How do US natural gas producers react to price changes?

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Motivation

- 'shale revolution'
- increasing demand for natural gas (in particular Asia)
- natural gas exports from the US
- ...

$\Longrightarrow$ **What is the supply responsiveness of producers to changes in prices?**

Contribution

- existing evidence on supply elasticities over the past years limited, results vary in an enormous range
- input for modelling exercises, useful for regulators, relevant for emission and pollution reduction discussion
- estimate the aggregate natural gas supply response to prices in a competitive fuel market

The Bigger Picture

International Energy Resource Markets under Climate Constraints - Strategic Behavior and Carbon Leakage in Coal, Oil and Natural Gas Markets

- Fossil resources continue to remain important in the worlds energy systems until 2050. Regional climate policies cannot mitigate the global upward trend due to large share of growing Asia.
- Supply-side climate policies require multilateral coordination in order to be effective.
- Fossil fuel consumers can use domestic renewables and energy efficiency strategically to increase security of supply and reduce GHG emissions.

Agenda

1. Literature review
2. Data and empirical strategy
3. Results

Natural gas supply elasticities

Study	Period	Sample Data	Elasticity
Erickson (1971) *new discoveries, regulation*	1946-1959	US Cross sectional time series	0.69(L)
Barret (1992) *elasticities of supply*	1960-1990	US Annual time series	0.014
Dahl (1992) *price elasticity of reserves, cost*	1986-1989	US Cross sectional time series	0.40(L)
Chermak (1995) *natural gas from tight sands, cost*	1988-1990	US Cross sectional time series	1.05 to −1.92
Krichene (2002) *price elasticity of supply*	1918-1999	Worldwide Annual time series	0.6
	1918-1973	Worldwide Annual time series	0.28(L)
	1973-1999	Worldwide Annual time series	0.8(L)
Arora (2014) *price elasticity of supply, allowing for a shale gas boom break in data*	1993-2013	US Monthly time series Quarterly time series	 0.3 to 0.5(L) 0.4 to 0.5(L)

(L) indicates a long-run estimate

- demand side: Dahl C. (2010): $>$ 1.900 references/950 (electricity, oil)
- supply side: Dahl, C. & Duggan, T. (1996): 48 studies (3)

Empirical Specification

Economic Model

natural gas supply = f(natural gas price, price of substitute energy source, working gas in storage, natural gas drilling activity, season of the year)

$$q = f(P_G, P_S, S, D, season)$$

we use publicly available monthly data (EIA, FRED, NCDC) from Aug 1987 to Dec 2012 (n=305)

Empirical Specification

Econometric Model: ARDL

$$q_0 = \alpha_0 + \sum_{j=1}^{a} \alpha_j q_{t-j} + \sum_{j=0}^{b} \beta_j P_{Gt-j} + \sum_{j=0}^{c} \zeta_j P_{St-j} + \sum_{j=0}^{d} \delta_j S_{t-j}$$

$$+ \sum_{j=0}^{e} \eta_j D_{t-j} + \theta_1 summer + \theta_2 winter + \theta_3 spring + \nu_t$$

q_t: $(Tx1)$ vector of the dependent variables
P_{Gt}, P_{St}, S_t, D_t: $(Tx1)$ explanatory variables
α_0: intercept
$\beta_j, \zeta_j, \delta_j, \eta_j$: scalars of coefficient
ν_t: $(Tx1)$ vector of disturbances

Empirical Specification

Econometric Model: ECM

$$\delta q_0 = \alpha_0 + \alpha_1^* q_{t-1} + \beta_j^* P_{Gt-1} + \zeta_j^* P_{St-1} + \delta_j^* S_{t-1} + \eta_j^* D_{t-1}$$

$$+\beta_0^* \Delta P_{Gt} + \zeta_0^* \Delta P_{St} + \sum_{j=1}^{a-1} \tau_j \Delta q_{t-j} + \sum_{j=1}^{b-1} \pi_j \Delta P_{t-j}$$

$$+ \sum_{j=1}^{c-1} \Phi_j \Delta P_{St-j} + \sum_{j=1}^{d-1} \delta_j \Delta S_{t-j} \sum_{j=1}^{e-1} \eta_j \Delta D_{t-j}$$

$$+\theta_0 summer + \theta_1 winter + \theta_2 spring + \nu_t$$

where the cointegration relationship defined as:

$$\alpha_1^* q_{t-j} + \beta_1^* P_{Gt-1} + \zeta_1^* P_{St-1} + \delta_1^* S_{t-1} + \eta_1^* D_{t-1} = 0$$

Elasticities

- interested in estimated coefficients β_0 and ζ_0 in the ARDL
- β_0 short-run own price elasticity of supply
- long-run elasticities dervied from long-run equation
- ζ_0 is the cross-price elasticity of supply between crude oil and natural gas
- long-run price elasticity of supply for the ARDL model is

$$LRM_{ARDL} = \frac{\sum_{j=0}^{b} \hat{\beta}_j}{1 - \sum_{j=1}^{a} \hat{\alpha}_j}$$

- can also be derived from ECM

$$LRM_{ECM} = \frac{\hat{\beta}_1^*}{\hat{\alpha}_1^*}$$

Descriptive Statistics

Variable	Description	Obs	Mean	Std. Dev.	Min	Max	Unit of measurement
q	Natural gas supply	305	53584	4986	39632	65169	million cubic meters
$\log q$		305	10.88	.09	10.58	11.08	
$prod$	Domestic Natural Gas production	305	47336.16	4406.38	37699	61363	million cubic meters
$logprod$		305	10.76	.09	10.54	11.02	
PG	Real natural gas	305	2.3	0.85	0.77	5.18	US Dollars per MBTU
$\log PG$	wellhead price	305	0.77	0.35	-0.27	1.64	
PS	Crude oil price (WTI)	305	71.3	77.0	11.29	361.82	US Dollars per barrel
$\log PS$		305	3.8	1.0	2.42	5.89	
S	Storage working gas	305	185761	20536	142773	234878	million cubic meters
$\log S$	(reserves underground)	305	12.1	0.1	11.87	12.37	
D	US natural gas rotary	305	720	362	250	1585	number of rigs
$\log D$	rigs in operation	305	6.5	0.5	5.52	7.37	in operation
$winter$	binary variable	305	0.25	0.4	0	1	1-0
$summer$	binary variable	305	0.25	0.4	0	1	1-0
$spring$	binary variable	305	0.25	0.4	0	1	1-0
ipi	Monthly industrial	305	81	14	56	101	Index
$\log ipi$	production	305	4.4	0.2	4.02	4.61	
inc	Real monthly	305	8582	1837	5578	11479	Billions of chained
$\log inc$	income	305	9.0	0.2	8.63	9.35	2009 US Dollars

Empirical Strategy

- exclude variables that are $I(2)$ or higher (ADF, DFGLS, PP)
- determine lag structure (13,3,2,13,2) to derive and estimate unrestricted ECM by 2SLS
- F-test of first lags of dependent and independent variables
- estimate ARDL with identified lag structure and the unrestricted ECM
- short-run price elasticity of supply (production)
- derive long-run ealsticities
- post-estimation tests to test for strengths of selected variables and for misspecification

Results (Supply)

ARDL			ECM		
Variable	**Coefficient**	**(Std. Err.)**	**Variable**	**Coefficient**	**(Std. Err.)**
$Supply_{t-1}$	0.494***	(0.068)	$\Delta Supply_{t-1}$	-0.445***	(0.067)
$Supply_{t-2}$	0.107**	(0.049)	$\Delta Supply_{t-2}$	-0.338***	(0.084)
$Supply_{t-3}$	0.095**	(0.048)	$\Delta Supply_{t-3}$	-0.243***	(0.098)
$Supply_{t-4}$	-0.020	(0.055)	$\Delta Supply_{t-4}$	-0.263***	(0.089)
$Supply_{t-5}$	0.013	(0.048)	$\Delta Supply_{t-5}$	-0.250***	(0.079)
$Supply_{t-6}$	-0.097**	(0.043)	$\Delta Supply_{t-6}$	-0.346***	(0.072)
$Supply_{t-7}$	0.032	(0.053)	$\Delta Supply_{t-7}$	-0.314***	(0.074)
$Supply_{t-8}$	0.025	(0.042)	$\Delta Supply_{t-8}$	-0.289***	(0.075)
$Supply_{t-9}$	0.071	(0.048)	$\Delta Supply_{t-9}$	-0.219***	(0.085)
$Supply_{t-10}$	-0.059	(0.056)	$\Delta Supply_{t-10}$	-0.278***	(0.070)
$Supply_{t-11}$	-0.055	(0.045)	$\Delta Supply_{t-11}$	-0.332***	(0.063)
$Supply_{t-12}$	0.677***	(0.061)	$\Delta Supply_{t-12}$	0.344***	(0.063)
$Supply_{t-13}$	-0.344***	(0.063)			
$Natural\ gas_t$	**0.079**	**(0.057)**	**$\Delta\ Natural\ gas_t$**	**0.079**	**(0.057)**
$Naturalgas_{t-1}$	-0.065	(0.057)	$\Delta Naturalgas_{t-1}$	0.044***	(0.015)
$Naturalgas_{t-2}$	-0.020	(0.024)	$\Delta Naturalgas_{t-2}$	0.024	(0.018)
$Naturalgas_{t-3}$	-0.024	(0.018)			
$Crude\ Oil$	**-0.009**	**(0.014)**	**$\Delta\ Crude\ Oil_t$**	**-0.009**	**(0.014)**
$CrudeOil_{t-1}$	0.008	(0.023)	$\Delta CrudeOil_{t-1}$	-0.001	(0.015)
$CrudeOil_{t-2}$	0.001	(0.015)			
$Storage_{t-1}$	0.050	(0.042)	$\Delta Storage_{t-1}$	0.051	(0.041)
$Storage_{t-2}$	-0.098*	(0.056)	$\Delta Storage_{t-2}$	-0.047	(0.029)
$Storage_{t-3}$	0.050	(0.043)	$\Delta Storage_{t-3}$	0.003	(0.028)
$Storage_{t-4}$	-0.021	(0.042)	$\Delta Storage_{t-4}$	-0.018	(0.031)
$Storage_{t-5}$	0.025	(0.042)	$\Delta Storage_{t-5}$	0.007	(0.027)
$Storage_{t-6}$	-0.065	(0.040)	$\Delta Storage_{t-6}$	-0.057**	(0.026)
$Storage_{t-7}$	0.019	(0.041)	$\Delta Storage_{t-7}$	-0.038	(0.026)
$Storage_{t-8}$	0.044	(0.041)	$\Delta Storage_{t-8}$	0.006	(0.026)
$Storage_{t-9}$	-0.011	(0.040)	$\Delta Storage_{t-9}$	-0.005	(0.028)
$Storage_{t-10}$	-0.033	(0.042)	$\Delta Storage_{t-10}$	-0.039	(0.025)
$Storage_{t-11}$	0.044	(0.042)	$\Delta Storage_{t-11}$	0.005	(0.027)
$Storage_{t-12}$	-0.080*	(0.042)	$\Delta Storage_{t-12}$	-0.074***	(0.025)
$Storage_{t-13}$	0.074***	(0.025)			
$DrillingAct_{t-1}$	0.053**	(0.027)	$\Delta DrillingAct_{t-1}$	0.028	(0.025)
$DrillingAct_{t-2}$	-0.028	(0.025)			
			$Supply_{t-1}$	-0.060**	(0.030)
			$Naturalgas_{t-1}$	-0.030***	(0.011)
			$CrudeOil_{t-1}$	-0.001	(0.004)
			$Storage_{t-1}$	-0.001	(0.015)
			$DrillingAct_{t-1}$	0.024***	(0.009)
summer	0.003	(0.005)	*summer*	0.003	(0.005)
winter	0.004	(0.006)	*winter*	0.004	(0.006)
spring	0.011**	(0.005)	*spring*	0.011**	(0.005)

Empirical Results

- empirical support for the existence of a stable long-run relationship among the variables (supply/domestic production)
- in the very short-run $\hat{\beta}_0$ not significantly different from zero $\rightarrow$ no immediate adjustments
- no immediate effect of crude oil price on natural gas supply

- long-run supply elasticity: 0.495** $\rightarrow$ slow adjsutment to price changes
- long-run cross-price elasticity not significant different from zero
- adjustment coefficient of ARDL indicates that after exogenous shock model achieves equilibrium after 17 months
- long-run elasticity of production is 0.66, adjustment after 13 months

Conclusion

- inelastic natural gas supply in the US
- a one-percent change in wellhead natural gas prices would lead to a 0.49 percent chance in supply.
- Own price elasticity of domestic producers (0.66) suggests that these react faster to price changes by themselves.

Producers do not react strongly to price changes in a competitive market.

Thank you.

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Results I (Unit Roots)

		Level					First Differences				
Variable	**Trend**	**ADF**		***DFGLS***[a]		**PP**	**ADF**		***DFGLS***[a]		**PP**
$\log q$	No	-0.84	(7)	1.99	(13)	-4.56***	-10.49***	(7)	-0.29	(15)	-40.48***
$\log prod$	No	0.57	(7)	2.55	(12)	-4.49***	-10.83***	(6)	-7.27***	(12)	-41.96***
$\log PG$	No	-2.28	(2)	-1.43	(11)	-2.37	-14.26***	(1)	-3.28***	(10)	-14.84***
$\log WTI$	No	-0.35	(1)	0.76	(13)	-0.72	-11.70***	(1)	-3.6***	(9)	-11.52***
$\log S$	No	-4.22***	(6)	-2.65***	(6)	-6.13***	–	–	–	–	–
$\log S^{b}_{sa}$	No	-3.28**	(4)	-2.07**	(13)	-3.48***	–	–	–	–	–
$\log D$	No	-0.04	(4)	-1.11	(11)	1.97	-8.9***	(3)	-4.56***	(10)	-8.8***

Lags are given in parenthesis. Two asterisks indicate significance at 5% level, and three asterisks, at the 1% level.
[a] Uses ESR critical values, selected by Ng and Perron (1995)
[b] subscript $_{sa}$ indicated seasonally adjusted time series.

Results II (F-Test)

Table 4
F-test for cointegration

	Aggregated supply model	Domestic production model
Computed F-statistic	14.43	26.69
P-value	(0.0131)	(0.0001)
Bound test critical values at 1%	3.41 (lower)	
	4.68(upper)	

Bound test critical values extracted from Pesaran et al. (2001),
p. 300 Table CI (iii) Case III: Unrestricted intercept and no trend.

Results III (Diagnostics)

TABLE 5
Results of diagnostic tests

	Aggregate supply model		Domestic production model	
Test	Statistic	Prob.	Statistic	Prob.
Overidentification				
Sargan Chi^2	0.20	0.89	.055	0.81
Strength of Instrument				
F-Statistic	11.16	0.00	9.27	0.00
Endogeneity				
Durbin Chi^2	2.30	0.13	.014	0.91

Results IV (Supply)

	ARDL			ECM	
Variable	**Coefficient**	**(Std. Err.)**	**Variable**	**Coefficient**	**(Std. Err.)**
$Supply_{t-1}$	0.494***	(0.068)	$\Delta Supply_{t-1}$	-0.445***	(0.067)
$Supply_{t-2}$	0.107**	(0.049)	$\Delta Supply_{t-2}$	-0.338***	(0.084)
$Supply_{t-3}$	0.095**	(0.048)	$\Delta Supply_{t-3}$	-0.243***	(0.098)
$Supply_{t-4}$	-0.020	(0.055)	$\Delta Supply_{t-4}$	-0.263***	(0.089)
$Supply_{t-5}$	0.013	(0.048)	$\Delta Supply_{t-5}$	-0.250***	(0.079)
$Supply_{t-6}$	-0.097**	(0.043)	$\Delta Supply_{t-6}$	-0.346***	(0.072)
$Supply_{t-7}$	0.032	(0.053)	$\Delta Supply_{t-7}$	-0.314***	(0.074)
$Supply_{t-8}$	0.025	(0.042)	$\Delta Supply_{t-8}$	-0.289***	(0.075)
$Supply_{t-9}$	0.071	(0.048)	$\Delta Supply_{t-9}$	-0.219***	(0.085)
$Supply_{t-10}$	-0.059	(0.056)	$\Delta Supply_{t-10}$	-0.278***	(0.070)
$Supply_{t-11}$	-0.055	(0.045)	$\Delta Supply_{t-11}$	-0.332***	(0.063)
$Supply_{t-12}$	0.677***	(0.061)	$\Delta Supply_{t-12}$	0.344***	(0.063)
$Supply_{t-13}$	-0.344***	(0.063)			
$Natural\ gas_t$	**0.079**	**(0.057)**	**$\Delta\ Natural\ gas_t$**	**0.079**	**(0.057)**
$Naturalgas_{t-1}$	-0.065	(0.057)	$\Delta Naturalgas_{t-1}$	0.044***	(0.015)
$Naturalgas_{t-2}$	-0.020	(0.024)	$\Delta Naturalgas_{t-2}$	0.024	(0.018)
$Naturalgas_{t-3}$	-0.024	(0.018)			
$Crude\ Oil$	**-0.009**	**(0.014)**	**$\Delta\ Crude\ Oil_t$**	**-0.009**	**(0.014)**
$CrudeOil_{t-1}$	0.008	(0.023)	$\Delta CrudeOil_{t-1}$	-0.001	(0.015)
$CrudeOil_{t-2}$	0.001	(0.015)			
$Storage_{t-1}$	0.050	(0.042)	$\Delta Storage_{t-1}$	0.051	(0.041)
$Storage_{t-2}$	-0.098*	(0.056)	$\Delta Storage_{t-2}$	-0.047	(0.029)
$Storage_{t-3}$	0.050	(0.043)	$\Delta Storage_{t-3}$	0.003	(0.028)
$Storage_{t-4}$	-0.021	(0.042)	$\Delta Storage_{t-4}$	-0.018	(0.031)
$Storage_{t-5}$	0.025	(0.042)	$\Delta Storage_{t-5}$	0.007	(0.027)
$Storage_{t-6}$	-0.065	(0.040)	$\Delta Storage_{t-6}$	-0.057**	(0.026)
$Storage_{t-7}$	0.019	(0.041)	$\Delta Storage_{t-7}$	-0.038	(0.026)
$Storage_{t-8}$	0.044	(0.041)	$\Delta Storage_{t-8}$	0.006	(0.026)
$Storage_{t-9}$	-0.011	(0.040)	$\Delta Storage_{t-9}$	-0.005	(0.028)
$Storage_{t-10}$	-0.033	(0.042)	$\Delta Storage_{t-10}$	-0.039	(0.025)
$Storage_{t-11}$	0.044	(0.042)	$\Delta Storage_{t-11}$	0.005	(0.027)
$Storage_{t-12}$	-0.080*	(0.042)	$\Delta Storage_{t-12}$	-0.074***	(0.025)
$Storage_{t-13}$	0.074***	(0.025)			
$DrillingAct_{t-1}$	0.053**	(0.027)	$\Delta DrillingAct_{t-1}$	0.028	(0.025)
$DrillingAct_{t-2}$	-0.028	(0.025)			
			$Supply_{t-1}$	-0.060**	(0.030)
			$Naturalgas_{t-1}$	-0.030***	(0.011)
			$CrudeOil_{t-1}$	-0.001	(0.004)
			$Storage_{t-1}$	-0.001	(0.015)
			$DrillingAct_{t-1}$	0.024***	(0.009)
summer	0.003	(0.005)	*summer*	0.003	(0.005)
winter	0.004	(0.006)	*winter*	0.004	(0.006)
spring	0.011**	(0.005)	*spring*	0.011**	(0.005)

Results V (Domestic Production)

	ARDL			ECM	
Variable	**Coefficient**	**(Std. Err.)**	**Variable**	**Coefficient**	**(Std. Err.)**
$Production_{t-1}$	0.504***	(0.058)	$\Delta Supply_{t-1}$	-0.421***	(0.059)
$Production_{t-2}$	0.130***	(0.047)	$\Delta Supply_{t-2}$	-0.291***	(0.070)
$Production_{t-3}$	0.024	(0.048)	$\Delta Supply_{t-3}$	-0.266***	(0.083)
$Production_{t-4}$	-0.089*	(0.050)	$\Delta Supply_{t-4}$	-0.355***	(0.077)
$Production_{t-5}$	0.020	(0.046)	$\Delta Supply_{t-5}$	-0.335***	(0.071)
$Production_{t-6}$	-0.084**	(0.042)	$\Delta Supply_{t-6}$	-0.419***	(0.067)
$Production_{t-7}$	0.115**	(0.049)	$\Delta Supply_{t-7}$	-0.304***	(0.065)
$Production_{t-8}$	0.074*	(0.042)	$\Delta Supply_{t-8}$	-0.230***	(0.067)
$Production_{t-9}$	0.005	(0.047)	$\Delta Supply_{t-9}$	-0.225***	(0.074)
$Production_{t-10}$	-0.092*	(0.051)	$\Delta Supply_{t-10}$	-0.318***	(0.066)
$Production_{t-11}$	-0.056	(0.044)	$\Delta Supply_{t-11}$	-0.374***	(0.060)
$Production_{t-12}$	0.727***	(0.062)	$\Delta Supply_{t-12}$	0.352***	(0.059)
$Production_{t-13}$	-0.352***	(0.059)			
$Natural\ gas_t$	**-0.016**	**(0.056)**	$\Delta\ Natural\ gas_t$	**-0.016**	**(0.056)**
$Naturalgas_{t-1}$	0.028	(0.055)	$\Delta Naturalgas_{t-1}$	0.062***	(0.016)
$Naturalgas_{t-2}$	-0.059**	(0.024)	$\Delta Naturalgas_{t-2}$	0.003	(0.017)
$Naturalgas_{t-3}$	-0.003	(0.017)			
$Crude\ Oil$	**0.001**	**(0.013)**	$\Delta\ Crude\ Oil_t$	**0.000**	**(0.014)**
$CrudeOil_{t-1}$	-0.005	(0.022)	$\Delta CrudeOil_{t-1}$	-0.008	(0.014)
$CrudeOil_{t-2}$	0.008	(0.014)			
$Storage_t a_{t-1}$	-0.021	(0.042)	$\Delta Storage_{t-1}$	-0.011	(0.039)
$Storage_t a_{t-2}$	-0.016	(0.056)	$\Delta Storage_{t-2}$	-0.027	(0.029)
$Storage_t a_{t-3}$	0.007	(0.042)	$\Delta Storage_{t-3}$	-0.020	(0.027)
$Storage_t a_{t-4}$	-0.016	(0.041)	$\Delta Storage_{t-4}$	-0.036	(0.030)
$Storage_t a_{t-5}$	0.033	(0.040)	$\Delta Storage_{t-5}$	-0.003	(0.026)
$Storage_t a_{t-6}$	-0.070*	(0.039)	$\Delta Storage_{t-6}$	-0.073***	(0.026)
$Storage_t a_{t-7}$	0.033	(0.040)	$\Delta Storage_{t-7}$	-0.040	(0.026)
$Storage_t a_{t-8}$	0.036	(0.040)	$\Delta Storage_{t-8}$	-0.004	(0.025)
$Storage_t a_{t-9}$	-0.026	(0.039)	$\Delta Storage_{t-9}$	-0.030	(0.025)
$Storage_t a_{t-10}$	0.003	(0.040)	$\Delta Storage_{t-10}$	-0.028	(0.025)
$Storage_t a_{t-11}$	0.012	(0.041)	$\Delta Storage_{t-11}$	-0.016	(0.026)
$Storage_t a_{t-12}$	-0.060	(0.040)	$\Delta Storage_{t-12}$	-0.076***	(0.024)
$Storage_t a_{t-13}$	0.076***	(0.024)			
$DrillingAct_{t-1}$	0.039	(0.026)	$\Delta DrillingAct_{t-1}$	0.007	(0.025)
$DrillingAct_{t-2}$	-0.007	(0.025)			
			$Production_{t-1}$	-0.075**	(0.038)
			$Naturalgas_{t-1}$	-0.050***	(0.014)
			$CrudeOil_{t-1}$	0.003	(0.004)
			$Storage_{t-1}$	-0.010	(0.016)
			$DrillingAct_{t-1}$	0.032***	(0.009)
$summer$	-0.009	(0.006)	$summer$	-0.009	(0.006)
$winter$	-0.009	(0.005)	$winter$	-0.009	(0.005)
$spring$	0.009*	(0.005)	$spring$	0.009*	(0.005)