales^{SS+,s}_{pm(t=r+1)r} + RO^{sales}_{pmr} sales^{SS-,s}_{pm(t=r+1)r} \\
& + RU^{inj}_{pmr} inj^{SS+,s}_{pm(t=r+1)r} + RO^{inj}_{pmr} inj^{SS-,s}_{pm(t=r+1)r} \\
& + RU^{xtr}_{pmr} xtr^{SS+,s}_{pm(t=r+1)r} + RO^{xtr}_{pmr} xtr^{SS-,s}_{pm(t=r+1)r} \\
& + \sum_{a \in A(p)} (RU^{flows}_{par} flows^{SS+,s,prod}_{pa(t=r+1)r} + RO^{flows}_{par} flows^{SS-,s,prod}_{pa(t=r+1)r}) \Big]
\end{aligned}
$$

Model: multi-player model

- Pipeline system operator:
  - choose pipeline flows between nodes/markets
  - so as to maximize their sales less
    - pipeline flows costs
    - cost of adjustments/ recourse costs
  - subject to:
    - pipeline constraints
    - adjustment constraints
- Market clearing conditions:
  - Total sales = demand
  - Amount of gas flowing through pipelines is balanced

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Model: multi-player model

Pipeline system operator's objective function:

$$\max_{flow^{*,tso}_{atr}} \sum_a \Bigg\{ \sum_{t=r}^{r+H-1} D_t DAYS_t E_{s(r)} \Big[(\tau^s_{atr} + \tau^{REG}_{at}) flows^{s,tso}_{atr} - C^a(flows^{s,tso}_{atr}) \Big]$$

$$- D_{t=r} DAYS_{t=r} (RU^{flows}_{ar} flows^{adj+,tso}_{a(t=r)r} + RO^{flows}_{ar} flows^{adj-,tso}_{a(t=r)r})$$

$$- D_{t=r+1} DAYS_{t=r+1} E_{s(r)} \Big[RU^{flows}_{ar} flows^{SS+,s,tso}_{a(t=r+1)r} + RO^{flows}_{ar} flows^{SS-,s,tso}_{a(t=r+1)r} \Big] \Bigg\}$$

Expected sales less cost

Adjustment costs

2nd stage recourse costs

Market clearing conditions:

$$flows^{s,tso}_{atr} = \sum_p flows^{s,prod}_{patr} \quad \forall s, a, t \quad (\tau^s_{atr})$$

Flow balancing

$$\sum_p DAYS_t sales^s_{pmtr} = Z^s_{mr} - B^s_{mr} \pi^s_{mtr} \forall s, m, t \quad (\pi^s_{mtr})$$

Supply and demand balancing

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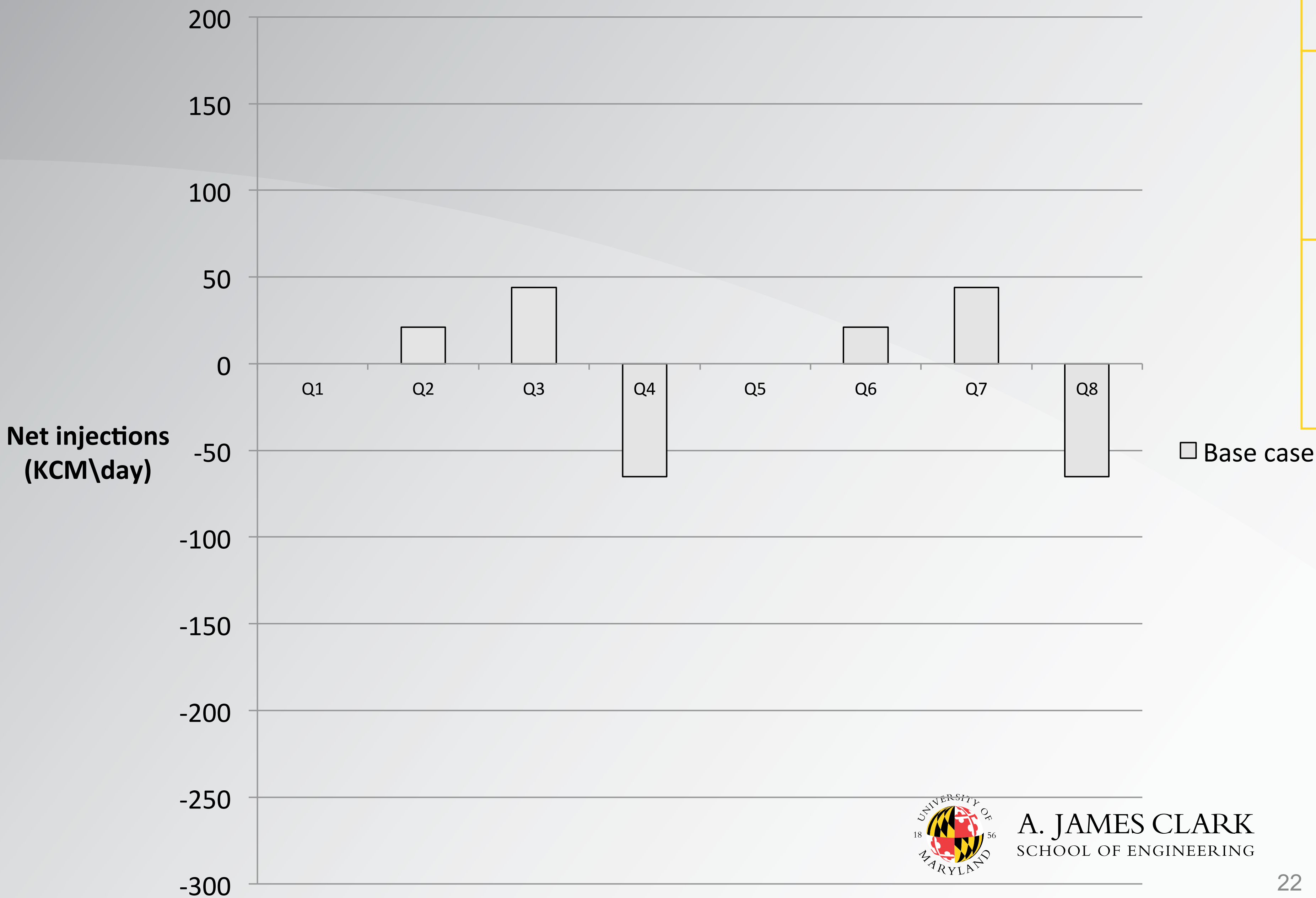
Model

- Update rules:
  - Storage: injections and extractions from previous roll used to update amount of gas in storage
  - Demand horizon rolls forward one period
  - Production capacities reduced by amount produced in previous roll
  - Learning algorithms
- Data: three-node toy model
  - Node 1: New Jersey, New York and Pennsylvania
  - Node 2: Illinois, Indiana, Michigan, Ohio, Wisconsin
  - Node 3: Delaware, District of Columbia, Florida, Georgia, Maryland, North Carolina, South Carolina, Virginia, West Virginia

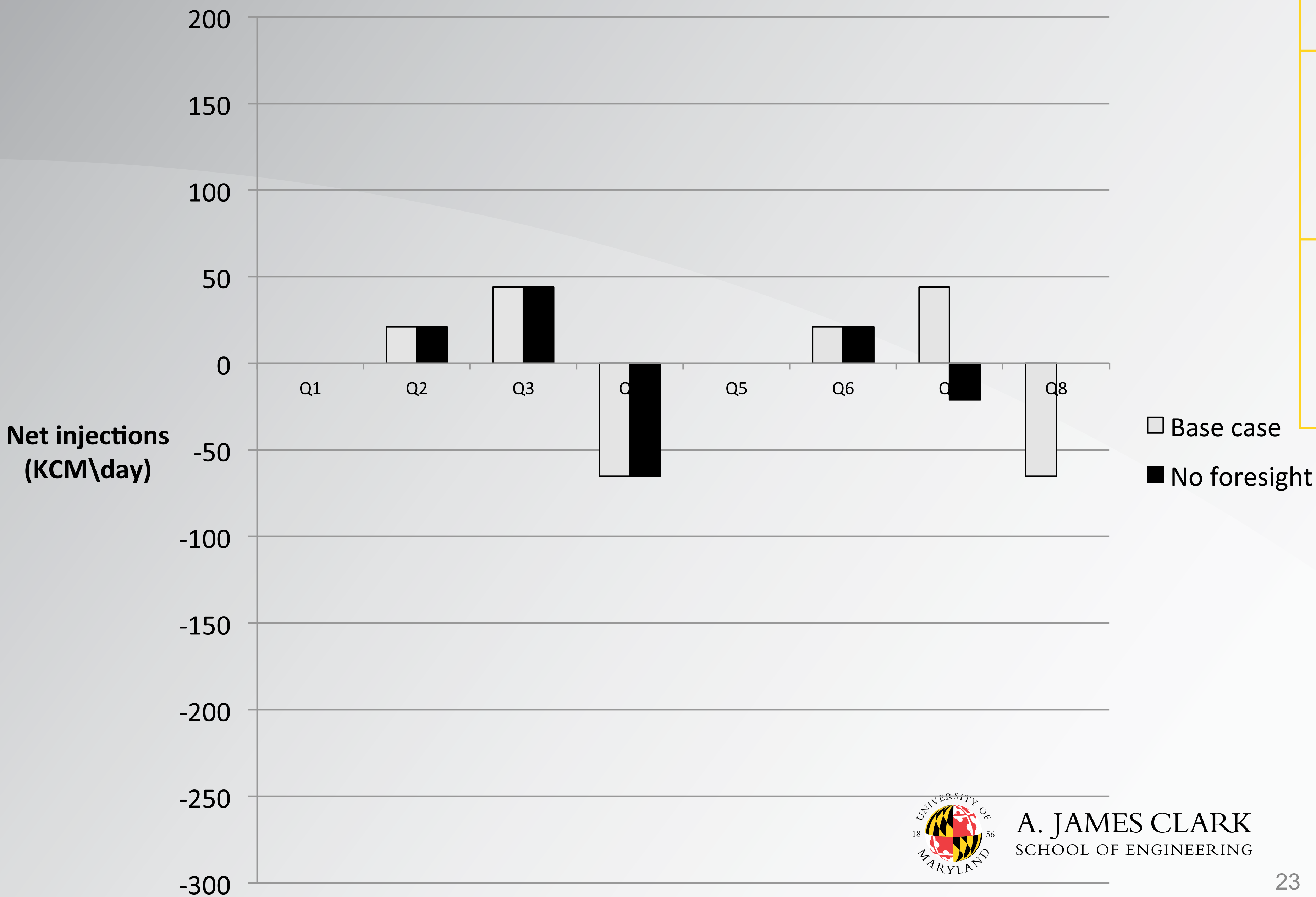
Illustrative Results

- Several scenarios to test foresight with increased demand in time period 7
- **Base Case**: rolling horizon MCP no increased demand
- **No Foresight Case**: none of the players have information about the increased demand until roll 7
- **1 Period Ahead Foresight Case**:each player can see the increased demand one period (roll) ahead, i.e., in roll 6
- **3 Period Ahead Foresight Case**:each player can see the increase in demand three periods (rolls) ahead, i.e., in roll 4.
- **Perfect Foresight Case**: there is only one roll of the model and each player can see all time periods ahead at the start of the model

Benefits of rolling horizon: increased demand in roll 7



Benefits of rolling horizon: increased demand in roll 7



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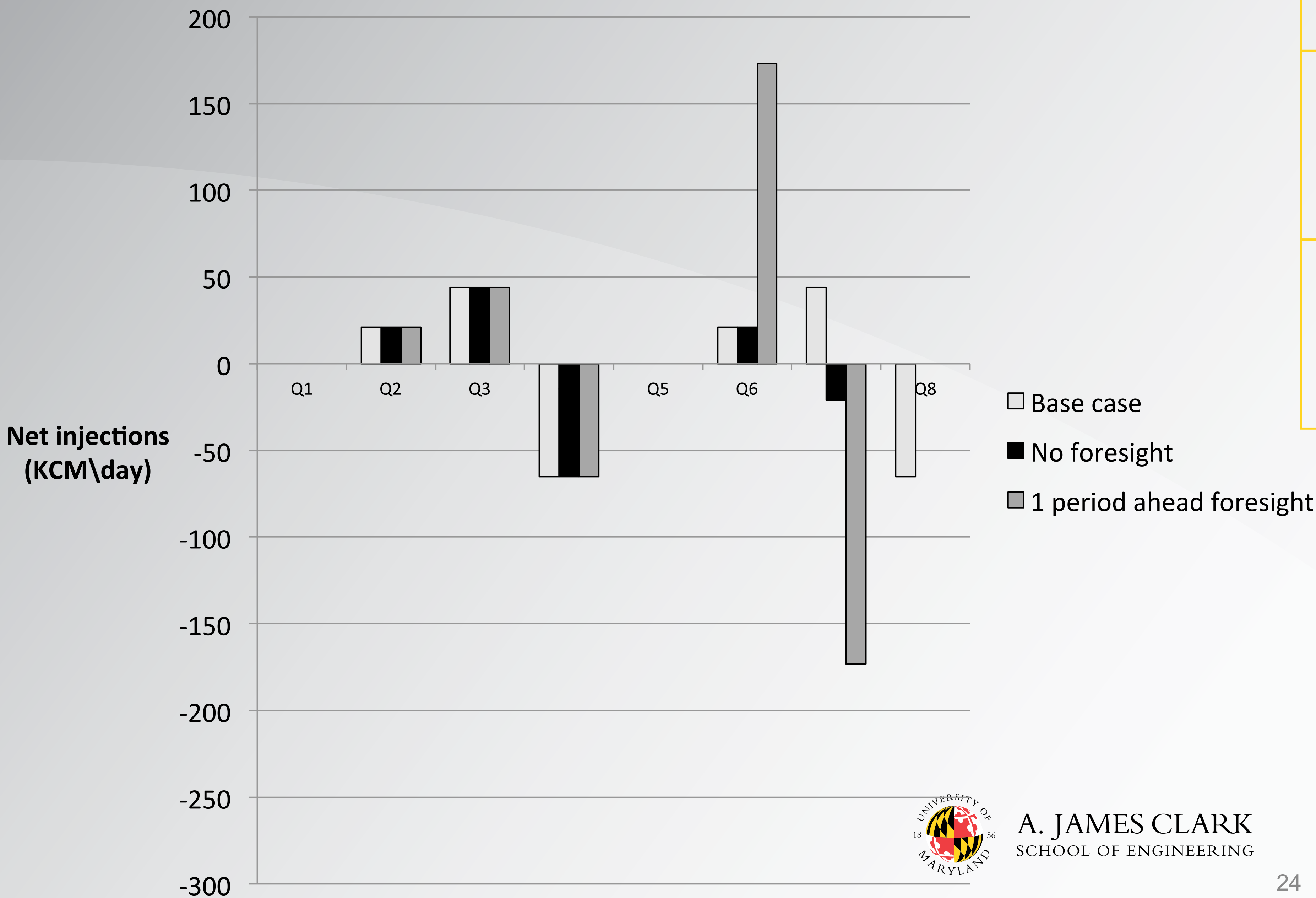
Benefits of rolling horizon: increased demand in roll 7



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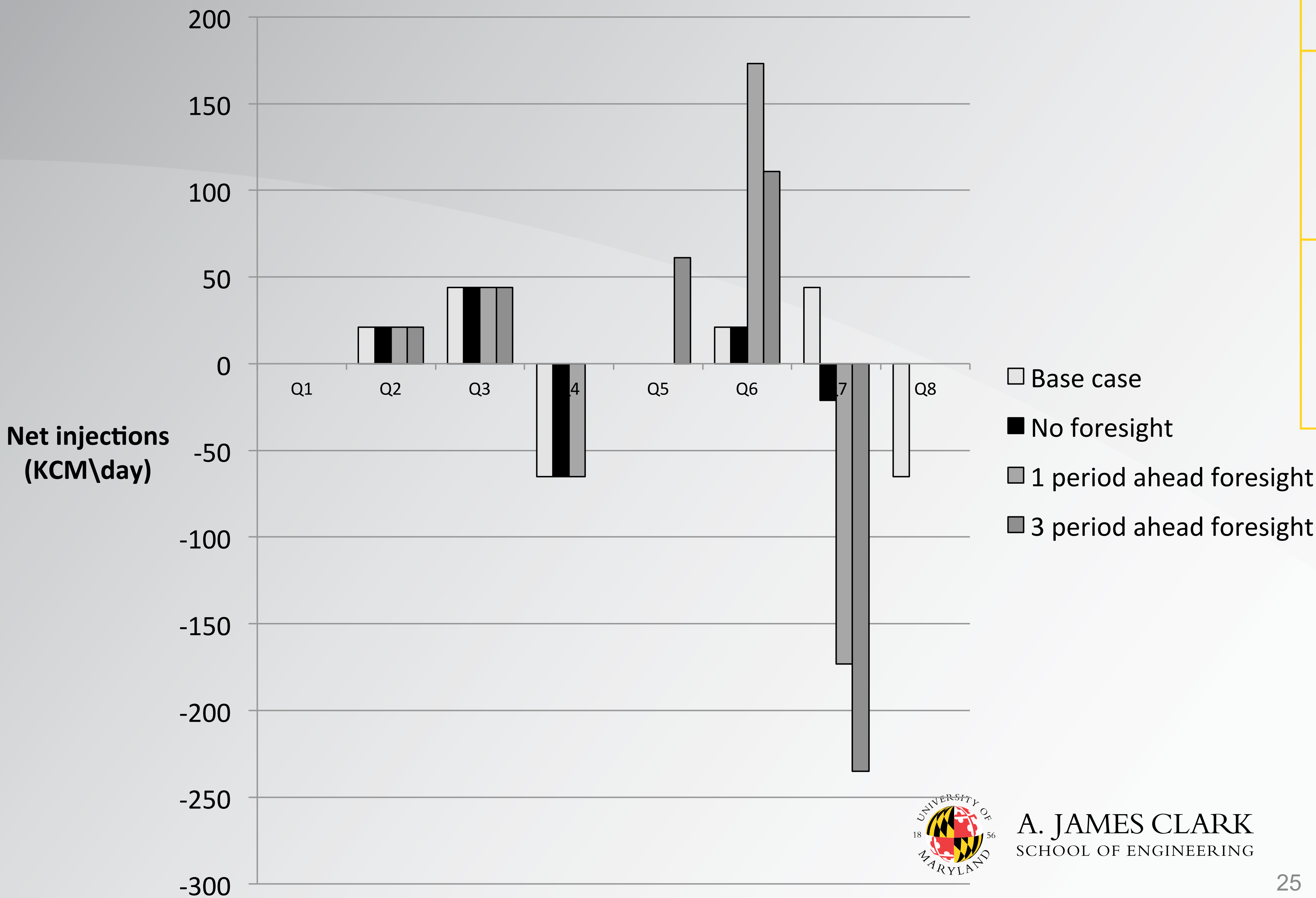
Benefits of rolling horizon: increased demand in roll 7



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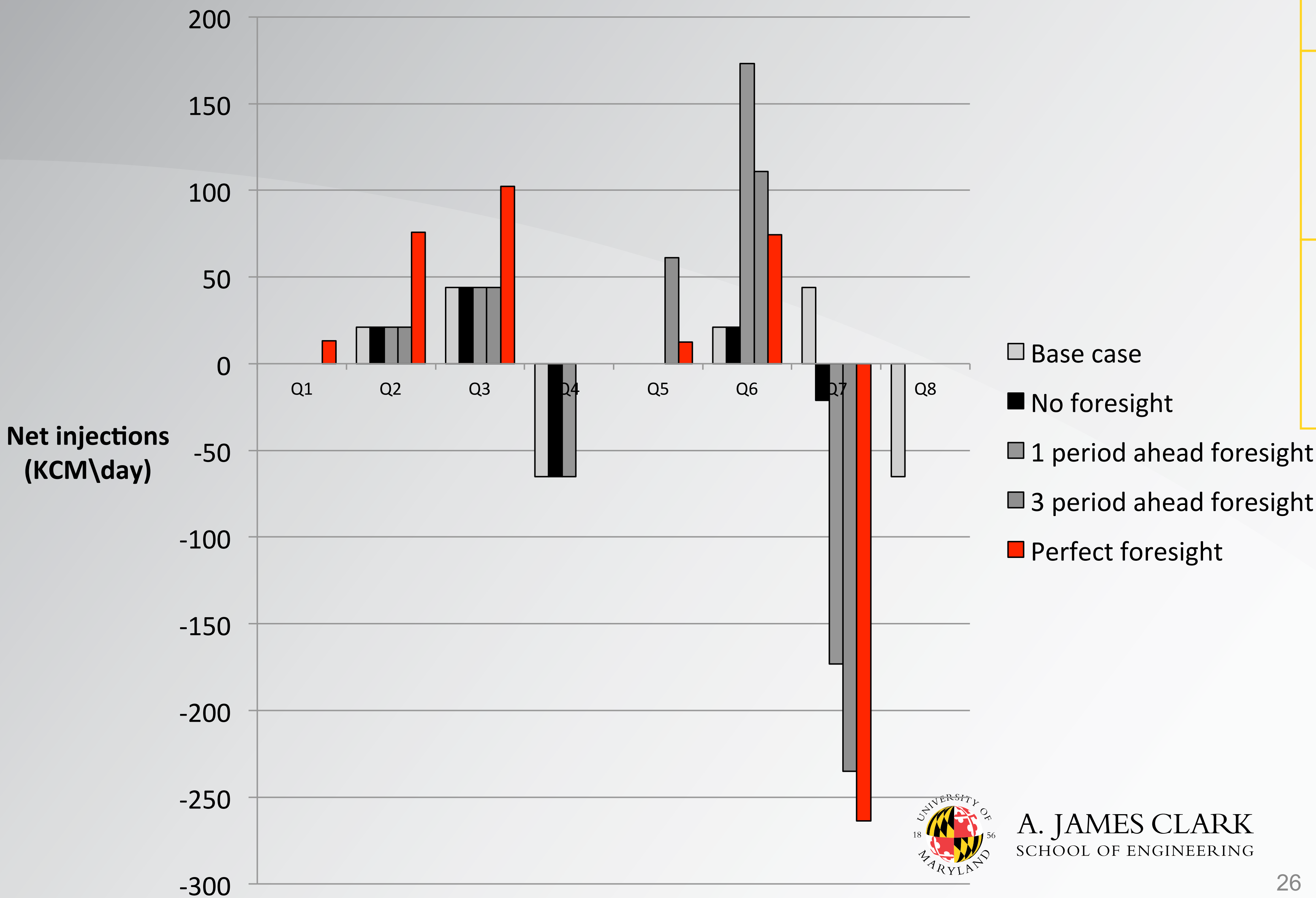
Benefits of rolling horizon: increased demand in roll 7



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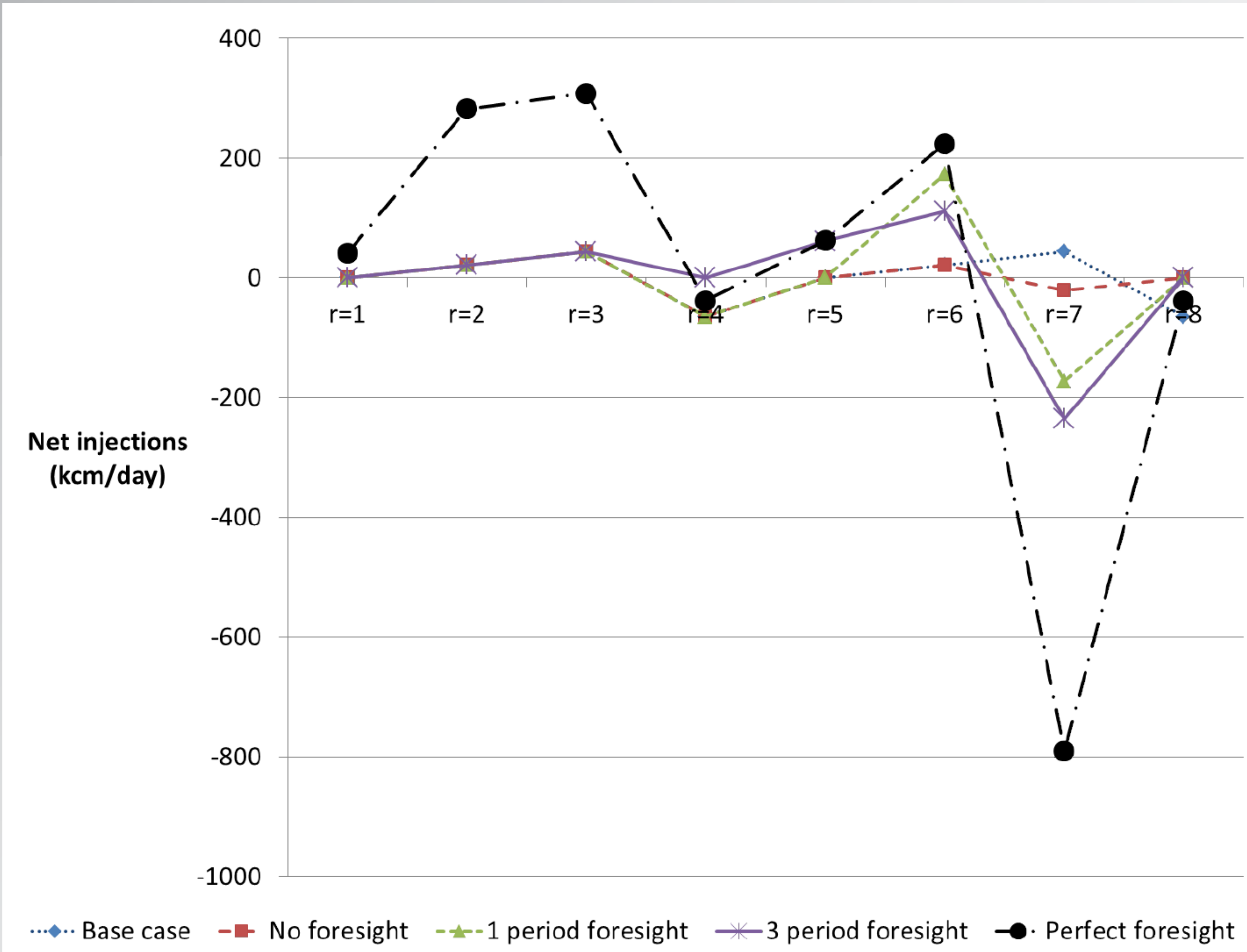
Illustrative Results: Net Injections (all markets)

Increased Information Leads to Earlier Storage Injections



Illustrative Results: Prices in Market 1

Increased Information Leads to Smaller Price Spikes

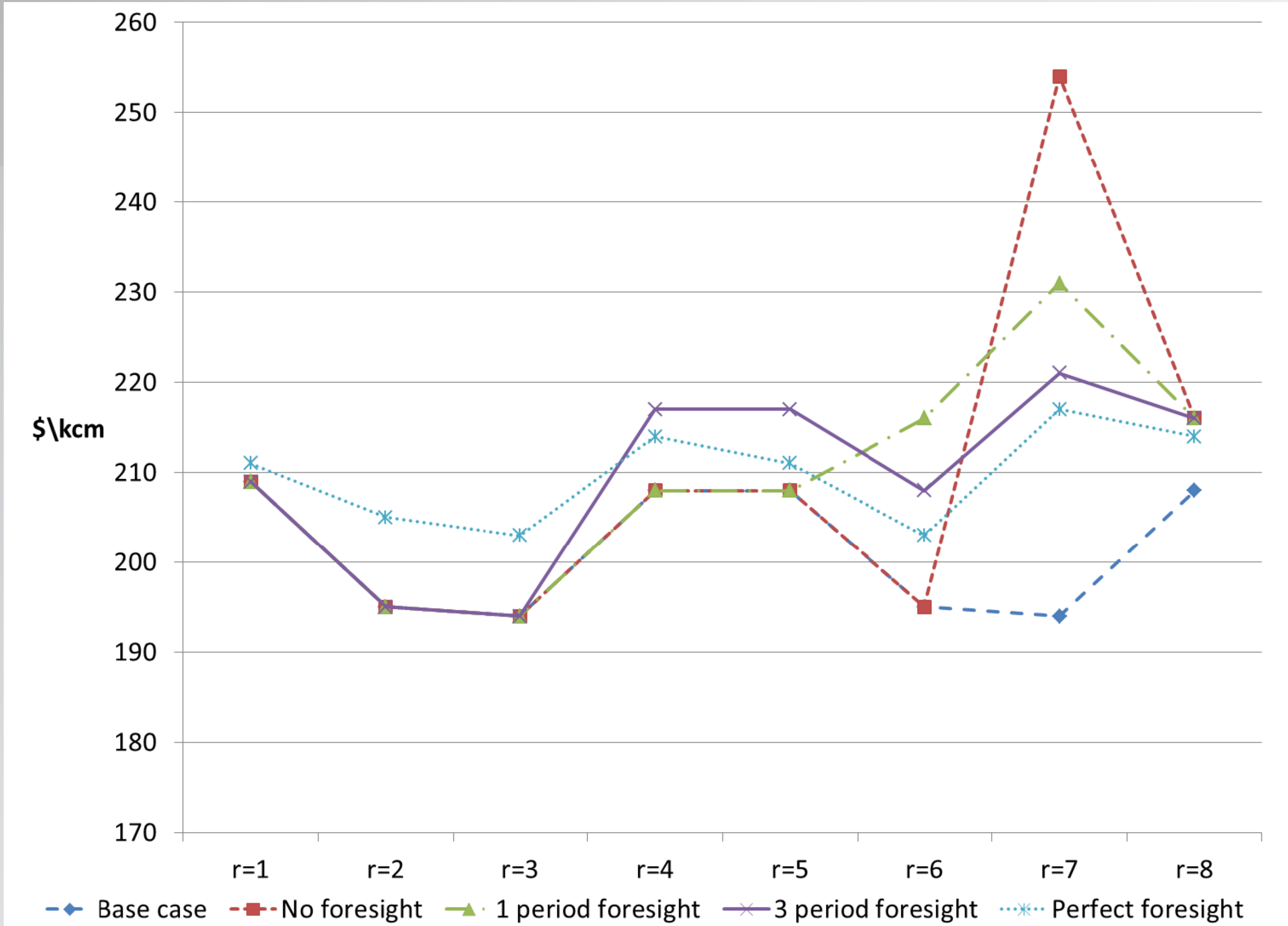


Figure 5: Prices in market $m = 1$.

K
NG

Learning algorithms

- Allow models to incorporate changing risk preferences and probabilities over time
- Example:
  - After each roll check:
  - ***IF*** First-Stage decisions for Sales over-estimate for actual demand
    - ***Then*** increase recourse cost associated over-estimating demand/production
  - ***ELSE IF*** First-Stage decisions for Sales under-estimate actual demand
    - ***Then*** increase recourse cost associated under-estimating demand/production
- Other algorithms based on profits

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Learning Algorithm/Endogenous Probabilities

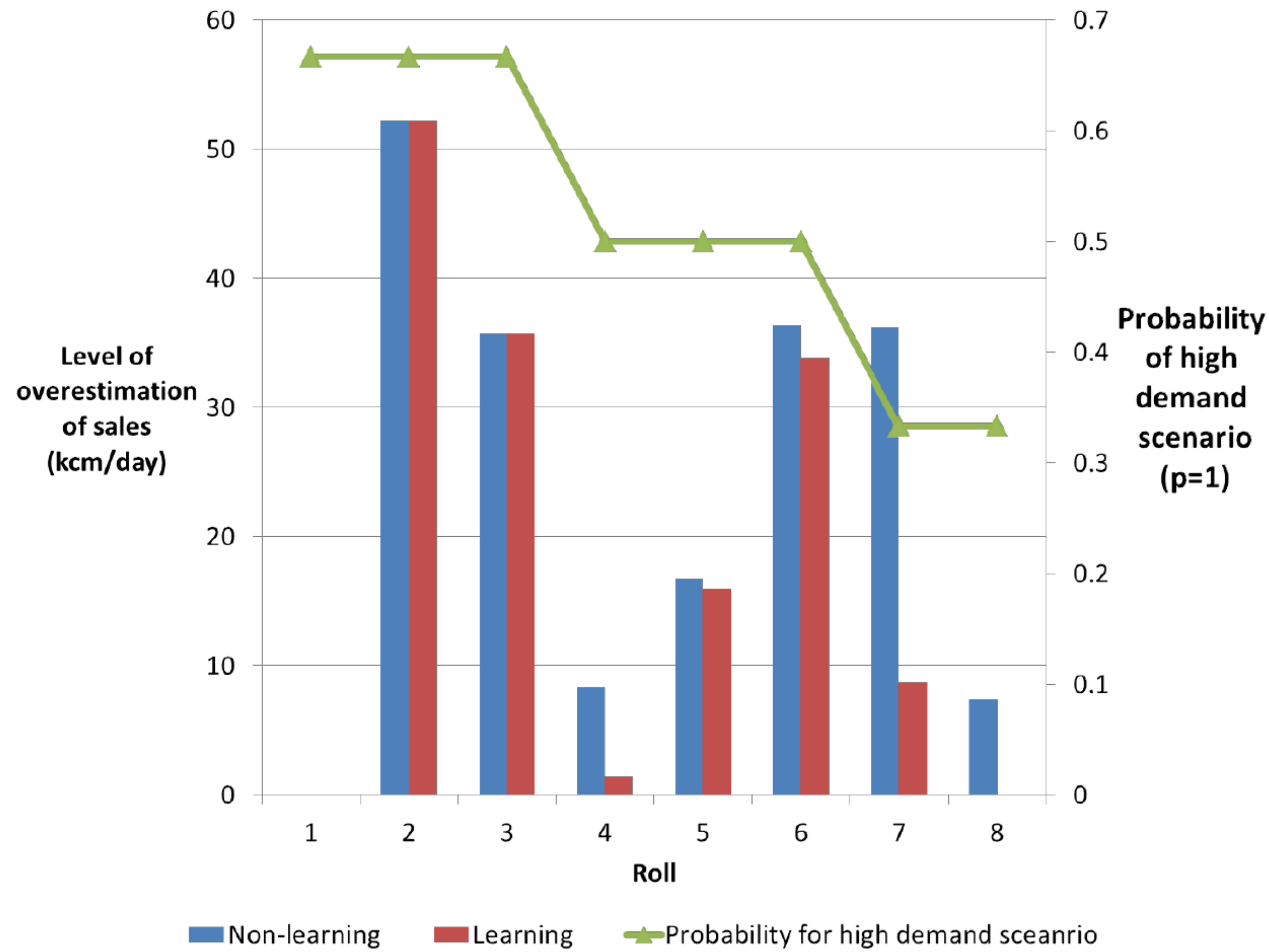

Figure 7: Amount by which producer $p = 1$ overestimates sales (bar charts and left vertical axis) for when a learning algorithm is and isn't used with the rolling horizon MCP plus probability (line chart and right vertical axis) associated with high demand scenario for producer $p = 1$.

Learning Algorithm VoRH
Using an Example Similar to the Base Case
Compared to the Perfect Foresight Case

Table 19: VoRH values for learning algorithm example in Section 4.3.1.

	VoRH	Relative VoRH	VoRH without large values	Relative VoRH without large values
No learning algorithm	396432.63	1.00	66.18	1.00
Learning algorithm	787902.35	1.99	75.28	1.14

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Summary and Conclusions

- Introduced rolling horizon mixed complementarity-based equilibrium model of natural gas market
  - Multi-player model
  - Repeated game
  - Stochastic program
- Described the benefits of rolling horizon in the situation of unforeseen stressed demand
- Examined the effects of a learning algorithm on a natural gas market model
- Rolling horizons and learning can add realism to gas market model models

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   1. S.A. Gabriel, A.J. Conejo, J.D. Fuller, B.F. Hobbs, 2013. *Complementarity Modeling in Energy Markets*, Springer.
2. Natural Gas
   1. Moryadee, S. and Gabriel, S.A., 2014. "Panama Canal Expansion: Will the Panama Canal be a Game Changer for LNG Exports to Asia?", in review, September.
   2. Moryadee, S., Gabriel, S.A., Avetisyan, H. 2014. "Investigating the Potential Effects of U.S. LNG Exports on Global Natural Gas Markets, accepted, *Energy Strategy Reviews*, 2 (3-4), 273-288.
   3. Moryadee, S., Gabriel, S.A., Rehulka, F. 2014. "The Effects of Panama Canal Tariffs on LNG Marketed", accepted, *Journal of Natural Gas Science & Engineering*, June.
3. Rolling Horizon Models
   1. M. T. Devine, J. P. Gleeson, J. Kinsella, D.M. Ramsey, D. M., (2014). *A Rolling Optimisation Model of the UK Natural Gas Market.* Networks and Spatial Economics, 1-36.
   2. **M. Devine, S.A. Gabriel, S. Moryadee, " A Rolling Horizon Approach for Stochastic Mixed Complementarity Problems with Endogenous Learning: Application to Natural Gas Markets," in review, 2015. preprint Cahiers du GERAD G-2015-14, February 2015, http://wwwold.gerad.ca/en/publications/cahiers.php**

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33

Extra Slides

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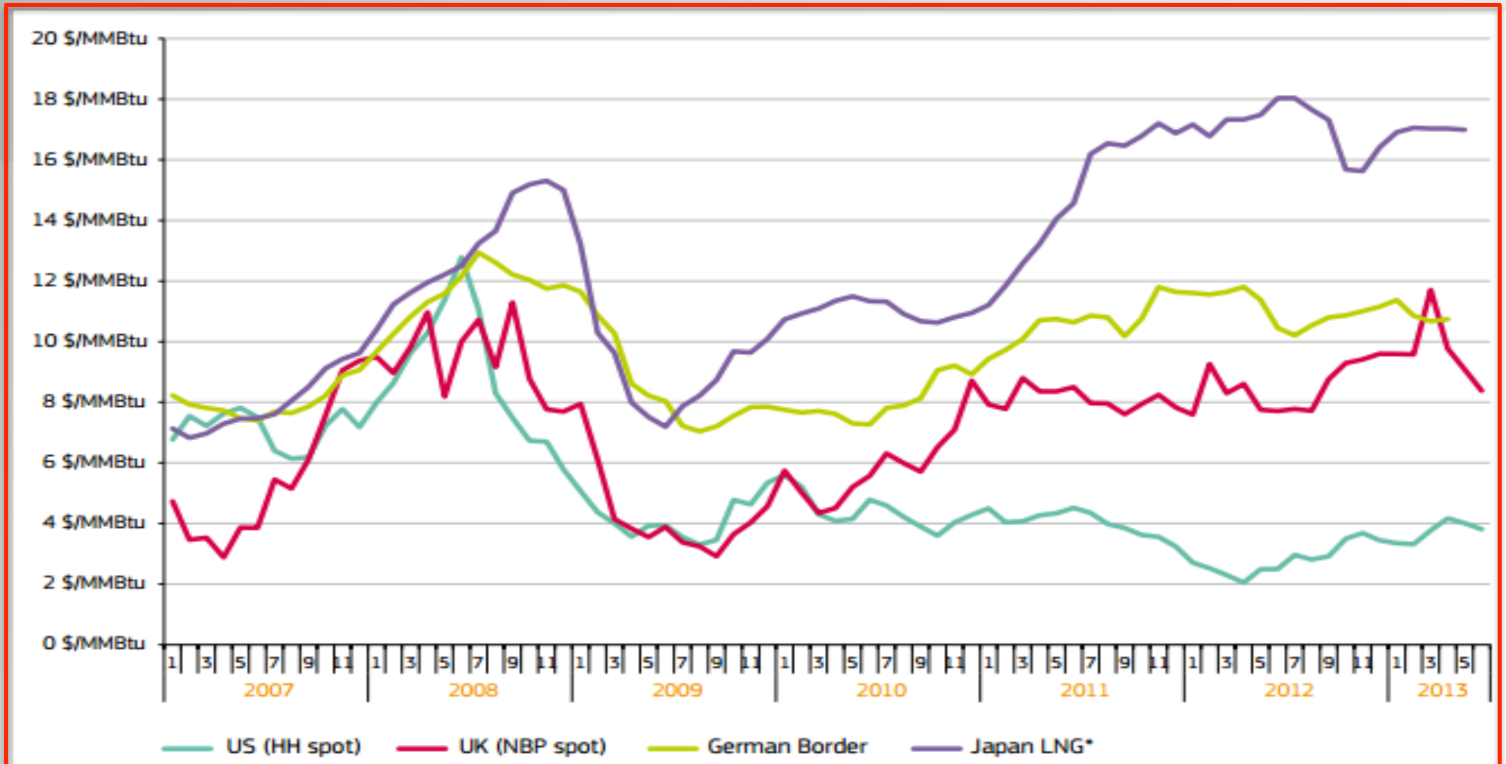
International Comparison of Wholesale Gas Prices



Source: European Commission,2013

- LNG prices in Japan over the first four months of 2013 were on average 55-70% above NBP and German border prices and 4.5 times higher than the U.S. Henry Hub prices

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Russia, Europe and Natural Gas Demand Insecurity: Looking West

- European demand/geopolitical insecurity for Gazprom and Russia
- The European Commisson abuse of dominance in natural gas, charging higher prices in Bulgaria, Estonia, Latvia, Lithuania, Poland (countries with a large dependence on natural gas)
- Regulators: Gazprom is trying to partition Central and Eastern European gas markets by "reducing customer's ability to resell the gas to other countries".
- Siberian pipeline gas to European utilities down 20% in Q1 (compared with historical average) – LNG from Qatar and elsewhere cheaper including U.S. shale gas.

Gazprom Faces Effects of Politics on Its Bottom Line

By ANDREW E. KRAMER APRIL 22, 2015

The Gaz-System distribution station in Gustorzyn, Poland. Poland and some other European countries are largely dependent on Russian gas. Agencja Gazeta/Reuters

http://www.nytimes.com/2015/04/23/business/international/gazprom-faces-effects-of-politics-on-its-bottom-line.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&_r=0

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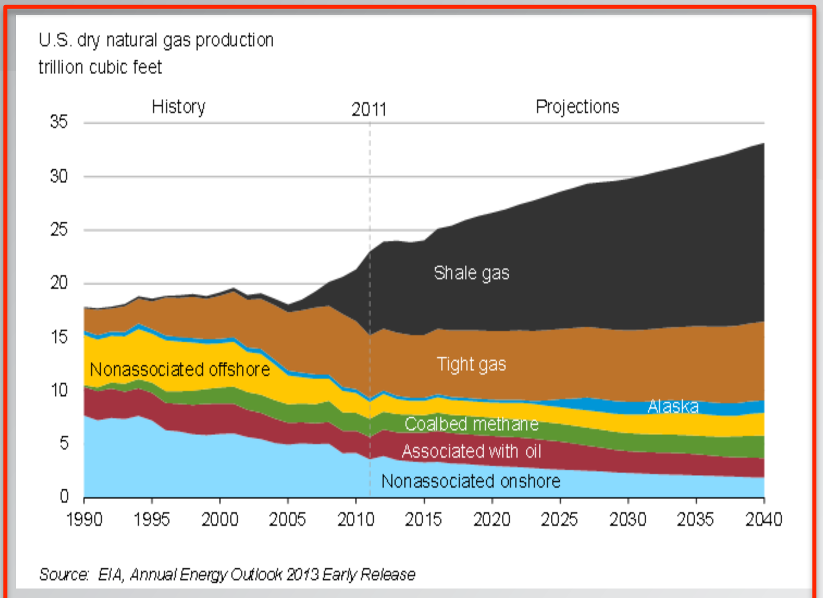
North American Gas Market
Shale Gas Revolution

U.S. Shale Gas Production Through 2040 (TCF)



- The share of U.S. shale gas in the total production is increasing
- U.S. LNG exports rise to approximately 1.6 trillion cubic feet (Tcf) in 2027
- The U.S. becomes a net exporter of LNG in 2016
- Hydrofracking environmental issue considered by each U.S. State and EPA

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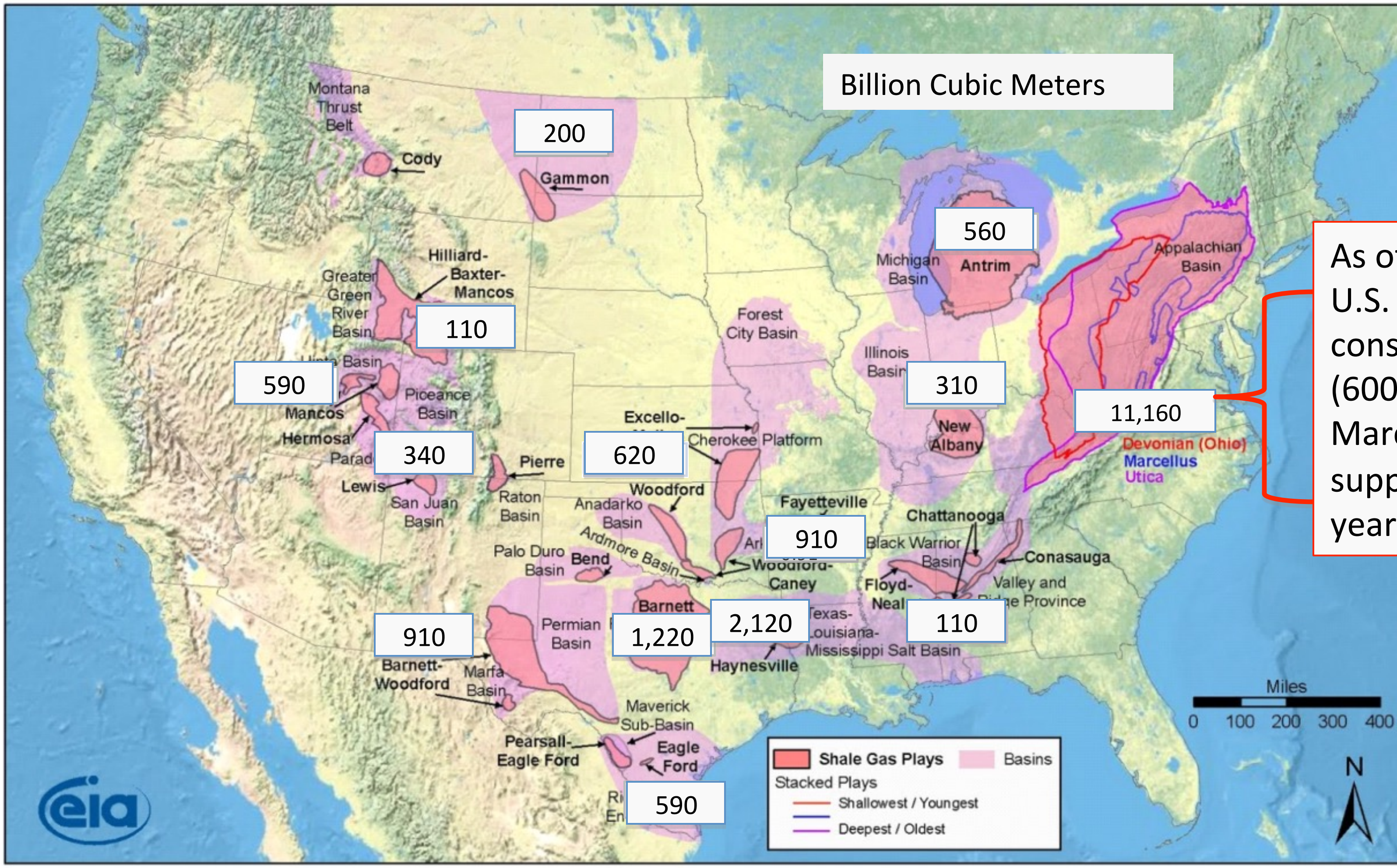
US Shale Gas Plays, Lower 48 States



Source: Energy Information Administration based on data from various published studies
Updated: May 28, 2009

As of 2010 U.S. consumption (600BCM*), Marcellus can supply for 20 years

*BP Statistical Review, 2011

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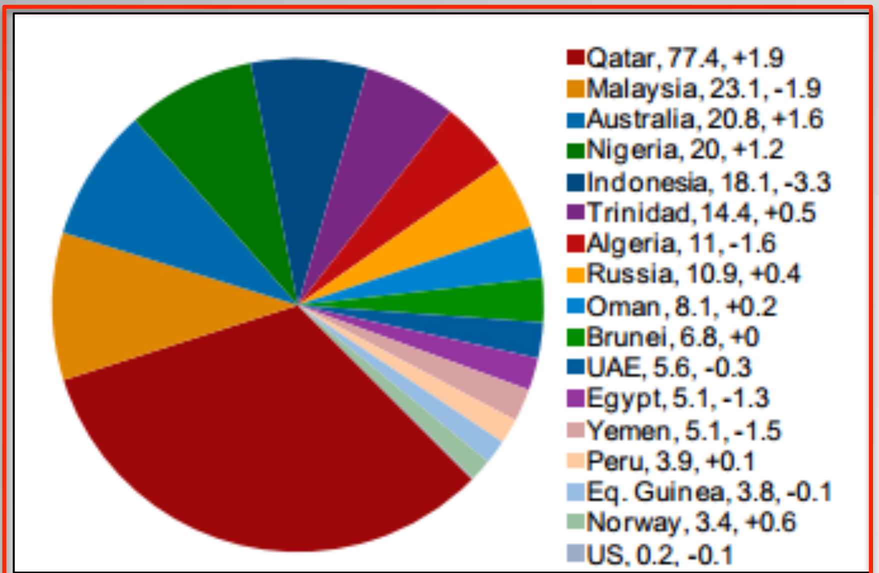
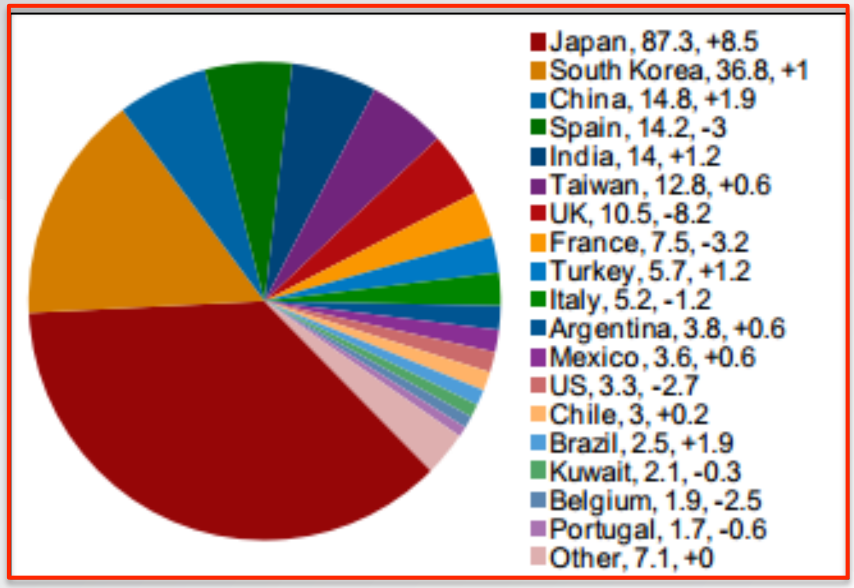
More Demand Insecurity: Overview of LNG Markets

LNG Exports in MTPA by Country



LNG Imports in MTPA by Country



- Japan and South Korea imported 52% of all LNG in 2012
- One-third of LNG in 2012 is supplied from Qatar
- Qatar, Australia, and Nigeria contributed more than 75% of total supplies

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U.S. LNG Export Status as of March 5, 2014

	Total of all applications	Approved	Pending
FTA application	38.50 Bcf/d (377.4Bcm/y)	37.80 Bcf/d (370.3 Bcm/y)	0.7 Bcf/d (7.1 Bcm/y)
Non-FTA application	35.58 Bcf/d (348.5 Bcm/y)	9.7 Bcf/d (95.03 Bcm/y)	25.88 Bcf/d (253.56 Bcm/y)

About 31% of LNG trade in 2012

FTA with the U.S. requires national treatment for trade in natural gas, including Australia, Bahrain, Canada, Chile, Colombia, Dominican Republic, El Salvador, Guatemala, Honduras, Jordan, Mexico, Morocco, Nicaragua, Oman, Peru, Republic of Korea and Singapore

http://energy.gov/sites/prod/files/2013/08/f2/Summary_of_Export_Applications.pdf

Source: U.S. Department of Energy

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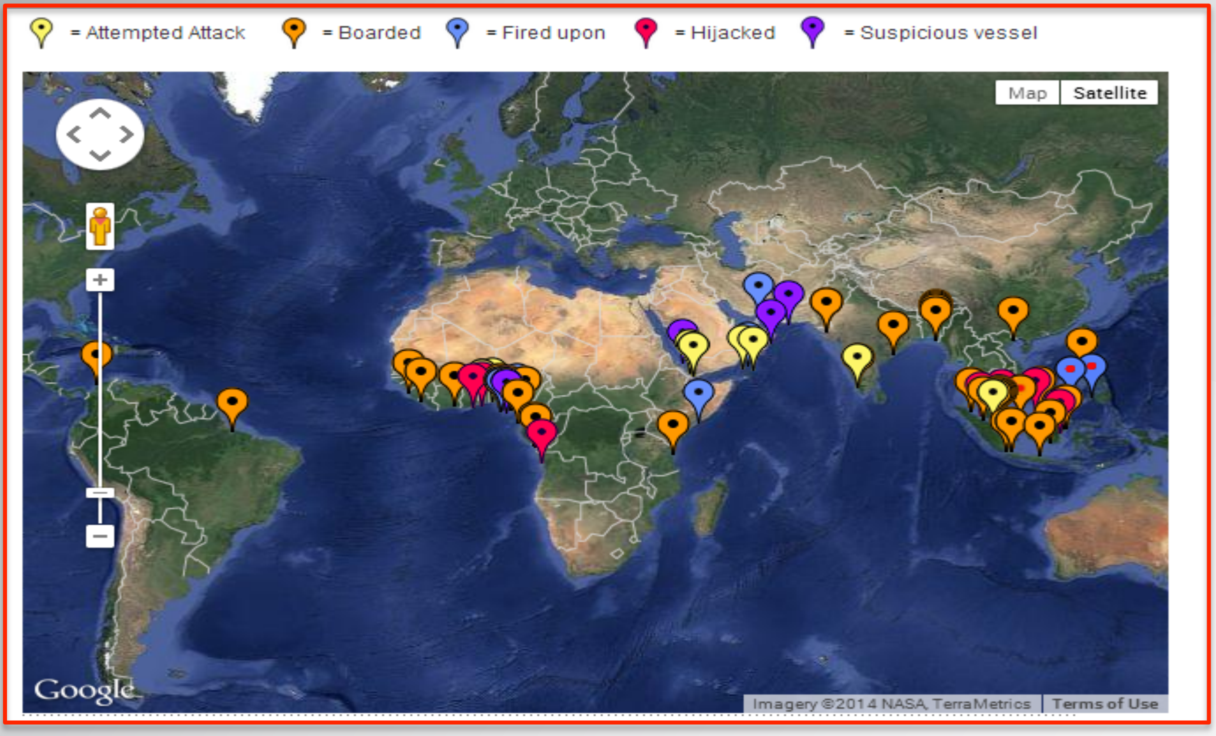
Energy Security: Vulnerability of Transport Routes, IMB Piracy Map 2013



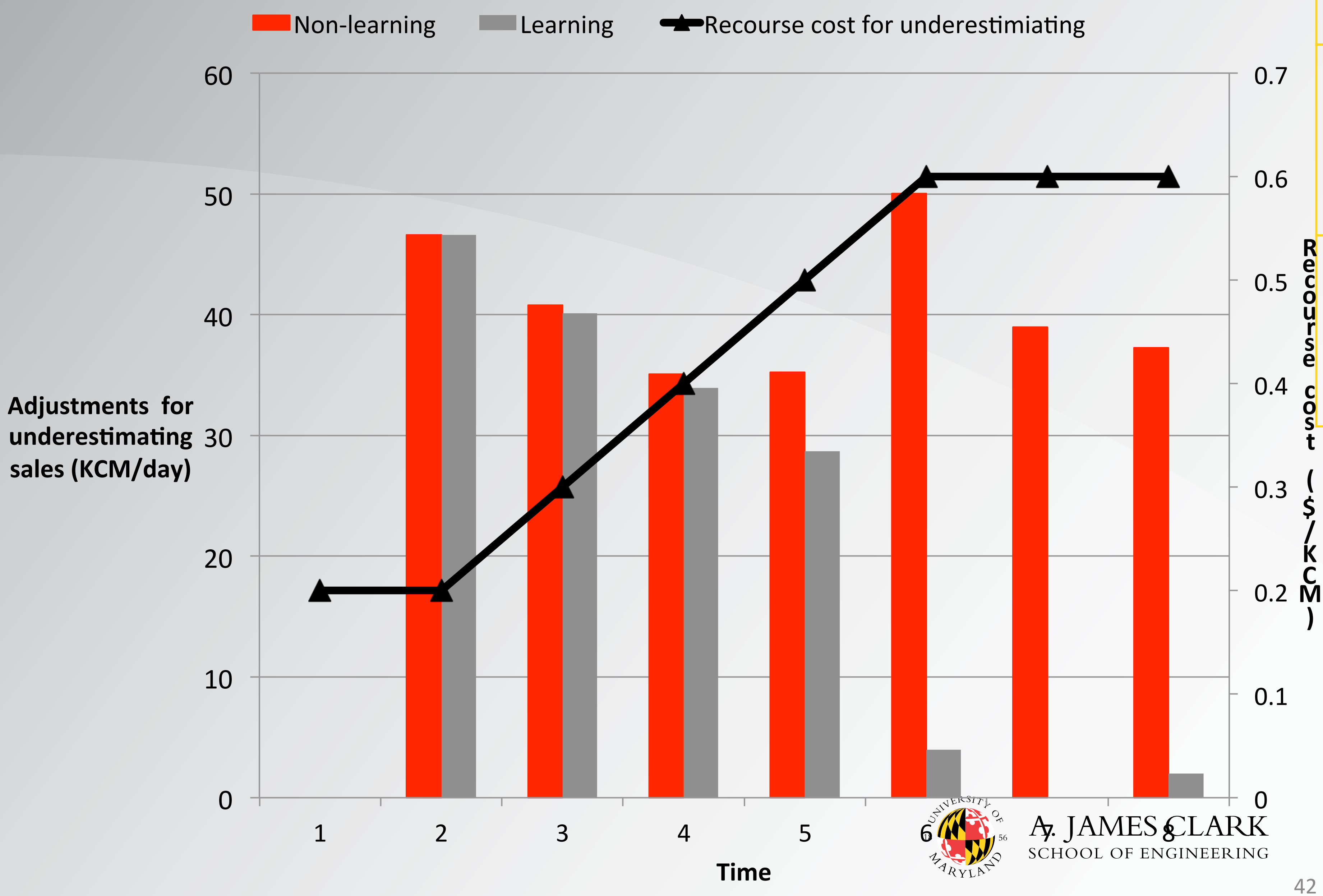
- The incidents happened around four major checkpoints, Suez Canal the Bab El Mandeb, the Strait of Hormuz, and Malacca

1. IMB stands for International Maritime Bureau
2. LNG tankers become the target. The bad thing is that if the tanker sank in the main waterway e.g., Suez Canal, it would very hard to get it back. It will be stuck in the waterway for a while : e.g., a week or more. for more details see:

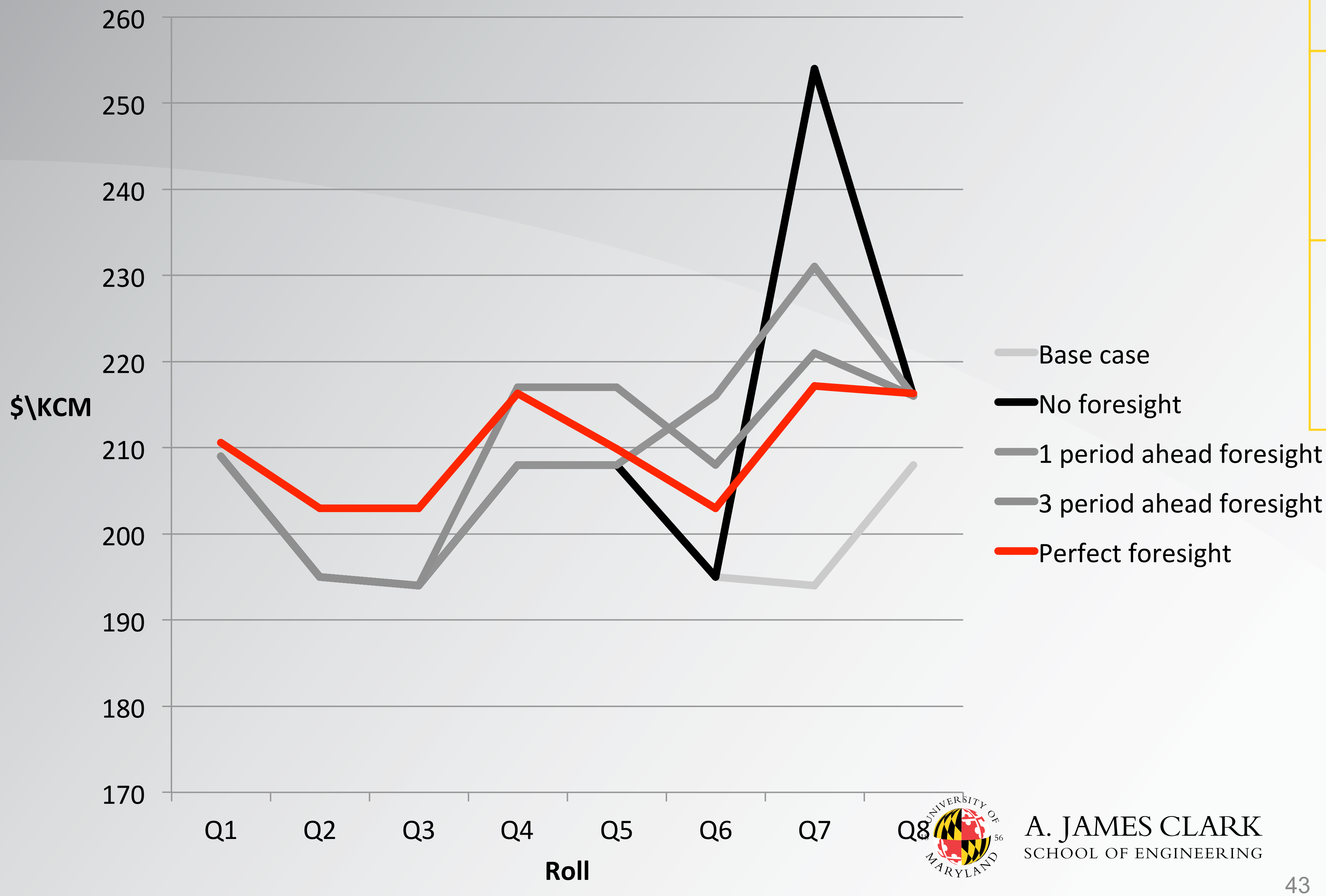
http://www.maritime-executive.com/article/lng-tanker-becomes-target-of-pirate-attack-shots-fired

http://www.lngworldnews.com/pirates-attack-lng-tanker-offshore-oman/

Endogenous uncertainty



Benefits of rolling horizon: stressed demand in roll 7



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Nonlinear Programs Expressed as Mixed Nonlinear Complementarity Problems

Consider a generic nonlinear program and its resulting KKT conditions

$$\min\ f(x)$$

$$s.t.\ g_i(x) \le 0, i = 1,\ldots,m \quad (u_i)$$

$$h_j(x) = 0, j = 1,\ldots,p \quad (v_j)$$

KKT conditions, find $\bar{x} \in R^n, \bar{u} \in R^m, \bar{v} \in R^p$ $s.t.$

$$\left\{ \begin{array}{l} (i) \nabla f(\bar{x}) + \sum_{i=1}^{m} \bar{u}_i \nabla g_i(\bar{x}) + \sum_{j=1}^{p} \bar{v}_i \nabla h_j(\bar{x}) = 0 \\ (ii) g_i(\bar{x}) \le 0, \bar{u}_i \ge 0, g_i(\bar{x})\bar{u}_i = 0, \text{ for all } i = 1,\ldots,m \\ (iii) h_j(\bar{x}) = 0, \bar{v}_j \text{ free, for all } j = 1,\ldots,p \end{array} \right\}$$

Nonlinear Programs Expressed as Mixed Nonlinear Complementarity Problems

Thus, we get a mixed NCP as follows:

$$F\begin{pmatrix} x \\ u \\ v \end{pmatrix} = \begin{pmatrix} \nabla f(x) + \sum_{i=1}^{m} u_i \nabla g_i(x) + \sum_{j=1}^{p} v_j \nabla h_j(x) \\ -g_i(x), i = 1,\ldots,m \\ h_j(x), j = 1,\ldots,p \\ \end{pmatrix}$$

$$\nabla f(x) + \sum_{i=1}^{m} u_i \nabla g_i(x) + \sum_{j=1}^{p} v_j \nabla h_j(x) = 0 \qquad x \text{ free}$$

$$-g_i(x) \geq 0, i = 1,\ldots,m \qquad u_i \geq 0, \left(-g_i(x)\right) * u_i = 0$$

$$h_j(x) = 0, j = 1,\ldots,p \qquad v_j \text{ free}$$

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Energy Producer Duopoly Expressed as a Complementarity Problem

-Two producers competing with each other on how much to produce given as $q_i, i = 1, 2$

- Market Inverse demand function

$p(q_1 + q_2) = \alpha - \beta(q_1 + q_2),$ where $\alpha, \beta > 0$

that the producers can manipulate by their production

- Production cost function

$c_i\left(q_i\right) = \gamma_i q_i, i = 1, 2,$ where $\gamma_i > 0$

Energy Producer Duopoly Expressed as a Complementarity Problem

Producer 1's optimization problem:

$$\max \left(\alpha - \beta(q_1 + q_2)\right) * q_1 - \gamma_1 q_1$$

$$s.t.\ q_1 \geq 0$$

KKT conditions:

$$\text{Find } q_1 \text{ s.t. } \quad 2\beta q_1 + \beta q_2 - \alpha + \gamma_1 \geq 0 \quad q_1 \geq 0 \quad \left(2\beta q_1 + \beta q_2 - \alpha + \gamma_1\right)\ q_1 = 0$$

For Producer 2, similar idea, that is:

$$\text{Find } q_2 \text{ s.t. } \quad \beta q_1 + 2\beta q_2 - \alpha + \gamma_2 \geq 0 \quad q_2 \geq 0 \quad \left(2\beta q_2 + \beta q_1 - \alpha + \gamma_2\right)\ q_2 = 0$$

Need to solve both at same time (why?) to get the resulting pure LCP

$$F\begin{pmatrix} q_1 \\ q_2 \end{pmatrix} = \begin{pmatrix} 2\beta q_1 + \beta q_2 - \alpha + \gamma_1 \\ \beta q_1 + 2\beta q_2 - \alpha + \gamma_2 \end{pmatrix}$$

Can generalize to N players, will get a Nash-Cournot equilibrium

Can more generally also add market-clearing conditions

For more examples, see *Complementarity Modeling in Energy Markets*, S.A. Gabriel, A.J. Conejo, J.D. Fuller, B.F. Hobbs, C. Ruiz (Springer, 2013)

Example of Diversification: European Natural Gas Pipeline Projects

Source: The Economist

- Four pipeline projects compete against each other (TANAP-TAP-TIGI-Nabucco) to bring gas from Central Asia to Europe
- Nabucco shareholders now believe that only a smaller version of the pipeline is realistic
- Russia aims to build second Baltic sea pipeline to increase supply to Europe as well as to bypass Ukraine

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Energy Security: Gas Import Dependency in Central and South-Eastern Europe (2013)

Source: Eurogas

Table 1: Gas import dependency in Central and South-Eastern Europe (2012)

Country	Gas import dependency	Share of Russia in gas imports	Share of Russia in consumption
Austria	78.9%	76.1%	60.0%
Bulgaria	97.7%	100%	83.3%
Croatia	34.5%	N/A	N/A
Czech Republic	98.0%	58.6%	57.5%
Greece	100.0%	55.6%	55.6%
Hungary	78.2%	100.0%	78.2%
Italy	88.5%	32.6%	28.9%
Poland	72.0%	81.3%	58.6%
Romania	24.3%	100.0%	24.3%
Slovakia	98.4%	83.5%	82.2%
Slovenia	100.0%	60.2%	60.2%
Average	79.1%	68.0%	53.5%

- Some European countries have a very large dependence on Russian gas
- Continuing disputes between Russia and Ukraine downstream W. Eur. Countries affected
- Need for supply security

- Increase of natural gas infrastructure e.g., storage
- Diversity of suppliers
- Flexibility to shift fuels
- Long-term contracts
- Shale gas development
- Expansion of natural gas grid
- Increased flexibility: LNG from spot market

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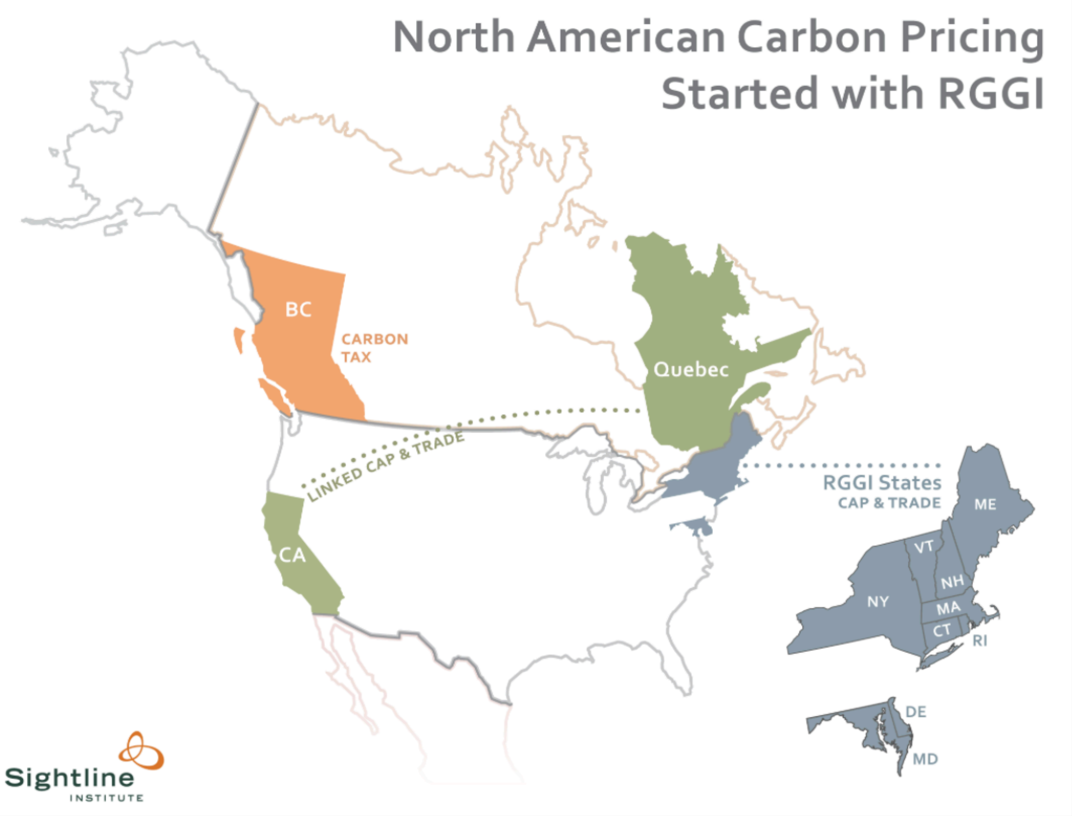
North American Canadian Energy-Environmental Insecurity Issues: Renewables & Shale Gas

- Disconnected carbon emissions markets, does it really matter?



http://www.hydroquebec.com/transmission-construction-projects/quebec-new-hampshire-interconnection/

Energy-Environmental Security: Natural Gas Fracking in China

- Jiaoshizhen, China, Sinopec (Chinese energy company) made the country's first "commercially viable" shale gas discovery
- Could help lower emissions from coal, China largest contributor to global warming
- China: companies must drill two to three times as deep as in U.S.
- More expensive, noisier and potentially more dangerous, much less interaction with local communities (for Chinese energy giants).
- " 'There was a huge ball of fire' " said Liu Jiazhen, a mustard greens farmer with three children who lives a five-minute walk from the site. 'The managers here all raced for their lives up the hill.' "

Huge drilling projects can be seen embedded into farm land outside of Fuling, China. Shale gas has been discovered in the region. Jonah M. Kessel for The New York Times

http://www.nytimes.com/2014/04/12/business/international/china-takes-on-big-risks-in-its-push-for-shale-gas.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&_r=0

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Fossil Fuels and Global Warming: How Bad Could it Get?

If We Dig Out All Our Fossil Fuels, Here's How Hot We Can Expect It to Get

APRIL 8, 2015

Michael Greenstone, NY Times

http://www.nytimes.com/2015/04/09/upshot/if-we-dig-out-all-our-fossil-fuels-heres-how-hot-we-can-expect-it-to-get.html?smprod=nytcore-iphone&smid=nytcore-iphone-share&abt=0002&abg=1

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Energy-Environmental Insecurity: Fossil Fuels and Global Warming

Buried Fuel and a Much Warmer World

Scientists predict global disaster at 3.6 degrees Fahrenheit over pre-industrial temperatures; there is enough fossil fuel extracted and within reach to raise temperatures 16.2 degrees.

2 degrees C

9 degrees C

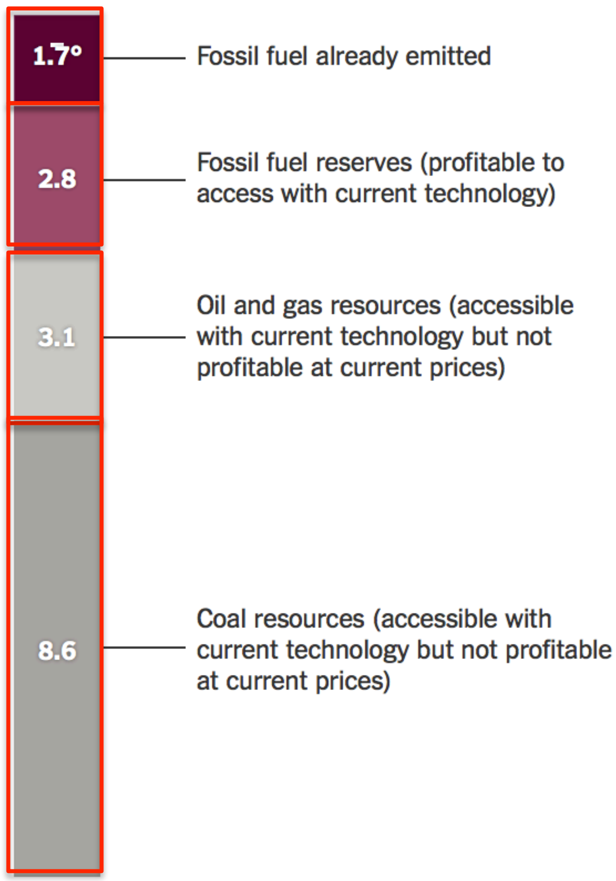
Associated warming in degrees Fahrenheit

0.94 degrees C

1.56 degrees C

1.72 degrees C

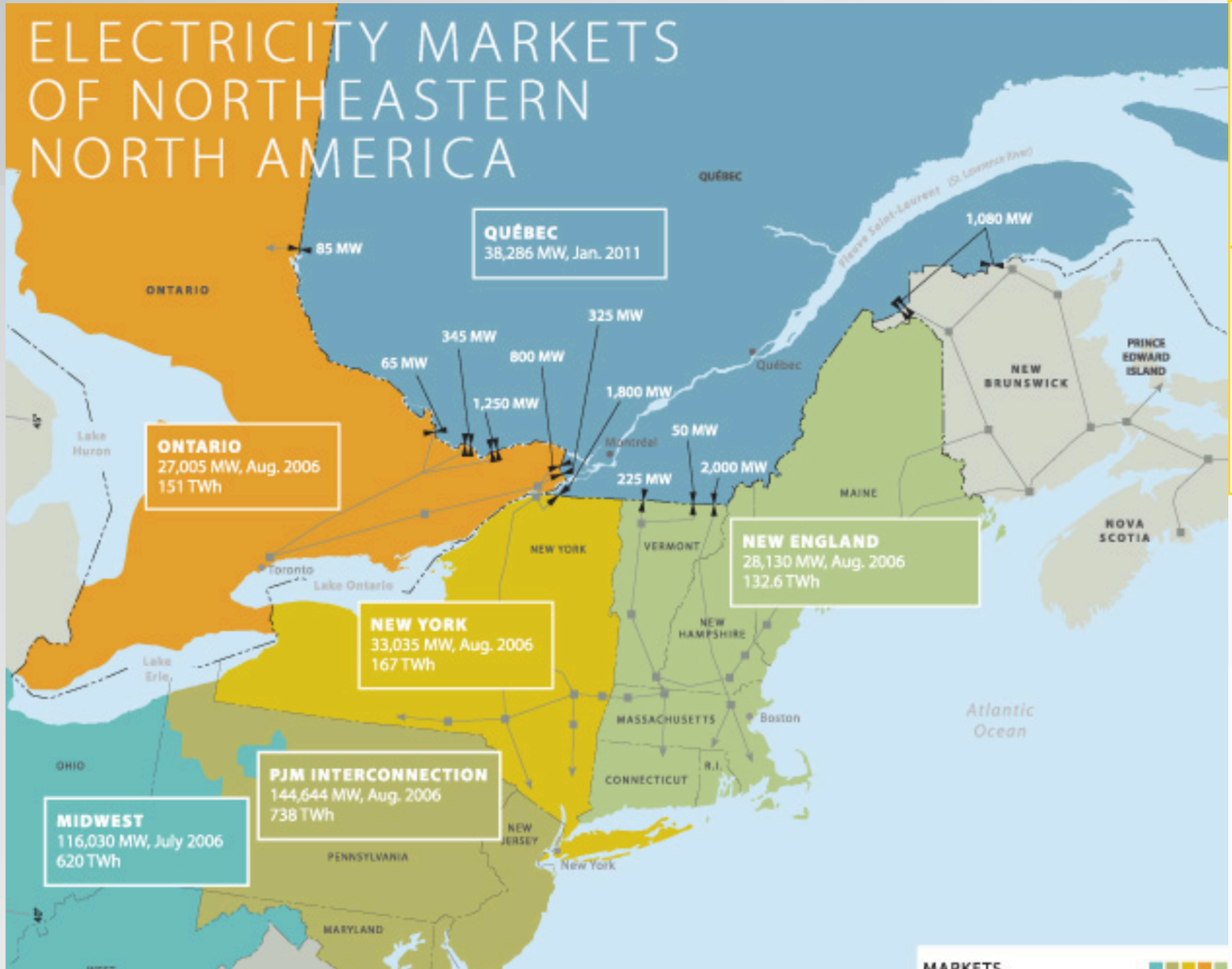
4.78 degrees C



Source: Calculations use the "carbon-climate response" model from Matthews et al. (2009, Nature) to convert cumulative carbon emissions into global mean temperature changes.

North American Canadian Energy-Environmental Insecurity Issues: Renewables & Shale Gas

- Hydro-Québec has been selling electricity to New England since the 1980s (~1/2 of HQ's exports)
- Since the early 1990s transmitted more than 100 billion kWh to substation near Boston.
- With Northeast Utilities and NSTAR, Hydro-Québec is currently studying a project for a direct-current interconnection with New Hampshire (approved by U.S. regulator).
- Electricity supply in New York State congested transmission lines, HQ can help supply western New York by wheeling power through Ontario.



http://hydroforthefuture.com/projets/34/developing-outside-markets

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Energy-Environmental Security/ Oil Price Volatility: The Rise of "Cowboyistan"

- Huge volatility in oil prices lately:
  - less than $45/bbl this winter,
  - more than $100/bbl last June, maybe lower even
- New center of the oil world?
  - Shale oil fields of Texas and North Dakota "Cowboyistan"
  - OPEC just can't cut production to increase prices (lose market share to U.S. production)
- OPEC (Saudia Arabia-leader) controls about 30 % of world oil production (was > 40 % in the 1970s)
- U.S. production now roughly 10 % of global production.)

http://www.nytimes.com/2015/04/23/business/energy-environment/new-balance-of-power.html

New Balance of Power

By CLIFFORD KRAUSS APRIL 22, 2015

A Colorado oil well developed by hydraulic fracturing, the blasting of oil and gas out of shale rock with water and chemicals. Ed Darack/Science Faction, via Corbis

Energy-Environmental Security/Oil Price Volatility: The Rise of "Cowboyistan"

- "Hydraulic fracturing, the blasting of oil and gas out of shale rock with water and chemicals, is the single most important factor of change in global markets in more than a decade, with an environmental outcry commensurate to its magnitude."
- Environmentalists: low hydrocarbon prices=> more consumption
  - Lower gasoline =>sales of sport utility vehicles and other large cars increased
  - Lower oil and natural gas prices related to hydraulic fracturing, still risky:
  - Escape of greenhouse gases into the atmosphere during exploration, production and transport
  - Potential seepage of toxic fluids into water supplies

http://www.nytimes.com/2015/04/23/business/energy-environment/new-balance-of-power.html

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Market Equilibrium Problems Expressed as Mixed Complementarity Problems

Mixed Nonlinear Complementarity Problem (MCP)

Having a function $F : R^n \rightarrow R^n$, find an $x \in R^{n_1}$, $y \in R^{n_2}$ such that

$$F_i(x, y) \geq 0, x_i \geq 0, F_i(x, y) * x_i = 0 \ for \ i = 1, \ldots, n_1$$

$$F_i(x, y) = 0, y_i \text{ free}, \ for \ i = n_1 + 1, \ldots, n$$

Multiple players: take Karush-Kuhn-Tucker (KKT) conditions to each optimization problem

Add market-clearing conditions

Result is a market-equilibrium (perfect or imperfect competition) expressed as an MCP

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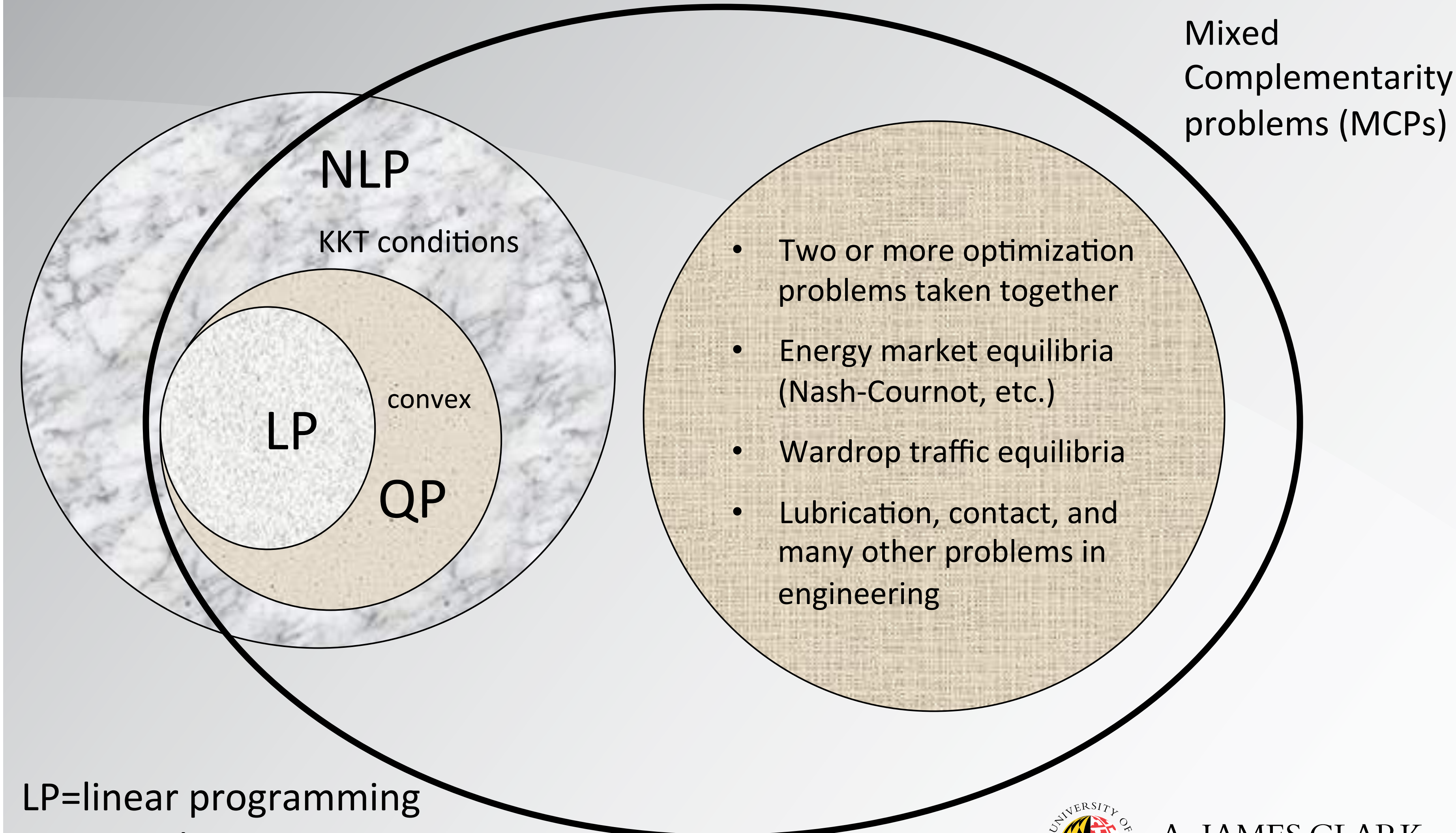
Optimization and Equilibrium Modeling: Engineering-Economic System Focus



LP=linear programming
QP= quadratic programming
NLP=nonlinear programming

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