Some Economics of Seasonal Gas Storage

Corinne Chaton, *EdF and University of Alberta*

Anna Cretì, *Università Bocconi-IEFE*

Bertrand Villeneuve, *Université de Tours and CREST*

Fourth Toulouse Conference on the Economics of the Energy Markets

ROADMAP

- Some data on the US Gas Industry
- Motivation of the paper
- Related literature

- The model
  - competitive storage
  - limit cycles
  - exhaustible supply

- Policy analysis: storage and domestic interest

- Estimation of the model
  - Evaluation of the impact on storage, prices and welfare of the various policies evoked

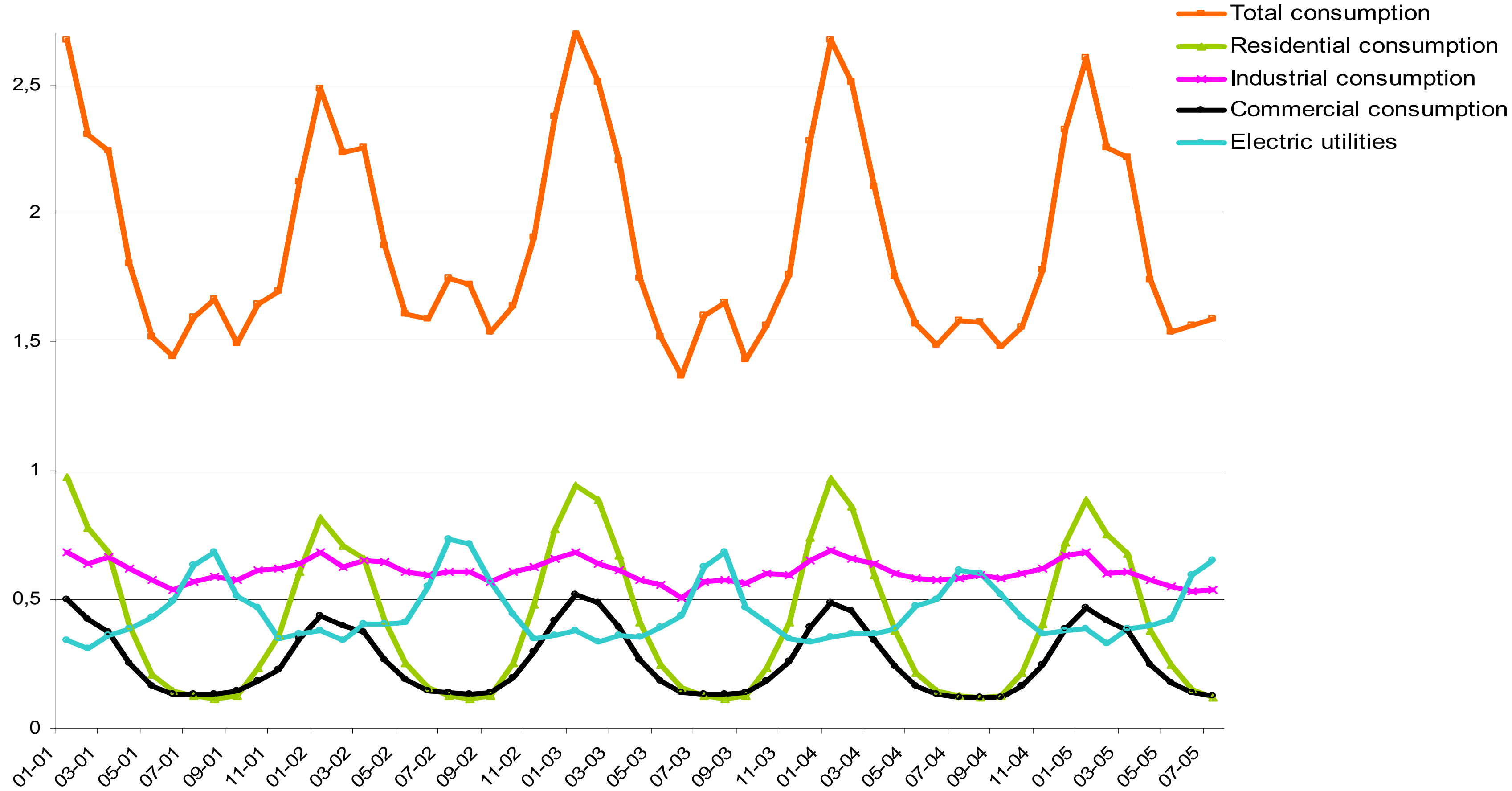
- Conclusions

The US Gas Industry

- US: major player in the gas industry at the world level
  - Second producer, first importer
- Production sector: rather competitive
  - There are about 8,000 gas producers, ranging from small operators to major international oil companies
  - The five largest producers account for around 25% of total US output.
- Data reliable and publicily available (main source: EIA)

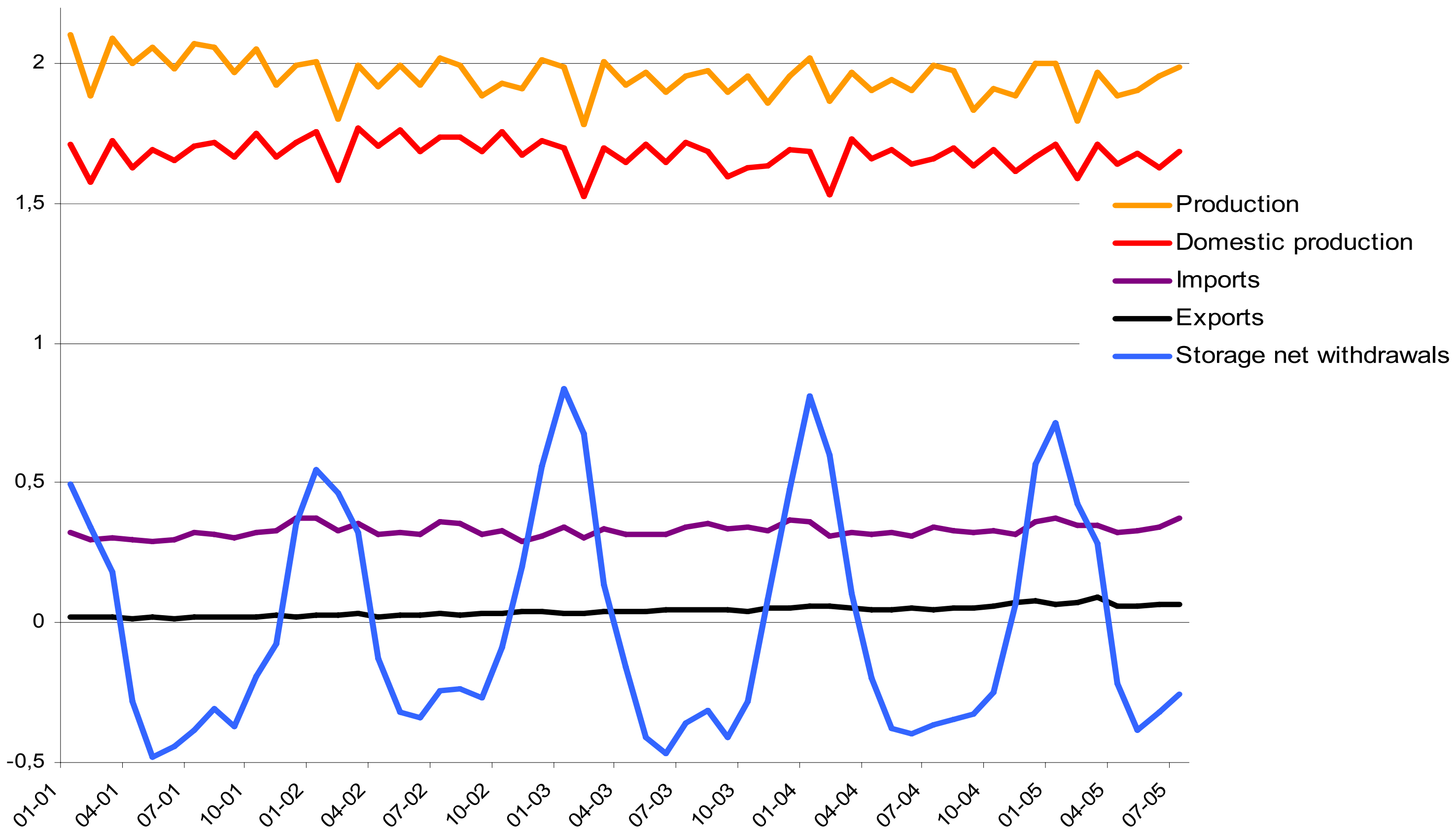
Consumption

- Weather is the primary driver of gas consumption.
- Electric utilities' consumption is counter-cyclical, but overall the yearly cycle alternates between winter peaks and summer troughs



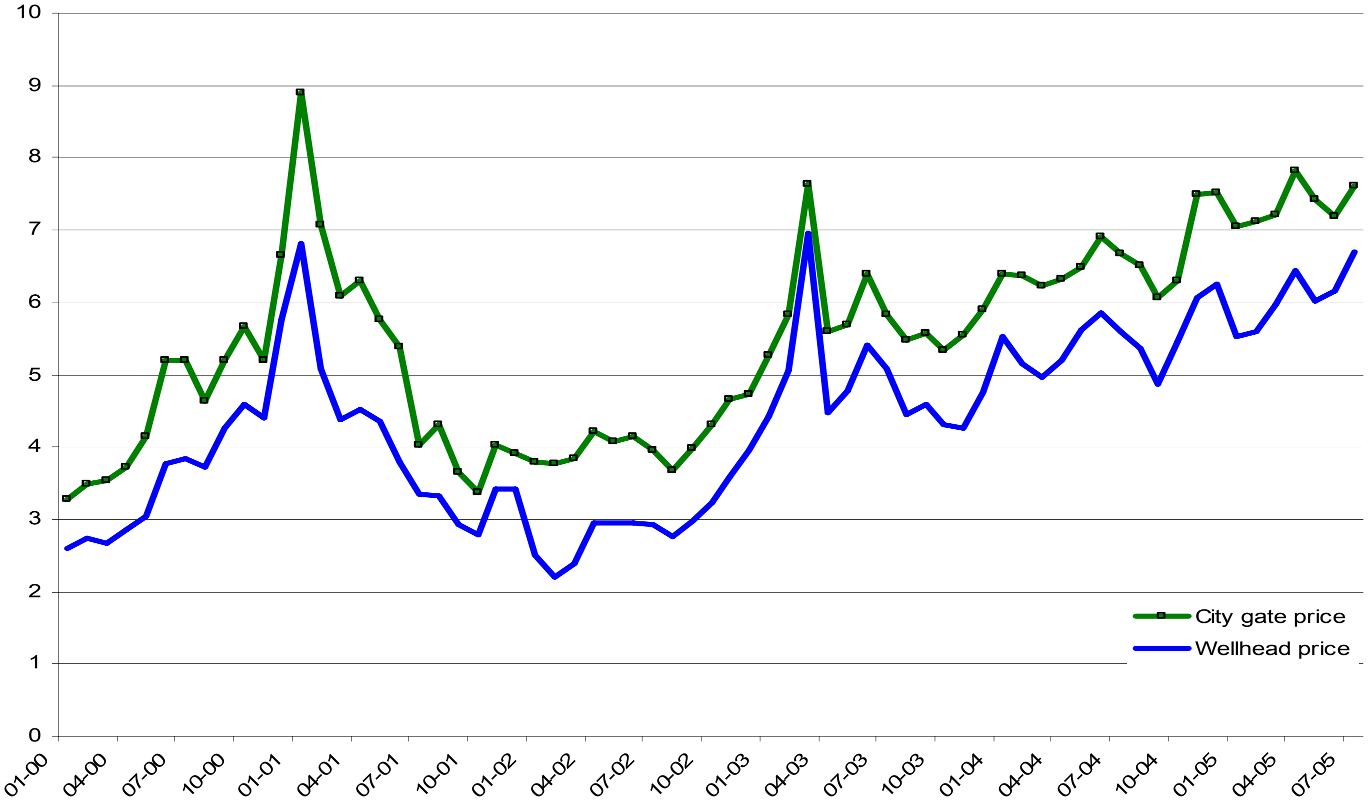
Production

- Extraction from gas wells as well as imports are flat
  - storage plays a key role in balancing seasonal and short-term loads



Prices

- Seasonality of the price is hardly visible
  - Over the last twenty years, the average price over the winter is significantly higher than the average price during the previous summer.



Motivation of the paper

- Our paper aims at analyzing in a coherent framework the gas industry by focusing on the economics of seasonal storage, including long-run trends and the impact of public policies.

  - Marked seasonal patterns and considerable storage activity deserve specific theoretical development.

    - years are split into two seasons;
    - stockpiling in summer and withdrawal in winter is shown to be consistent with random shocks and with exhaustibility of natural gas.

Related literature

Storage

- “Supply of storage" models (Kaldor, 1939, Working, 1948, Brennan, 1958)
  - role of storage when the economy experiences unexpected shocks;
  - convenience yield: an embedded timing option, whose value is null for predictable variations like seasonal effects

Seasonal storage

- Seasonal effects have been considered as a theoretical issue that can be treated in general purpose models (Brennan, 1960, Williams and Wright, 1991, Routledge et al., 2000).
- Few exceptions: Samuelson (1966), Pyatt (1978), Lowry et al. (1987)

Renewed interest for energy markets:

- Pindyck (2002) : structural approach to various energy commodities markets that might fail to capture important phenomena linked to demand flexibility.
- Modjtahedi and Movassagh (2005): seasonal effects have been filtered in a way that offers no guarantee on the consistency of the estimates.
- Uría and Williams (2005): seasonal effects limit the responsiveness of injection decisions in California to the futures market.
- Byers (2006), Mu (2007), Serletis *et al.* (2007): finance approach.

in all these empirical papers, seasonal effects are more evoked as an encumbrance than as an object of study

Public policies

- Buffer stocks used by public agencies to stabilize prices (Waugh, 1944, Oi, 1961, Massel, 1969).
- Trade models (for example, Hueth and Schmitz, 1972, Just et al., 1977, Devadoss, 1992): public market interventions to protect national interests from imported price fluctuations.
- Williams and Wright (1991): very complex dynamic stochastic models that make the characterization of the effectiveness and efficiency of public interventions quite rough.

The model: definitions and assumptions

- Time is discrete and infinite.
- A year is composed of two six-month periods; it starts with summer *S* and ends with winter *W*.
- A period is denoted by $y\sigma$ for year and season.
- The year after *y* is denoted $y+1$, whereas the season that follows $y\sigma$ is $n(y\sigma)$ where *n* is for next, e.g. $n(yS)=yW$ and $n(yW)=(y+1)S$
- $n^m(y\sigma)$ and $n^{-m}(y\sigma)$ with *m* a positive integer, indicate the *mth* period forward and backward respectively.

- $Cons_{y\sigma}[\cdot]$: consumption strictly decreasing with respect to the price function at period $y\sigma$

- $Prod_{y\sigma}[\cdot]$: domestic and foreign production (imports) at period $y\sigma$; non-decreasing with respect to the price
  - for all $y\sigma$, $Cons_{y\sigma}[\cdot]$. and $Prod_{y\sigma}[\cdot]$ cross only once for some $p^{0}_{y\sigma}>0$

- Excess supply function

$$\triangle_{y\sigma}[\cdot] = \mathrm{Prod}_{y\sigma}[\cdot] - \mathrm{Cons}_{y\sigma}[\cdot].$$

- To characterize the difference between summer and winter, we only need $p^{0}_{yw} \geq p^{0}_{yS}$ and $p^{0}_{yw} \geq p^{0}_{(y+1)S}$

  - These weak restrictions stress the importance of seasonal effects (higher prices in winters) without assuming that the yearly cycle is repeated over time

- Storage is assumed to be a competitive activity with constant returns to scale up to the maximum capacity *K.*
  - the unit storage charge is $\kappa_{y\sigma} \geq c$ = marginal storage cost
  - the interest rate from one period to the next is *r*.

- With positive storage $G_{y\sigma}$, there are 2 fundamental equations:

1. the *no-arbitrage condition* $$G_{y\sigma} > 0 \Rightarrow \frac{p_{n(y\sigma)}}{1+r} = p_{y\sigma} + \kappa_{y\sigma}.$$

2. *conservation of matter* $$\triangle_{y\sigma}[p_{y\sigma}] = G_{y\sigma} - G_{n^{-1}(y\sigma)}.$$

- Transversality Condition $$\lim_{i \to +\infty} \frac{p_{n^i(y\sigma)}}{(1+r)^i} = 0.$$

Competitive equilibrium

Definition 1 (Competitive Equilibrium) *A competitive equilibrium starts in period $0S$, with some stocks G_{0S}; it is a sequence of prices $p_{y\sigma}, \kappa_{y\sigma}$ with a storage policy $G_{y\sigma} \geq 0$ such that, for all $y\sigma$ after $0S$*

$$\begin{cases} \text{if } \frac{p_{n(y\sigma)}}{1+r} < p_{y\sigma} + c \text{ then } G_{y\sigma} = 0; \\ \text{if } \frac{p_{n(y\sigma)}}{1+r} = p_{y\sigma} + c \text{ then } 0 \leq G_{y\sigma} \leq K; \\ \text{if } \frac{p_{n(y\sigma)}}{1+r} = p_{y\sigma} + \kappa_{y\sigma} \text{ with } \kappa_{y\sigma} > c \text{ then } G_{y\sigma} = K; \\ \triangle_{y\sigma}[p_{y\sigma}] = G_{y\sigma} - G_{n^{-1}(y\sigma)}; \\ \lim_{i \to +\infty} \frac{p_{n^i(y\sigma)}}{(1+r)^i} = 0. \end{cases}$$

- Price-taking behavior of the agents, strictly increasing excess supply functions, linearity of the storage technology: the competitive equilibrium maximizes total surplus

- If the economy starts with huge reserves, it will experience a drainage phase of several years and will then follow the cyclical dynamics.
- Prices start low and increase steadily season after season (no-arbitrage eq.).
- Once the stocks are exhausted, the seasonal dynamics consists of stockpiling in summer and depleting reservoirs in winter

  $\Rightarrow$ conservation of matter and the no-arbitrage condition give the unique solution (p_{yS},p_{yW})

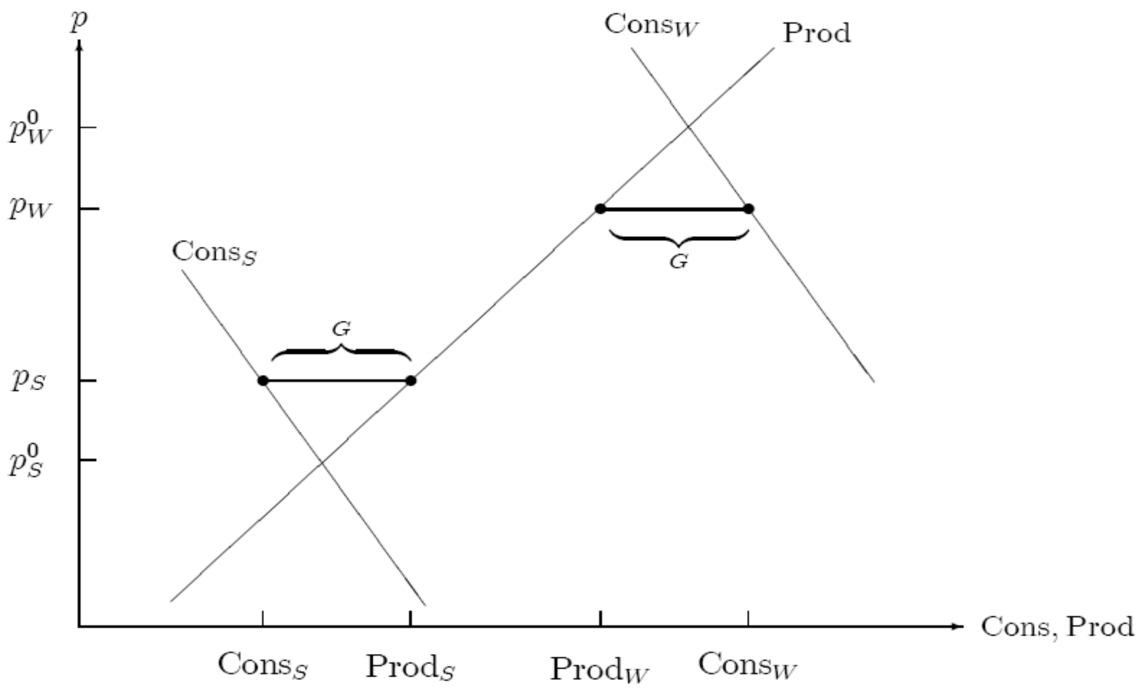


Figure 4: Unconstrained Competitive Storage.

Transition and limit cycles

Restricting the rate at which supply and demand change over time, we prove the convergence to seasonal pattern

- *N[p]≡(1+r)(p+c)* denotes the price attained after one season of unconstrained positive stockholding.
  - Consistently, $N^m[p]$ denotes the price attained after *m* seasons of uninterrupted stockholding.

Definition 2 *The economy is said to be regular if for all season σ, all year y and for all price p*

$$\Delta_{(y+1)\sigma}[N^2[p]] \geq \Delta_{y\sigma}[p].$$

Proposition 1 (Convergence to seasonal pattern) *If the economy is regular, then in any competitive equilibrium, storage becomes* seasonal *(stocks are empty each year at the end of winter) in finite time and remains so.*

Extension 1: shocks

Idea: if the shocks are limited (support is bounded), then there is no possible state of the economy in which speculators store at the end of the winter for the coming summer

- Assume that season specific shocks impact the excess supply function (i.e. demand and supply) and that this shock is known only at the beginning of the season.
  - decisions taken one season before were ignorant of the magnitude of the current shock, whereas decisions taken during the season takes it into account

- *First step*: solve the equilibrium in which the year starts and finishes with empty stocks.

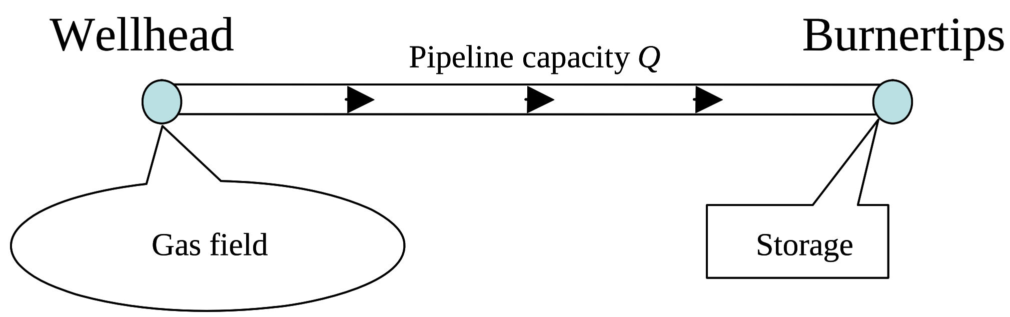
- *Second step*: search for conditions under which storage from winter to summer is never desirable in any realization of the possible states of nature.

  $\Rightarrow$stockout at the end of winters is systematic

Extension 2: Cycles and trends with exhaustible supply

- Natural gas is an exhaustible resource.

- Production is determined by intertemporal arbitrage as exposed in Hotelling (1931) and by the transportation capacity from gas fields to the consumers.



- We show that the equilibrium is never stationary (except if production and consumption become null) and the economy crosses three significantly different phases:

  - *the beginning* (low prices): the economy follows a trend at the wellhead, but is cyclical at the consumption place; the pipeline is congested; positive storage
  - *the transition* (intermediate prices): as in the previous case, but with the pipeline congested in winter only
  - *the end* (high prices): prices grow more slowly at B than at Wh; no storage - only imports
    - A slightly more realistic description would be a model in which fields are increasingly costly or increasingly far from the consumption region as depletion goes on.

- The *first phase* is particularly relevant for economies that depend highly on energy imports. Price observed at the local level may well be stationary for a while, even if the world price follows the Hotelling rule.

Policy Analysis

- As from 1978, in the US, progressive market liberalization
- Energy Policy Act of 2005
  - moderating the recurrence and severity of "boom and bust" cycles while meeting increasing demand at reasonable prices
  - proposals to ensure adequate domestic energy supply and infrastructure.
- Public interventions
  - Gas price cap (temporary or emergency measure)
  - Excise tax

Price cap

Price ceilings succeed in reducing prices, but storage is discouraged.

Proposition 2 *With a non-extreme price ceiling* ($(1+r)\cdot(p_S^0+c) < \overline{p} < p_W$),

1. *Storage* $\overline{G}$, *seasonal prices* $\overline{p}_W = \overline{p}$ *and* $\overline{p}_S = \frac{\overline{p}}{1+r} - c$ *decrease as* $\overline{p}$ *decreases; consumers are rationed in winter;*

2. *A price cap slightly below the unconstrained competitive winter price increases consumers' surplus.*

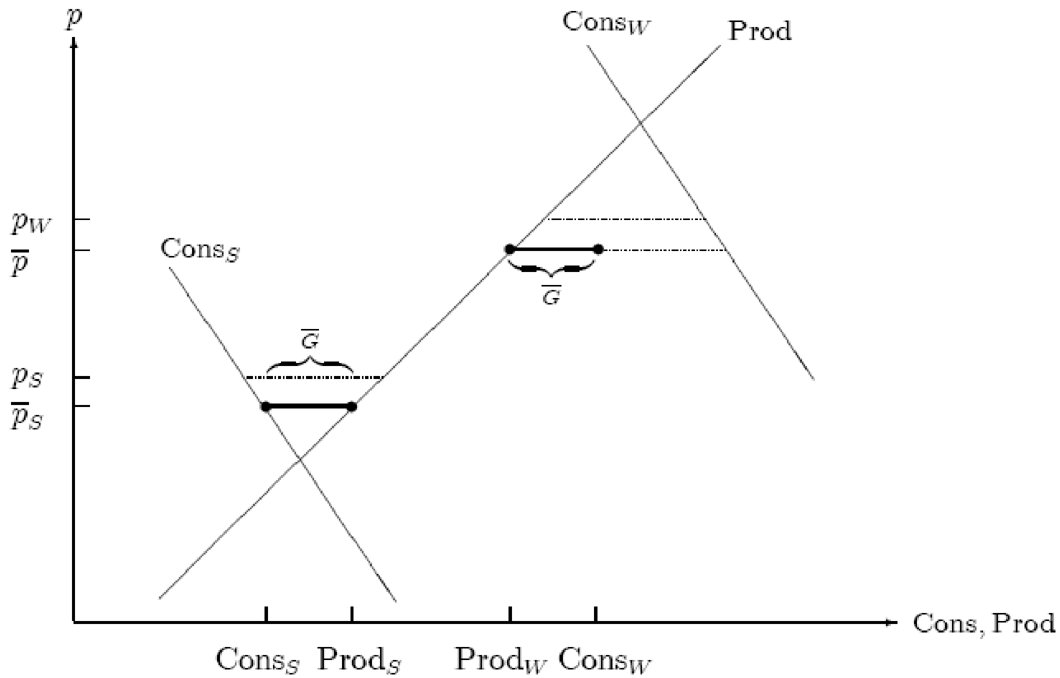


Figure 6: Competitive Storage with Price Ceiling

Optimal allocation

We characterize the optimal policy in the interest of the residents

- The government maximises the intertemporal consumer surplus

$$U_S[q_S^C] - m_S + \frac{U_W[q_W^C] - m_W}{1+r},$$

  - U_S and U_W are increasing and concave utility functions
  - q_σ^C season σ gas consumption
  - m_σ season σ expenditure.

- We distinguish domestic and foreign production (imports)

- Storage is assumed to be domestic.

- At the optimum:
  - consumers' marginal utilities equal domestic marginal costs;
  - consumers' intertemporal MRS satisfies the no-arbitrage equation
  - each period, the government exerts monopsony power on foreign producers.

Proposition 3 *Compared to the competitive allocation, consumption, domestic production and imports at each period decrease. There are economies in which storage is smaller and others in which it is greater.*

$\Rightarrow$ Storage may be greater with the optimal policy than under laissez-faire.

- The allocation maximizing domestic surplus can be sustained with tariffs on imports each season

$$\begin{aligned}
&\text{Domestic prices:} && p_S = U'_S[q_S^C] = C'_S[q_S^D], \\
& && p_W = U'_W[q_W^C] = C'_W[q_W^D]. \\
&\text{Import prices:} && p_S^I = p_S^I[q_S^I], \\
& && p_W^I = p_W^I[q_W^I]. \\
&\text{Tariffs:} && \tau_S = p_S^{I\prime}[q_S^I]q_S^I > 0, \\
& && \tau_W = p_W^{I\prime}[q_W^I]q_W^I > 0.
\end{aligned}$$

Tariffs are just the wedge between domestic and import prices.

(natural gas imported from Algeria and other sources must still pay a small merchandise processing fee to the US custom services!)

Estimation of the model

- Based on the stochastic version of the model
- The observed variables per season are:

$\Delta_{y\sigma}$: variation of the stock;

$p_{y\sigma}$: average gas price;

$Y_{y\sigma}$: GDP;

$T_{y\sigma}$: average temperature.

where season average temperature and GDP are exogenous controls

$$\mathbf{Z}_{yW} = (T_{yW}\ Y_{yW})' \qquad \mathbf{Z}_{yS} = (T_{yS}\ Y_{yS})'$$

- The equilibrium involves, for each year, four equations:

  1. excess supply in summer
  2. excess supply in winter
  3. price arbitrage
  4. annual balance.

- We use the following linear specification

$$
\begin{aligned}
\Delta_{yS} &= \beta_1^0 + \beta_{1p} p_{yS} + (\beta_{1T}\ \beta_{1Y})\mathbf{Z}_{yS} + \varepsilon_{y1} \\
\Delta_{yW} &= \beta_2^0 + \beta_{2p} p_{yW} + (\beta_{2T}\ \beta_{2Y})\mathbf{Z}_{yW} + \varepsilon_{y2} \\
Ep_{yW} &= \beta_3^0 + \beta_{3p} p_{yS} \\
\Delta_{yW} &= \beta_4^0 + \beta_{4\Delta}\Delta_{yS} + \varepsilon_{y4}
\end{aligned}
$$

- We test the following restrictions:

1. Total annual excess supply is null on average: $\beta_4^0 = 0$ and $\beta_{4\Delta} = -1$
2. Weak interannual effects: $\Delta_{yS} + \Delta_{yW}$ is not correlated with $\Delta_{(y+1)S}$
3. Higher current prices increase excess supply: $\beta_{1p} \geq 0$ and $\beta_{2p} \geq 0$
4. Higher temperatures in summer decrease excess supply and higher temperatures in winter increase excess supply

   $\beta_{1T} \leq 0$ and $\beta_{2T} \geq 0$
5. GDP affects demand and then has a negative impact on excess supply $\beta_{1Y} \leq 0$ and $\beta_{2Y} \leq 0$
6. Indirect estimation of *r and c:* r as $\widehat{\beta}_{3p} - 1$ c as $\widehat{\beta}_3^0 / \widehat{\beta}_{3p}$

- A "year" *y* is composed of two six-month periods and starts with the "summer" (accumulation period) and finishes with the "winter" (drainage period).

- Using monthly data, we calculated the two consecutive six-month periods that maximize the variability of the stock variation (smoothing the cycle the least possible) over the sample.

- The best aggregates we find are 2nd and 3rd quarters for the summer, 4th quarter and subsequent 1st quarter for the winter.
  - Price and temperature averages as well as GDP are calculated for the same periods.

- The dataset covers April 1986 (year in which deregulation started) to March 2005.

- Winter price is modelled as follows: $p_{yW} = \beta_3^0 + \beta_{3p} p_{yS} + \varepsilon_{y3};$

- We use 3SLS

- Estimation results:
  - Test 1 (annual cycle): passed in a first round $\beta_4^0 = 0$ and $\beta_{4\Delta} = -1$
  - Test 2 (low catch up effects): correlation -.299 and standard error .185 (prob of .126 under the null hypothesis)
  - Tests 3, 4 and 5 (impact of prices, temperature and GDP) are passed.
  - The estimates for the interest rate is *r=10%;* no significant evidence of the impact of storage unit cost

$\Rightarrow$ Overall, the theory we exposed is not contradicted by the data.

Equation	Coeff.	St. Err.	z	$P > \|z\|$
$\Delta_{yS} = \cdots$				
Constant	1.57×10^7	6.82×10^6	2.30	.022
p_{yS}	2.50×10^5	1.46×10^5	1.72	.086
Y_{yS}	−35.4	93.2	−0.38	.705
T_{yS}	-2.29×10^5	1.05×10^5	−2.18	.029
$\Delta_{yW} = \cdots$				
Constant	-5.51×10^6	1.78×10^6	−3.08	.002
p_{yW}	2.58×10^5	1.10×10^5	2.33	.020
Y_{yW}	−336	91.6	−3.66	.000
T_{yW}	1.35×10^5	4.76×10^4	2.84	.005
$p_{yW} = \cdots$				
Constant	−.168	.181	−0.93	.351
p_{yS}	1.10	.068	1.47*	.144*

*Tested against 1.

Table 1. Core equations of the seasonal storage model.

Evaluation of welfare effects of price policies

- Estimation of domestic production and net imports
  - Productive capacity: number of wells

- Sample: from 1993 to 2005, the period between 1986 and 1992 having a strong influence on the estimates.
  - In accordance with economic intuition, the implied price elasticity of demand is negative and domestic production appears to be less price-elastic than imports.

- We reason on the average year (sample average temperature, GDP, number of wells).
  - Linear demand and supply functions are integrated to give linear-quadratic utility and cost functions.

- Three scenarios:

1. Pure competition.

2. The optimal price cap for residents (consumers and domestic producers) with winter efficient rationing

3. The residents' optimum: optimal tariffs, associated equilibrium prices and quantities (no rationing)

- The total maximum surplus is set by convention to 0, other surplus are given as differences with the maximum.

- The optimal price cap is overall less distortionary than optimal tariffs
  - these latter are nevertheless, by definition, more attractive for the residents.
- The optimal tariffs are very large (about $7 per MMcf) and do more than halve the import price.
  - This effect is due to the relative inflexibility of imports.
- The price cap discourages storage, as predicted, and more than tariffs, whose effect is ambiguous in theory.

Scenario	Perfect comp.	Opt. price cap	Opt. tariffs
Total surp./year	0	−1.06	−1.84
Dom. surp./year	−12.7	−11.5	−10.4
Stocks (10^6)	1.65	1.47	1.60
Summer			
Import price	2.49	1.29	1.23
Domestic price	2.49	1.29	7.51
Tariff	0	0	6.28
Winter			
Import price	2.56	1.6	0.91
Domestic price	2.56	1.6	8.08
Tariff	0	0	7.16

Table 2. Comparison of three price policies.
Quantities in MMcf, prices in $/MMcf, surpluses in M$.

Conclusions

- The model enabled us to expose a comprehensive view of the seasonal natural gas markets.

- The estimates based on the US data over 1986-2005 were used to calculate the potential surplus gains the country could achieve.

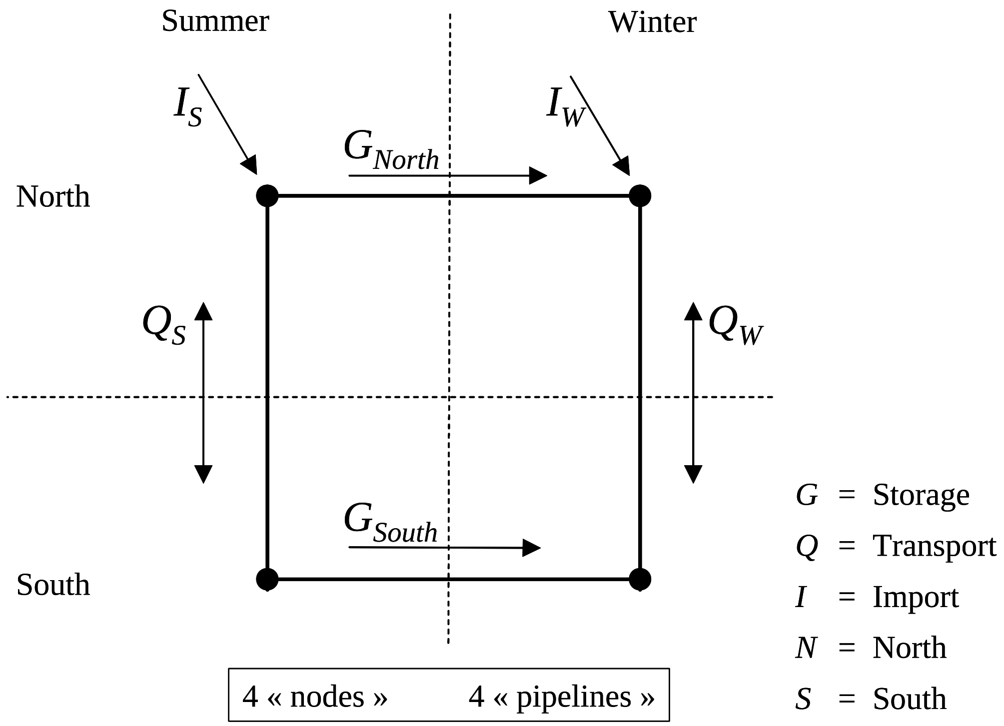
- Given the relatively low values found and the uncertainty attached to the parameters, no intervention through tariffs is a defensible policy.
  - This is in line with the current US policy.

    - Gas has typically been very lightly taxed compared to oil, “not only because it is not much used in transport but also to encourage a shift on dependence away from oil” (Newbery, 2005).

    - When a state wants to exert monopsony power, it only distorts import price leaving unaffected the national ones.

Extensions

- Our model is focused on liberalized gas markets, but it can be used as a building block when one considers regulatory issues such as
  - access to storage (allocation of scarcity rents)
  - transportation charges and nodal prices.



Descriptive Statistics

Variable	Unit	Mean	Std. Dev.	Min.	Max.
GDP_S	B$	8313	1439	6262	10846
GDP_W	B$	8317	1436	6265	10838
Wells	#	307129.7	49949.19	241527	401480
T_S	°F	62.77842	.6637795	61.57	63.88
T_W	°F	44.41	.145406	41.97	46.71
Δ_S	MMcf	1638388	325292.7	1160000	2262996
Δ_W	MMcf	−1649048	294352.6	−2323528	−1163000
Dom. prod. S	MMcf	9331938	621662	7970839	1.01×10^7
Dom. prod. W	MMcf	9600006	303795	8898230	1.01×10^7
Net imp. S	MMcf	1282275	453669	469932	1930174
Net imp. W	MMcf	1164139	505577	261408	1819766
p_S	$/Mcf	2.46	1.13	1.46	5.42
p_W	$/Mcf	2.53	1.22	1.56	5.57

Table 3. Descriptive statistics.

Note: MMcf = one million cubic feet, Mcf = one thousand cubic feet. GDP in annual value.

A.5 Production and imports

Equation	Coeff.	St. Err.	z	$P > \|z\|$
Summer dom. prod.				
Constant	8.60×10^6	9.18×10^5	9.37	.000
p_{yS}	-1.40×10^5	1.27×10^5	-1.10	.280
Wells	4.59	3.66	1.25	.217
Summer net imp.				
Constant	1.05×10^6	1.44×10^5	7.29	.000
p_{yS}	2.08×10^5	4.66×10^4	4.46	.000
Winter dom. prod.				
Constant	1.08×10^7	6.47×10^5	16.71	.000
p_{yW}	9070	8.47×10^4	0.11	.915
Wells	-3.18	2.58	-1.23	.226
Winter net imp.				
Constant	1.19×10^6	1.31×10^5	9.09	.000
p_{yW}	1.92×10^5	4.03×10^4	4.78	.000

Table 4. Domestic production and imports.