Phasing out the US Federal Helium Reserve:

Policy insights from a world helium model

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Background:
the U.S. helium program

"We choose to go to the Moon"

"We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard; […] because that challenge is one that we are willing to accept, one we are unwilling to postpone, and one we intend to win".

U.S. President John F. Kennedy.

"Address at Rice University on the Nation's Space Effort", Rice Stadium, Houston TX. September 12, 1962

Helium

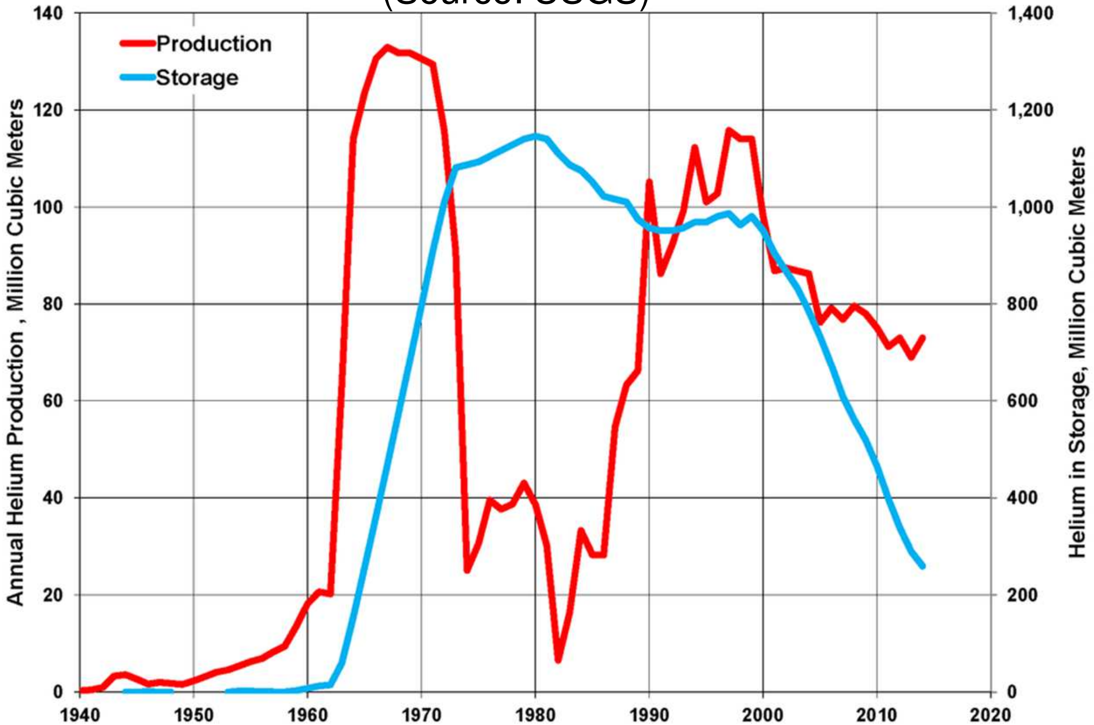
- **a noble gas**
  - **a unique collection of physical properties**
  - **used in a number of advanced technologies**
    - leak detection, chromatography, welding under inert conditions, breathing mixtures for deep-sea diving.
    - **nearly non-substitutable** in fiber-optic technology, electronic manufacturing, **rocket launching**, and cryogenics (e.g., in MRI scanners).

- **an exhaustible finite resource**
  - **an optional by-product of natural gas.**
    - He can be separated from the gas streams extracted from a limited number of helium-rich natural gas deposits.
  - **If not separated, that helium is wasted**
    - it dissipates in the atmosphere when the gas is burned.

The U.S. Helium program: the build-up of a vast strategic stockpile

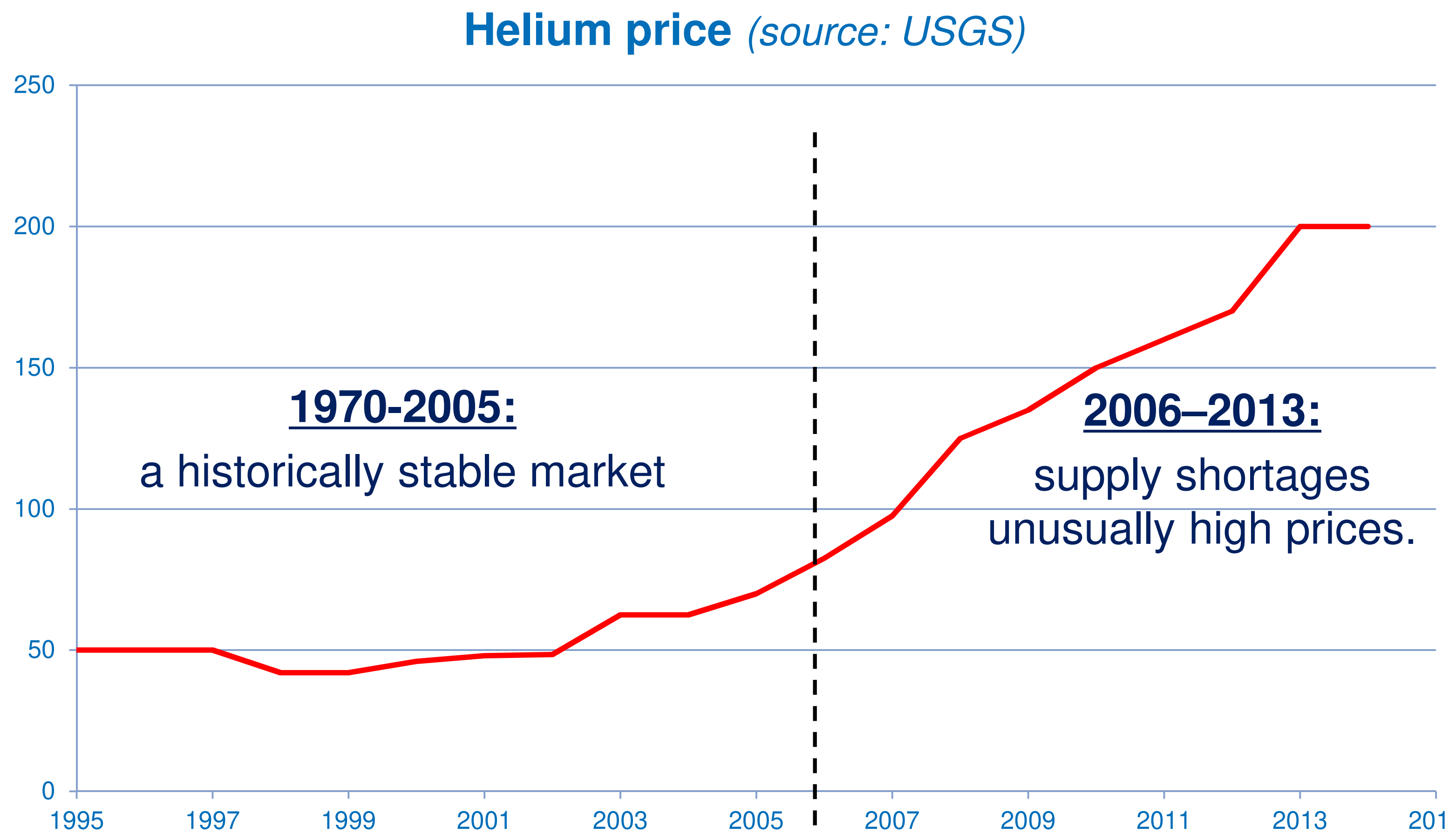
Map of the U.S. BLM system (source: USGS)

He production and storage in the U.S., 1940-2014 (Source: USGS)



- **The aim was to store He in the 1960s that would be needed in the 1970s**
  - the revenues obtained from these sales would permit to recover the cost by 1980
- **<u>That plan failed</u>**
  - the U.S. government had to wait until 1996 before being able to start selling its reserve and gradually repaying the $1.4 billion debt accumulated by the He program (NRC, 2000).

Background:
2007: He as a source of political concern



- Articles in the media (e.g., The Economist)
- Insititutional studies (e.g., National Research Council (2010))
- Emergence of a literature dedicated to the future availability of helium resources (authored by science and technology experts). (Nuttall et al., (2012))

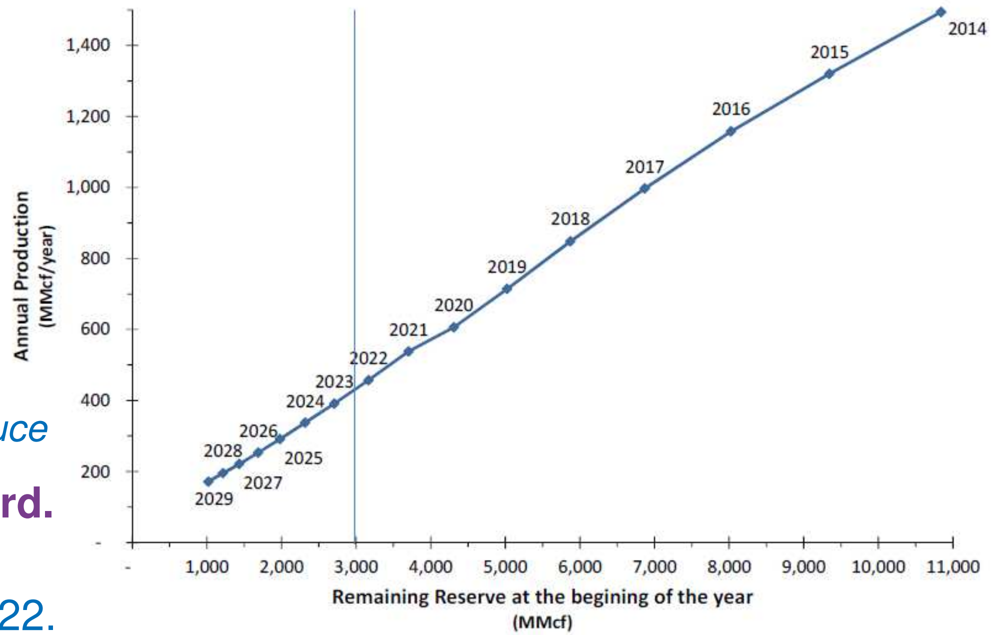
Background:

- In 2013, the US Treasury debt was finally paid back, yet nearly 1/3rd of the original stockpile still remained in the Federal He Reserve (FHR)

The **2013 Helium Stewardship Act** instructs the US BLM to:

- **allocate 3 Bcf to future noncommercial uses**
  - *e.g., federally-funded scientific research*
- **use a « market-based » mechanism to set the BLM price**
- **rapidly deplete the remaining inventory**
  - *it imposes to sell in each year a flow of He equals to the amount that the FHR can produce*
- **cease its commercial operations afterward.**
  - the Federal government's commercial operations are expected to cease in 2022.

Figure 1. The time-path of the FHR's planned production trajectory



Source: www.blm.gov/style/medialib/blm/nm/programs/0/helium_docs.Par.6729.File.dat/Helium%20Delivery%20Model.pdf

Research Question

Is that rapid phase out of the U.S. Reserve supported by the future evolution of the world helium market?

- **Does-it blur pricing on the world helium market?**
  - Recall that the BLM controlled circa 30% of the global helium supplies in 2013 (USGS, 2015).

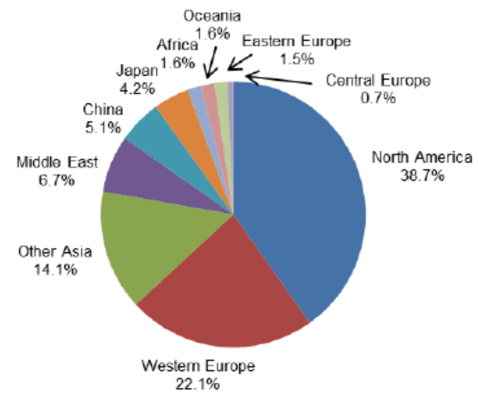
Literature

- **The applied literature: old and limited to the U.S. market**
  - dates back to the 1980s. At that time, the discussion chiefly revolved around the issue of the rationale for governmental stockpiles.
  - **Epple and Lave (1980): a numerical model of the U.S. He industry.**
    - a LP aimed at determining the rate of helium production and storage over time that maximizes the discounted social welfare.
  - **The early empirical studies of Liu (1983) and Uri (1986, 1987)**
    - structural econometric models of the helium market aimed at
      - building supply and demand projections (Liu, 1983; Uri, 1987)
      - Checking whether demand and supply respond to normal market forces (Uri, 1986).
- **The theoretical literature on natural resources economics**
  - Pindyck (1982) considers the joint extraction of two finite exhaustible resources forming a composite ore
  - Hughey (1989) investigates the role of helium demand in the market equilibria for both natural gas and helium
  - Hughey (1991) assesses the economics of three subsidy policies

Background:
A changing world helium scene

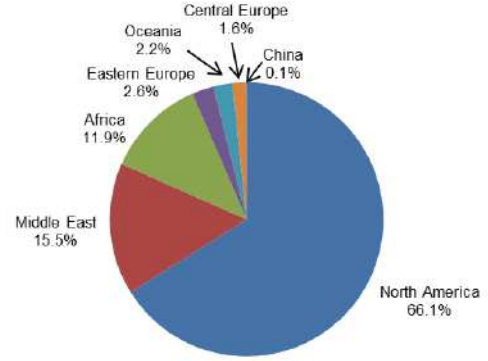
- **Stylized facts**
  - **Within the U.S.**, the industry structure is **radically changing**
    - He production is declining in Texas, Oklahoma, and Kansas
    - New projects are developed in regions not connected to the BLM pipeline infrastructure
  - He supply has long been dominated by the U.S. but most **new sources are developing elsewhere**
    - New suppliers: Qatar, Algeria, Australia…
    - Between 2008 and 2013, the U.S. share of worldwide helium extraction capacity declined from 75.5% to 66.1% percent (IHS, 2014).
  - A **concentrated market structure**
    - Supply depends on a small number of separation plants worldwide
  - **Demand**
    - **Price & GDP sensitive**
    - a substantial share of helium is used in long-lived equipment
- **A series of possible outlooks**
  - Russia is endowed with substantial helium reserves in East Siberia.
    - If fully developed, that He separation project could make Russia the world's largest helium producer
    - It is believed that this project will have to be phased.
  - Future demand levels?

World Consumption of Helium—2013



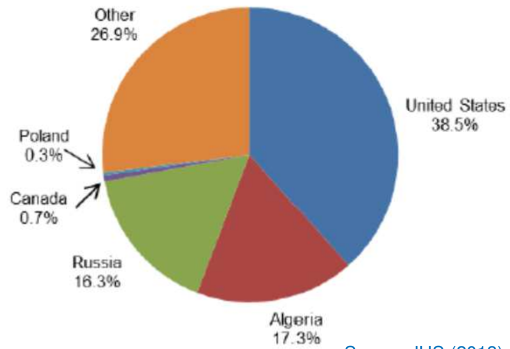
Total = 185.0 Million Cubic Meters

World Capacity for Helium—2013



Total = 250.9 Million Cubic Meters

World Reserves of Helium—2012



Source: IHS (2013)

Total = 10,400 Million Cubic Meters

Model

The World Helium Model (WHM)

- **Methodology:** **a detailed partial equilibrium model**
  - A dynamic, open-loop, Nash-Cournot oligopoly model
    - deterministic,
    - time-discrete, finite-horizon $t \in \mathrm{T} := \{1, ..., T\}$
    - a linear-quadratic specification
    - solved as an instance of a mixed complementarity problem (MCP)
  - that captures the essential features of that industry:
    - the “inertia” of global helium consumption,
      - *impacted by both current and past decisions;*
    - the strategic behavior of market participants;
    - the role of both public and private storage inventories;
    - and the endogenous modeling of capacity investments.

The World Helium Model

- The WHM portrays the **strategic interactions** between two main types of suppliers:
  - the **U.S. federal government** that operates the FHR
  - and **the private firms** separating helium from natural gas.
    - 3 types of private firms

      J_1 Those processing He from gas fields where future production cannot increase

      J_2 The U.S. firms connected to the BLM's storage system
      - => storage decisions have to be modeled

      J_3 The private suppliers located in resource-rich regions that are capable of expanding their future annual production of helium.
      - => investment decisions have to be modeled

Ingredients

- **Time horizon**
  - From 2014 (year 1) to 2050 (year 37) $t \in \mathrm{T} := \{1, \ldots, T\}$
  - Our discussion will be centered on the first 20 years
- **The demand side**
  - An (empirically-estimated) helium demand function

$$d_t = \alpha_t - \gamma\, p_t + \lambda\, d_{t-1}, \qquad \forall t \in \mathrm{T},\ d_0 \text{ given.}$$

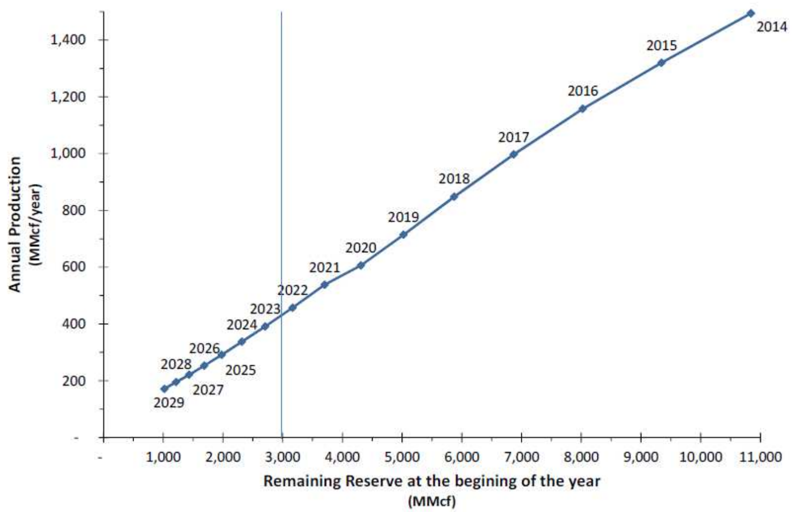
    - and the associated inverse linear demand function $p_t = P_t\left(d_t, d_{t-1}\right)$
- **Market-clearing condition**

$$\sum_{j \in J} q_t^j = d_t, \qquad \forall t \in \mathrm{T}.$$

Players: The US BLM

- **Model I: supply is determined by the geology**

Figure 1. The time-path of the FHR's planned production trajectory



Source: www.blm.gov/style/medialib/blm/nm/programs/0/helium_docs.Par.6729.File.dat/Helium%20Delivery%20Model.pdf

- **Model II: profit maximization**

$$\underset{q_t^{BLM}}{\mathrm{Max}} \quad \Pi_{BLM} = \sum_{t \in \mathrm{T}_{BLM}} \beta_{BLM}{}^{t} \left[P_t\left(q_t^{BLM} + q_t^{-BLM*}, q_{t-1}^{BLM} + q_{t-1}^{-BLM*}\right) - C_{BLM} \right] q_t^{BLM} \qquad \text{(BLM II – 1)}$$

$$\text{s.t.} \quad q_t^{BLM} \le \eta R_{t-1} + \mu\,, \qquad \forall t \in \mathrm{T}_{BLM}\,, \qquad \text{(BLM II – 2)}$$

$$R_t = R_{t-1} - q_t^{BLM}\,, \qquad \forall t \in \mathrm{T}_{BLM}\,,\; R_0 \text{ given,} \qquad \text{(BLM II – 3)}$$

$$R_{T_{BLM}} = \underline{R}\,, \qquad \text{(BLM II – 4)}$$

$$q_t^{BLM} \ge 0 \qquad \forall t \in \mathrm{T}_{BLM}\,. \qquad \text{(BLM II – 5)}$$

Players:
J_1 The existing separators

- **The existing separators with non-increasing future helium-processing capacities**
  - Behave à la Cournot $\delta_j = 1$ or as price taking firms $\delta_j = 0$
  - They can supply helium up to an exogenously determined capacity $\overline{H_t^j}$

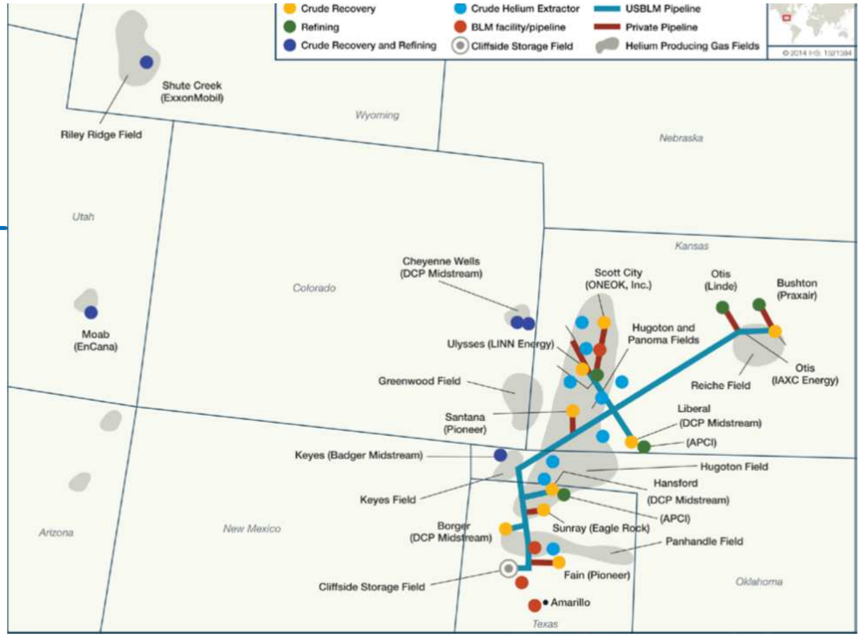
$$\underset{q_t^j}{\mathrm{Max}} \quad \Pi_j = \sum_{t \in \mathrm{T}} \beta_j^{\,t} \left[\left(1-\delta_j\right) p_t^* + \delta_j P_t \left(q_t^j + q_t^{-j*}, q_{t-1}^j + q_{t-1}^{-j*} \right) - C_j^e \right] q_t^j \qquad \text{(J1–1)}$$

$$\text{s.t.} \quad q_t^j \le \overline{H_t^j}, \qquad \forall t \in \mathrm{T}, \qquad \text{(J1–2)}$$

$$q_t^j \ge 0, \qquad \forall t \in \mathrm{T}. \qquad \text{(J1–3)}$$

Players:
J_2 The U.S. separators

- **The U.S. separators connected to the BLM storage infrastructure**
  - They can store helium until the closure of the U.S. BLM



$$\underset{q_t^j, h_t^j, i_t^j, w_t^j, v_t^j}{\mathrm{Max}} \quad \Pi_j = \sum_{t \in \mathrm{T}} \beta_j^t \left[p_t^* q_t^j - C_j^e h_t^j - C_j^i i_t^j - C_j^w w_t^j - S\, v_t^j \right] \qquad \text{(J2–1)}$$

$$\text{s.t.} \quad h_t^j \le \overline{H_t^j}, \qquad \forall t \in \mathrm{T}, \qquad \text{(J2–2)}$$

Storage equations

$$q_t^j + i_t^j = h_t^j + w_t^j, \qquad \forall t \in \mathrm{T}, \qquad \text{(J2–3)}$$

$$v_t^j = v_{t-1}^j + i_t^j - w_t^j, \qquad \forall t \in \mathrm{T},\ v_0^j \text{ given}, \qquad \text{(J2–4)}$$

$$v_t^j = 0, \qquad \forall t \ge T_{BLM}, \qquad \text{(J2–5)}$$

$$q_t^j \ge 0,\ h_t^j \ge 0,\ v_t^j \ge 0,\ i_t^j \ge 0,\ w_t^j \ge 0, \qquad \forall t \in \mathrm{T}. \qquad \text{(J2–6)}$$

Players:
$\mathbf{J_3}$ The new players

- **These firms are capable of investing to further expand their future helium production**
  - But possible capacity expansions are limited by the deployment of LNG plants in these areas

$$\underset{q_t^j, k_t^j}{\text{Max}} \quad \Pi_j = \sum_{t \in \mathrm{T}} \beta_j^t \left[\left[\left(1-\delta_j\right) p_t^* + \delta_j P_t \left(q_t^j + q_t^{-j^*}, q_{t-1}^j + q_{t-1}^{-j^*} \right) - C_j^e \right] q_t^j - C_j^k k_t^j \right] \qquad \text{(J3–1)}$$

$$\text{s.t.} \quad K_t^j = K_{t-1}^j + k_t^j , \qquad \forall t \in \mathrm{T} ,\ K_0^j \text{ given,} \qquad \text{(J3–2)}$$

$$q_t^j \le K_{t-1}^j , \qquad \forall t \in \mathrm{T} , \qquad \text{(J3–3)}$$

$$K_t^j \le \overline{K_t^j} , \qquad \forall t \in \mathrm{T} , \qquad \text{(J3-4)}$$

$$q_t^j \ge 0 , \quad k_t^j \ge 0 , \qquad \forall t \in \mathrm{T} . \qquad \text{(J3–5)}$$

Solution strategy

- By definition, the vector $x^{\star} = \left(x_1^{\star}, \dots, x_j^{\star}, \dots, x_J^{\star}\right)$ is an open-loop Nash equilibrium of the WHM if no market participant has an incentive to unilaterally deviate from his equilibrium actions, given his opponents' actions, i.e.:

$$\Pi_j\left(x^{\star}\right) \geq \Pi_j\left(x_1^{\star}, \dots, x_{j-1}^{\star}, x_j, x_{j+1}^{\star}, \dots, x_J^{\star}\right), \quad \forall x_j \in \Omega_j, \ \forall j \in J,$$

- **Solution**
  - **The essence of the numerical approach is to find an equilibrium that simultaneously satisfies each market participant's KKT conditions for profit-maximization together with the demand equation and the market-clearing condition.**
  - **=> solving a Linear Complementarity Problem…**

Simulations

Four counterfactual scenarios

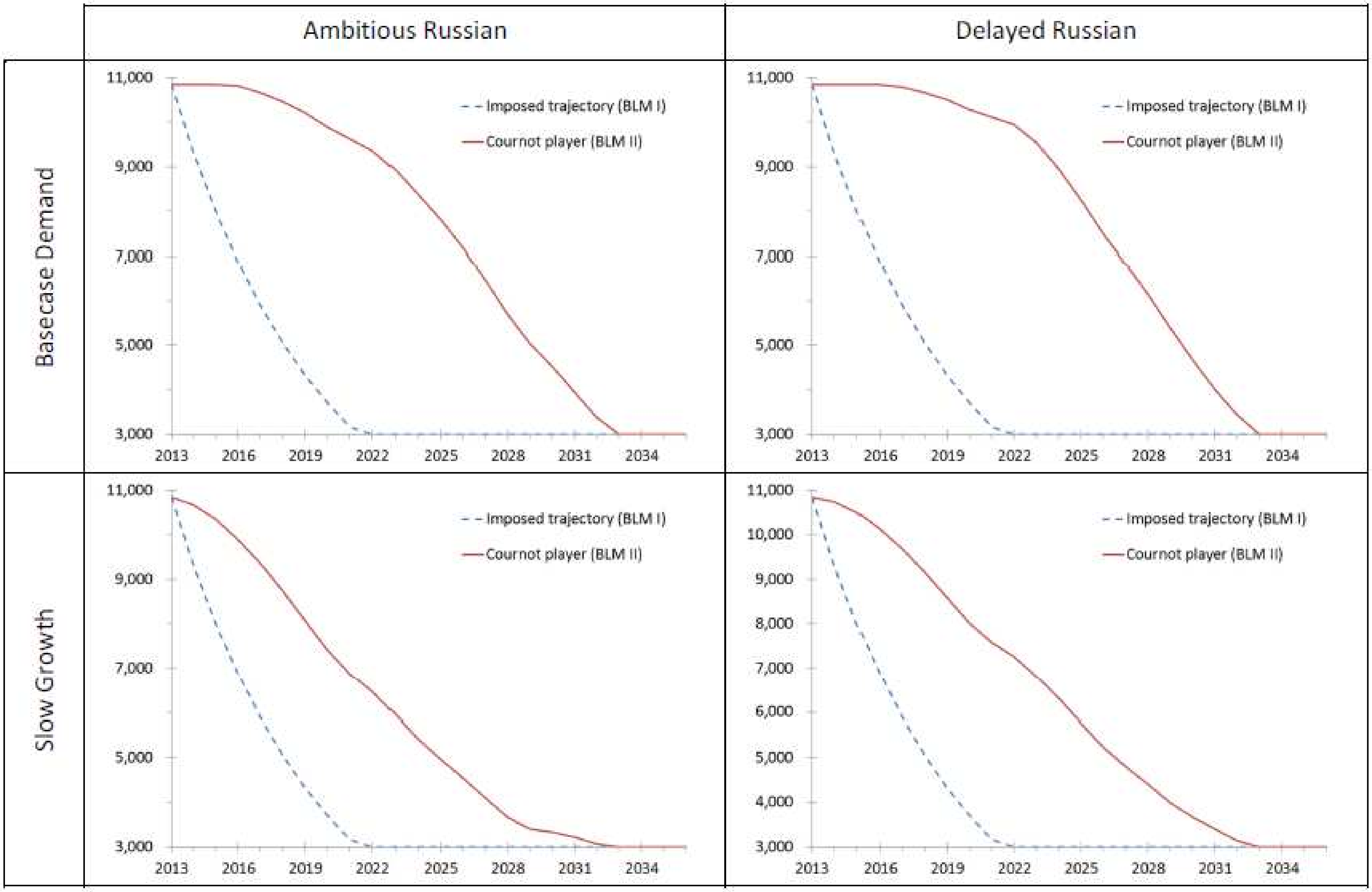
Four counterfactual scenarios

- **Demand**
  - **« base case »**
    - World GDP growth rate = +2.5% p.a.
  - **« slow growth » :**
    - World GDP growth rate = +1.5% p.a.
- **Russia's development**
  - **the "Ambitious Russian" (AR) trajectory**
  - **the "Delayed Russian" (AR) trajectory**

Table 1. Players

Type of player	Player	Posited Strategic Behavior
BLM	U.S. BLM	See Section 3.2
J_1	Australia	Cournot
	China	Price-taking
	Poland	Price-taking
	Colorado 1	Price-taking
	Kansas	Price-taking
	New Mexico	Price-taking
	Wyoming 1	Cournot
	Utah 1	Price-taking
J_2	Hugoton-Panhandle complex [a]	Price-taking
J_3	Algeria	Cournot
	Canada	Price-taking
	Iran	Cournot
	Qatar	Cournot
	Russia	Cournot
	South Africa	Price-taking
	Colorado 2	Cournot
	Wyoming 2	Cournot
	Utah 2	Price-taking

Figure 2. The BLM's remaining reserve at the end of the year (in MMcf)



Quantities & Prices

- **The BLM I strategy generates low prices during the early years**

Figure 3. Annual helium consumption (in MMcf)

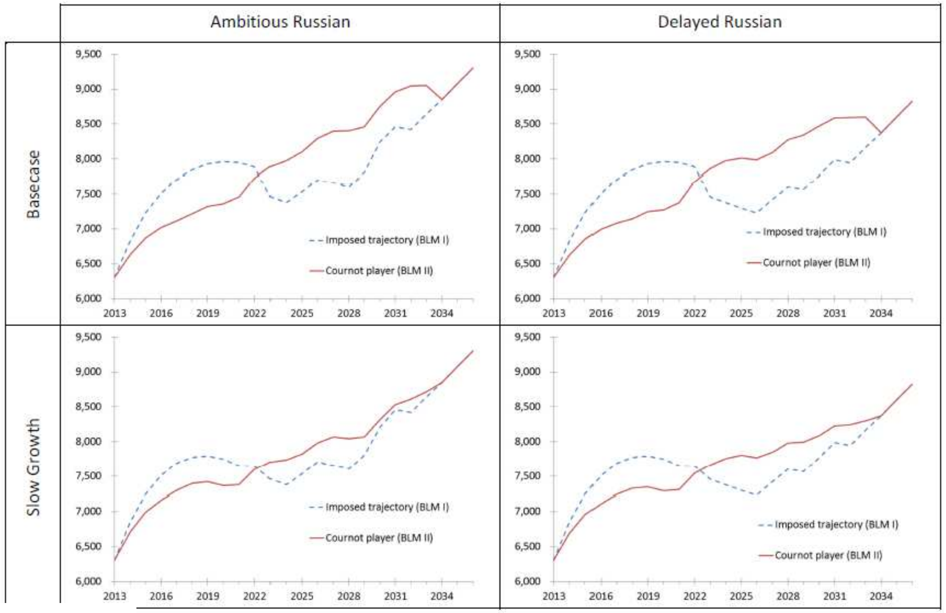
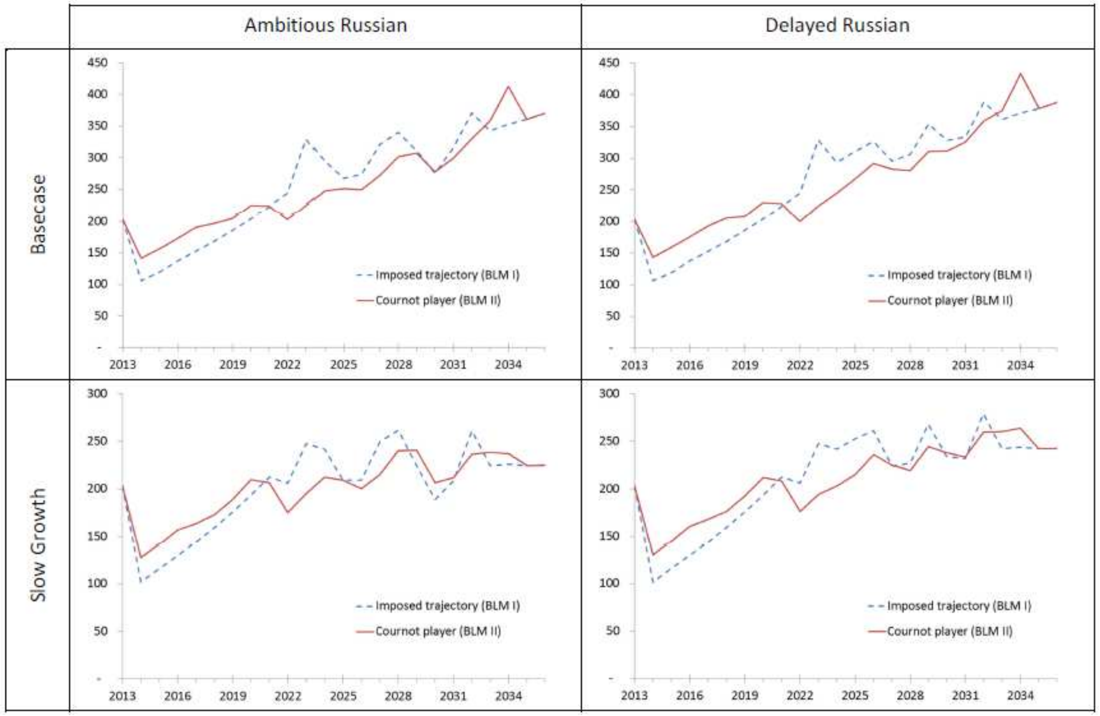


Figure 4. Equilibrium prices (in $/Mcf)



Side effects

- **Private storage**

& venting

Figure 5. Volume of storage owned by private producers at the end of the year (MMcf)

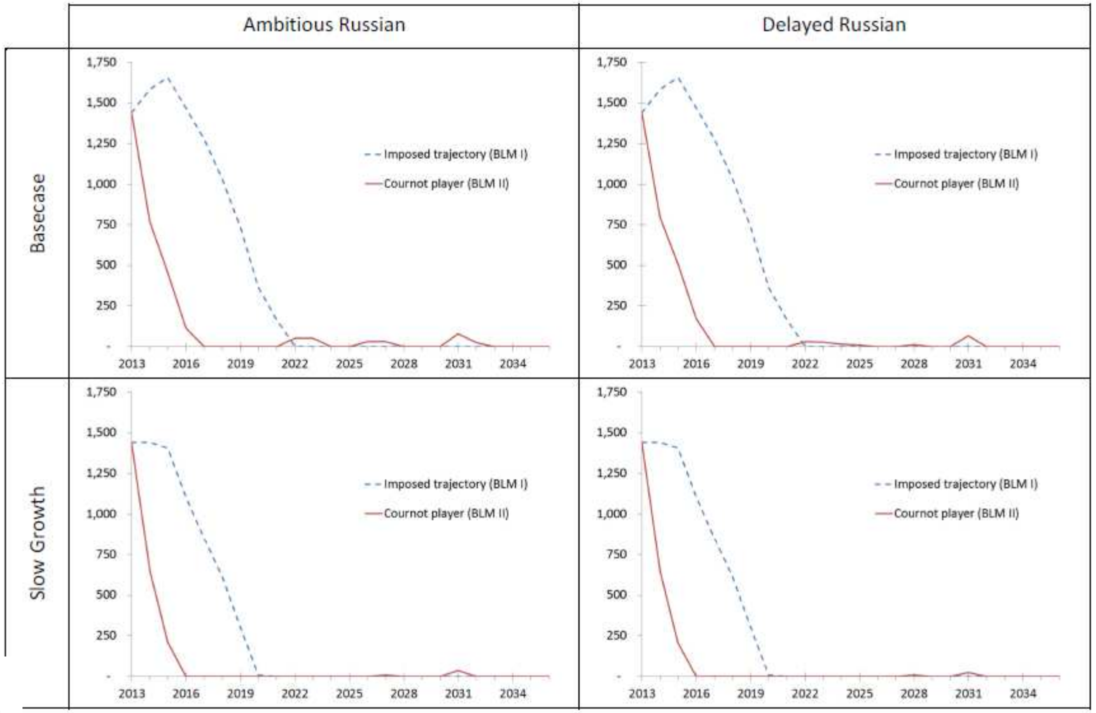


Table 2. Annual helium venting (in MMcf)

	Base-case demand		Slow growth scenario	
	Ambitious Russian	Delayed Russian	Ambitious Russian	Delayed Russian
Imposed trajectory (BLM Model I)				
Utah 1				
Year 1	160.0	160.0	160.0	160.0
Year 2	160.0	160.0	160.0	160.0
Year 3	160.0	160.0	160.0	160.0
Year 4	160.0	160.0	160.0	160.0
Wyoming 1				
Year 1	48.7	24.1	48.7	48.7
Total helium wasted	*688.7*	*664.1*	*688.7*	*688.7*
Cournot player (BLM Model II)				
Utah 1				
Year 1	160.0	160.0	160.0	160.0
Year 2	0.0	0.0	160.0	160.0
Year 3	0.0	0.0	0.0	0.0
Year 4	0.0	0.0	0.0	0.0
Wyoming 1				
Year 1	0.0	0.0	0.0	0.0
Total helium wasted	*160.0*	*160.0*	*320.0*	*320.0*

ote: A zero slack is observed in the other years and/or the other agents and has not been reported for the sake of brevity.

Market & social outcomes

Table 3. The total discounted surplus obtained by consumers and producers (million $2014)

Scenarios				Imposed trajectory (BLM I)	Cournot Player (BLM II)	Difference
Scenarios	Basecase demand	Ambitious Russian	Consumer Surplus	91,425.3	**92,759.0**	1,333.7
			BLM's Surplus	831.4	**1,263.7**	432.3
			US Producers' Surplus	8,290.0	**8,290.7**	0.7
			Foreign Producers' Surplus	**13,853.2**	13,613.0	-240.2
			Social Welfare	*114,399.9*	***115,926.3***	*1,526.4*
		Delayed Russian	Consumer Surplus	87,796.7	**88,968.1**	1,171.4
			BLM's Surplus	831.4	**1,337.1**	505.7
			US Producers' Surplus	8,641.7	**8,653.1**	11.4
			Foreign Producers' Surplus	**14,074.1**	13,851.5	-222.6
			Social Welfare	*111,343.9*	***112,809.8***	*1,465.9*
	Slow demand growth	Ambitious Russian	Consumer Surplus	**90,284.6**	89,815.0	-469.6
			BLM's Surplus	776.9	**986.7**	209.8
			US Producers' Surplus	6,134.8	**6,229.3**	94.5
			Foreign Producers' Surplus	**9,280.4**	9,137.4	-143.0
			Social Welfare	***106,476.6***	*106,168.5*	*-308.1*
		Delayed Russian	Consumer Surplus	**86,691.6**	86,639.6	-52.0
			BLM's Surplus	776.9	**1,015.5**	238.6
			US Producers' Surplus	6,483.9	**6,556.0**	72.1
			Foreign Producers' Surplus	**9,743.9**	9,575.7	-168.2
			Social Welfare	*103,696.4*	***103,786.8***	*90.4*

Note: For the sake of readability, the maximum values attained under each scenario are in bold.

Conclusions

Our findings call for a rapid modification of the rapid phase out imposed in the 2013 Act

1. **this extraction path does not maximize the total financial return to the U.S. federal budget,**
   - *which contradicts one of the policy objectives stated in the 2013 Act.*
2. **It does not help to conserve the resource**
   - *that policy, and the low prices it generates during the early years, systematically induces a net waste of helium.*
3. **A higher level of social welfare could be achieved in 3 out of the 4 scenarios examined in this paper.**

Thank you!