Convex Supply Curves

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Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed. The contribution of Pandalai-Nayar has been prepared under the Lamfalussy Fellowship Program sponsored by the European Central Bank.

Motivation

- Up until ~10 years ago: macro mostly linear (Parker, 2011)
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  - misleading if nonlinearities are important

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  - evidence on state-dependent effects of fiscal and monetary policy
- Empirics difficult, evidence often controversial

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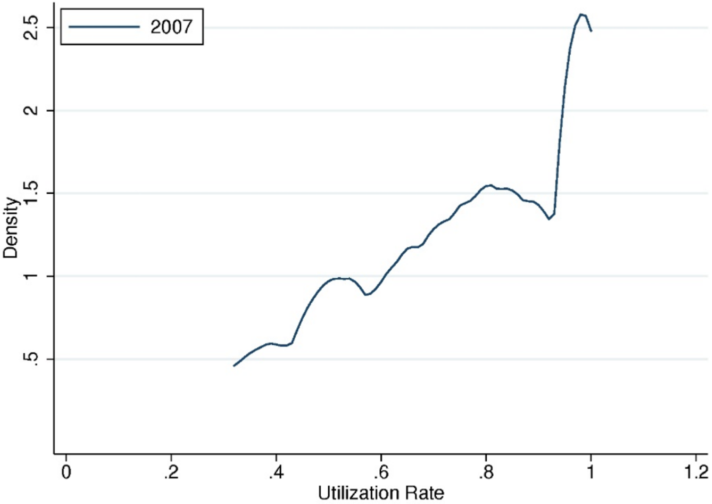
- More recently: surge of interest in nonlinearities
  - many models emphasize importance of nonlinearities
  - evidence on state-dependent effects of fiscal and monetary policy
- Empirics difficult, evidence often controversial
- **Our objective:** provide stronger evidence for one nonlinearity

Why convex supply curves?

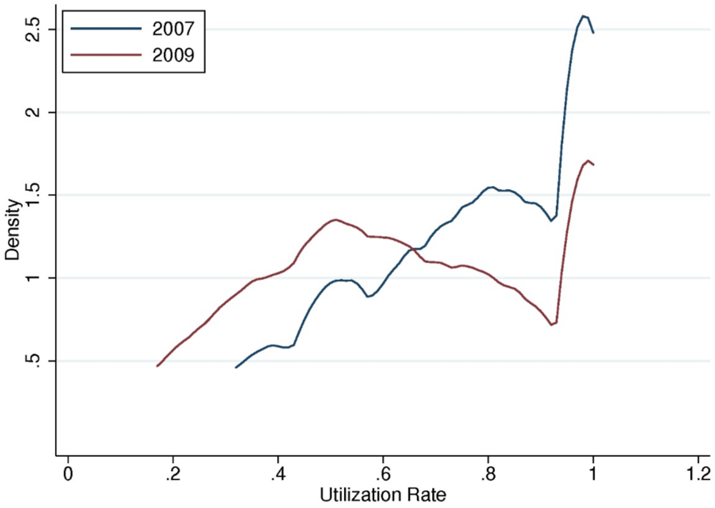
- Simple
  - identification problem well understood
- Broad, interesting, policy-relevant implications
  - state-dependent fiscal multiplier
  - convex Phillips curve
  - greater welfare costs of business cycles
  - ...
- Why should supply curves be convex?
  - capacity constraints

Cross-sectional distribution of utilization



Source: Quarterly Survey of Plant Capacity ▸ details

Cross-sectional distribution of utilization



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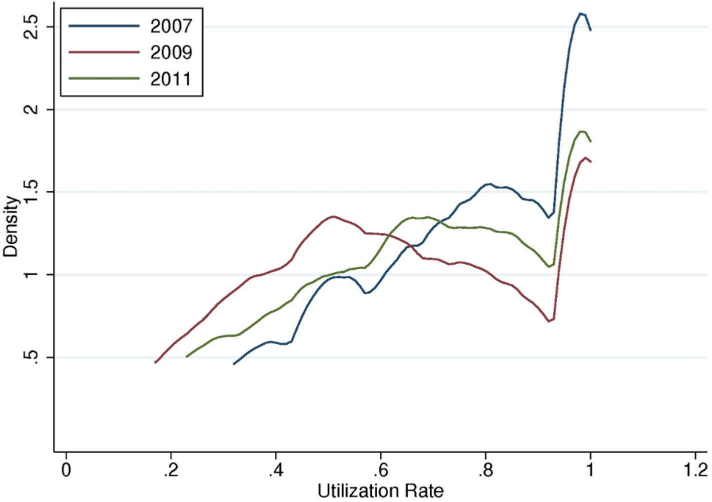

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Related Literature

- **State-dependent effects of stabilization policy**
  Auerbach and Gorodnichenko (12, 13a, 13b), Michaillat (14), Ramey and Zubairy (18), Santoro et al. (14), Tenreyro and Thwaites (16), Ghassibe and Zanetti (20)

- **Capacity and capacity utilization**
  Klein (60), Perry (73), Shapiro (89), Corrado and Mattey (97), Fagnart, Licandro, and Portier (99), Gilbert, Morin, and Raddock (00), Morin and Stevens (04)

- **Capital utilization**
  Greenwood, Hercovitz, and Huffman (88), Bils and Cho (94), Cooley, Hansen, and Prescott (95), Gilchrist and Williams (00)

- **Returns to scale/estimation of production functions**
  Hall (90), Burnside, Eichenbaum, and Rebelo (95), Basu and Fernald (97), Bils and Klenow (98), Shea (93)

Roadmap

1. Model

2. Data and estimation

3. Conclusion

Model outline

- Object of analysis: industry
- Agents: aggregating firm (CES), monopolistically competitive suppliers
- Key assumptions
    1. capacity constraint (Fagnart, Licandro, and Portier, 99)
        $\Rightarrow$ maximum output predetermined within period

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     $\Rightarrow$ uncertainty about whether capacity constraint binds

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     $\Rightarrow$ maximum output predetermined within period
  2. idiosyncratic demand shock (ω)
     $\Rightarrow$ uncertainty about whether capacity constraint binds
  3. imperfect substitutability of goods within industry
     $\Rightarrow$ substitution towards unconstrained varieties costly

Price setting and aggregation

- Price setting

$$p^y = \frac{\theta}{\theta - 1}\left(mc + \rho\right), \qquad \rho = 0 \quad \text{whenever} \quad y < q,$$

  - plant-level capacity q
  - marginal costs mc
  - multiplier on capacity constraint ρ

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- Aggregation to industry level
  - output Y_t
  - capacity Q_t — output when all plants produce at capacity
  - utilization $u_t := Y_t/Q_t$

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- Aggregation to industry level
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  - utilization $u_t := Y_t/Q_t$

  note: definition aligns with Federal Reserve Board

The supply curve

- Industry price index

$$\ln P_t^Y = \mathcal{M}\left(\ln u_t\right) + \ln\left(mc_t\right)$$

  - Note: capacity Q_t is supply shifter ($u_t = Y_t/Q_t$)

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  - Note: capacity Q_t is supply shifter $(u_t = Y_t/Q_t)$

- Properties of $\mathcal{M}$

  1. $\mathcal{M}' \geq 0$
  2. $\lim_{u\to 0} \mathcal{M}\left(\ln u\right) = \ln \frac{\theta}{\theta-1}$, $\lim_{u\to 1} \mathcal{M}\left(\ln u\right) = \infty$
  3. $\lim_{u\to 0} \mathcal{M}'\left(\ln u\right) = 0$, $\lim_{u\to 1} \mathcal{M}'\left(\ln u\right) = \infty$
  4. Typically $\mathcal{M}'' > 0$ details

Estimating equation

- Linear approximation around $t-1$ values

$$\Delta \ln P^{Y}_{i,t} = \mathcal{M}'\left(\ln u_{i,t-1}\right)\left(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t}\right) + \Delta \ln mc_{i,t}$$

Estimating equation

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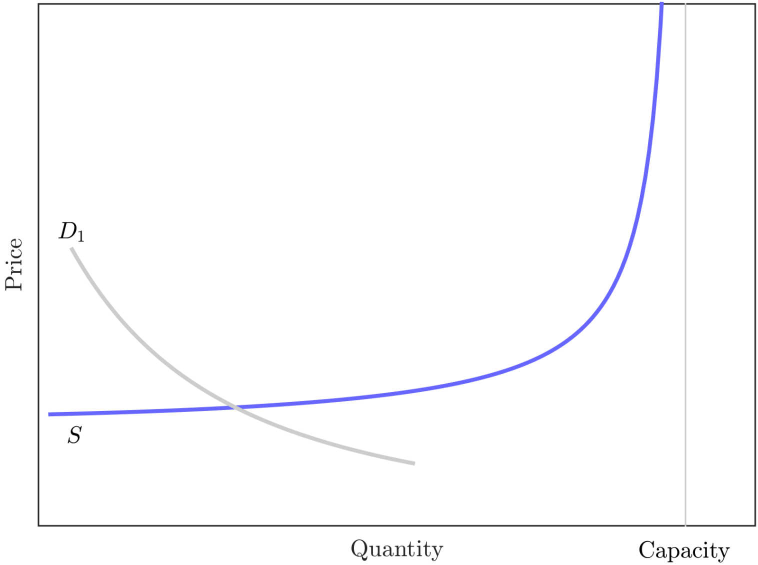
- Approximate $\mathcal{M}'$ linearly

$$\mathcal{M}'\left(\ln u_{i,t-1}\right) \approx \mathcal{M}'\left(\ln \bar{u}_i\right) + \frac{\mathcal{M}''\left(\ln \bar{u}_i\right)}{\bar{u}_i} \cdot \left(u_{i,t-1} - \bar{u}_i\right)$$

- Note:
  - interaction term $\Delta \ln Y_{i,t} \cdot \left(u_{i,t-1} - \bar{u}_i\right)$ identifies curvature
  - replace marginal costs $mc_{i,t}$ with unit variable costs ▸ details

Intuition



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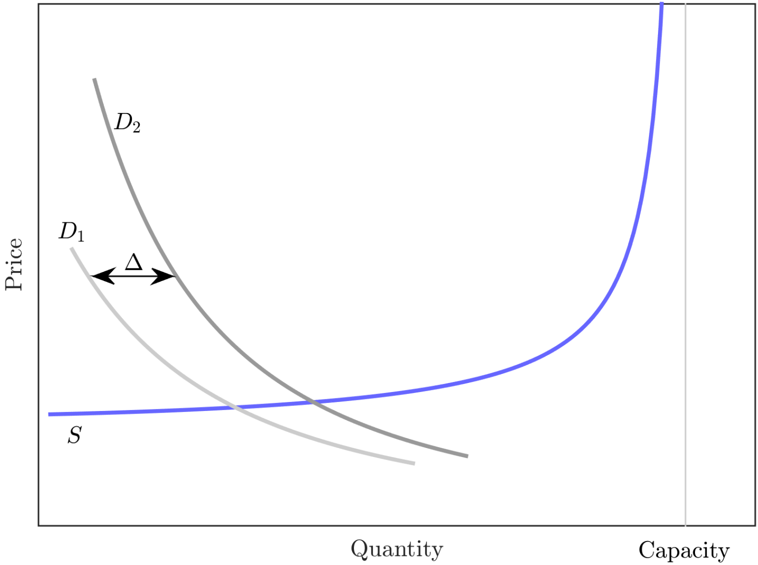

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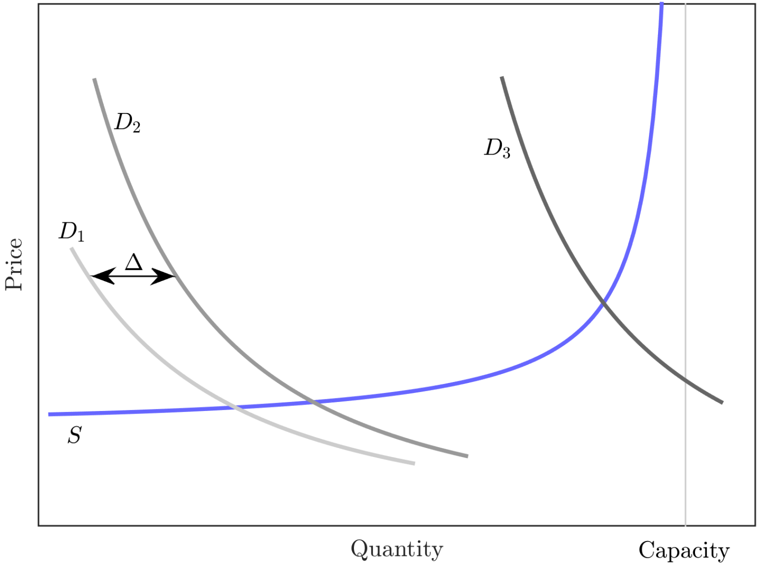

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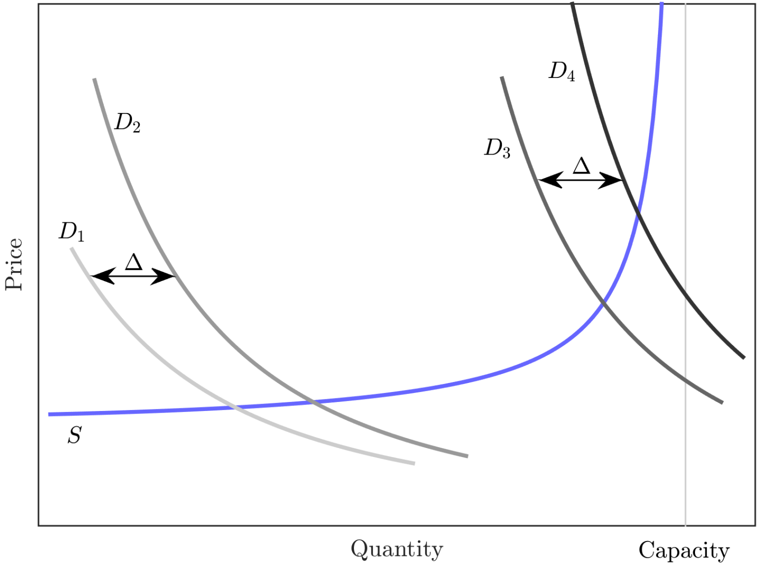

Roadmap

1. Model
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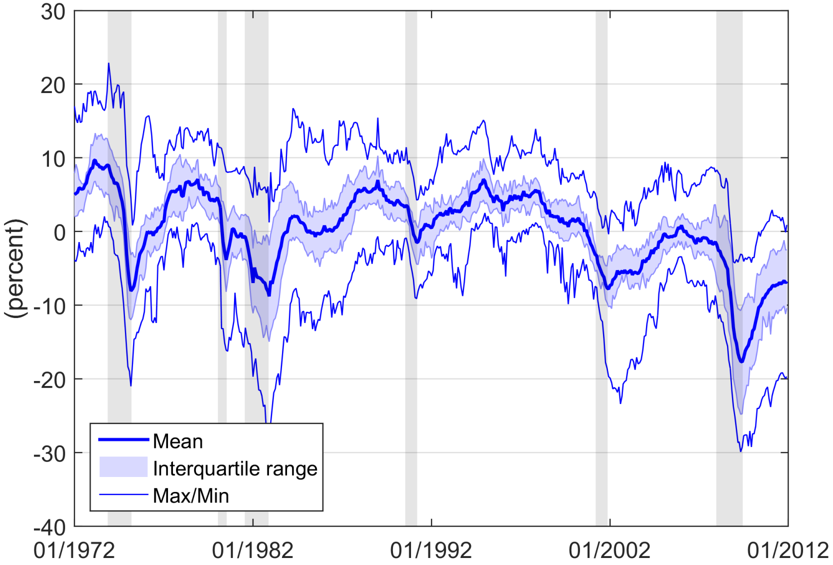
Data

- Sample
  - manufacturing 3-digit NAICS industries (21)
  - 1972 - 2011, annual
  - 819 observations

Data

- Sample
  - manufacturing 3-digit NAICS industries (21)
  - 1972 - 2011, annual
  - 819 observations
- Data sources
  - Federal Reserve Board: capacity, utilization
  - NBER CES Manufacturing Industry Database: prices, sales, inventories, variable costs = production wages + material cost + energy cost
  - BEA Use-tables: Sales shares, imports
  - BEA Industry Accounts, BEA NIPA: downstream quantities and prices
  - US Census and Customs: exports (via Peter Schott's website)
  - UN Statistics Division: exchange rates, GDP, deflator

Demeaned utilization



Instruments and identification

- Quantity and price determined simultaneously
- Unobserved supply shocks affect $\Delta \ln P_{i,t}^{Y}$ and
  - main effect $\Delta \ln Y_{i,t}$
  - interaction $\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$
- Instruments ▸ details
  1. World Import Demand (WID, Hummels et al., 14)
  2. Shea's instrument (Shea, 93a,b)
  3. exchange rate

Linear estimates

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

Estimator	OLS	OLS	OLS	OLS	2SLS
Instruments	-	-	-	-	WID, Shea, $\Delta e_{i,t}$
$\Delta \ln Y_{i,t}$	-0.09				
	(0.08)				
$\Delta \ln Q_{i,t}$					
$\Delta \ln \mathrm{UVC}_{i,t}$					
R-squared	0.010				
Fixed effects	no				
First stage and instrument diagnostics					
F main effect					
Hansen J (p-value)					

Note: Driscoll-Kraay standard errors in parentheses.

Linear estimates

Dependent variable: $\Delta \ln P_{i,t}^{Y}$

Estimator	OLS	OLS	OLS	OLS	2SLS
Instruments	-	-	-	-	WID, Shea, $\Delta e_{i,t}$
$\Delta \ln Y_{i,t}$	-0.09	0.08			
	(0.08)	(0.02)			
$\Delta \ln Q_{i,t}$					
$\Delta \ln \mathrm{UVC}_{i,t}$		0.91			
		(0.02)			
R-squared	0.010	0.873			
Fixed effects	no	no			
First stage and instrument diagnostics					
F main effect					
Hansen J (p-value)					

Note: Driscoll-Kraay standard errors in parentheses.

LINEAR ESTIMATES

Dependent variable: $\Delta \ln P^Y_{i,t}$

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Instruments	-	-	-	-	WID, Shea, $\Delta e_{i,t}$
$\Delta \ln Y_{i,t}$	-0.09	0.08	0.13		
	(0.08)	(0.02)	(0.02)		
$\Delta \ln Q_{i,t}$			-0.16		
			(0.03)		
$\Delta \ln \mathrm{UVC}_{i,t}$		0.91	0.90		
		(0.02)	(0.02)		
R-squared	0.010	0.873	0.880		
Fixed effects	no	no	no		
First stage and instrument diagnostics					
F main effect					
Hansen J (p-value)					

Note: Driscoll-Kraay standard errors in parentheses.

Linear estimates

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

Estimator	OLS	OLS	OLS	OLS	2SLS
Instruments	-	-	-	-	WID, Shea, $\Delta e_{i,t}$
$\Delta \ln Y_{i,t}$	-0.09	0.08	0.13	0.17	
	(0.08)	(0.02)	(0.02)	(0.02)	
$\Delta \ln Q_{i,t}$			-0.16	-0.12	
			(0.03)	(0.04)	
$\Delta \ln \text{UVC}_{i,t}$		0.91	0.90	0.89	
		(0.02)	(0.02)	(0.03)	
R-squared	0.010	0.873	0.880	0.910	
Fixed effects	no	no	no	yes	
First stage and instrument diagnostics					
F main effect					
Hansen J (p-value)					

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Linear estimates

Dependent variable: $\Delta \ln P^Y_{i,t}$

Estimator	OLS	OLS	OLS	OLS	2SLS
Instruments	-	-	-	-	WID, Shea, $\Delta e_{i,t}$
$\Delta \ln Y_{i,t}$	-0.09	0.08	0.13	0.17	0.23
	(0.08)	(0.02)	(0.02)	(0.02)	(0.10)
$\Delta \ln Q_{i,t}$			-0.16	-0.12	-0.16
			(0.03)	(0.04)	(0.08)
$\Delta \ln \mathrm{UVC}_{i,t}$		0.91	0.90	0.89	0.90
		(0.02)	(0.02)	(0.03)	(0.03)
R-squared	0.010	0.873	0.880	0.910	0.908
Fixed effects	no	no	no	yes	yes
First stage and instrument diagnostics					
F main effect					20.03
Hansen J (p-value)					0.441

Note: Driscoll-Kraay standard errors in parentheses.

Nonlinear estimates

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instruments:						
Main effect		WID, Shea, $\Delta e_{i,t}$				WID, Shea
Interaction $(\cdot\,(u_{i,t-1}-\bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17 (0.02)					
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1}-\bar{u}_i)$	-0.33 (0.24)					
R-squared	0.910					
Other controls	yes					
Fixed effects	yes					
First stage and instrument diagnostics†						
F Main effect						
F Interaction						
Cragg-Donald Wald F						
Hansen J (p-value)						

Notes: Driscoll-Kraay standard errors in parentheses.
†: Sanderson and Windmeijer (2016) partial F-statistics reported in paper.

Nonlinear estimates

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instruments:						
Main effect		WID, Shea, $\Delta e_{i,t}$				WID, Shea
Interaction $(\cdot\,(u_{i,t-1} - \bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17	0.27				
	(0.02)	(0.09)				
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.33	0.97				
	(0.24)	(0.31)				
R-squared	0.910	0.902				
Other controls	yes	yes				
Fixed effects	yes	yes				
First stage and instrument diagnostics†						
F Main effect		10.84				
F Interaction		16.84				
Cragg-Donald Wald F		9.08				
Hansen J (p-value)		0.409				

Notes: Driscoll-Kraay standard errors in parentheses.

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Dependent variable: $\Delta \ln P^Y_{i,t}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
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Interaction $(\cdot (u_{i,t-1} - \bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17	0.27	0.28			
	(0.02)	(0.09)	(0.09)			
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.33	0.97	1.36			
	(0.24)	(0.31)	(0.72)			
R-squared	0.910	0.902	0.897			
Other controls	yes	yes	yes			
Fixed effects	yes	yes	yes			
First stage and instrument diagnostics†						
F Main effect		10.84	19.23			
F Interaction		16.84	6.43			
Cragg-Donald Wald F		9.08	7.76			
Hansen J (p-value)		0.409	0.380			

Notes: Driscoll-Kraay standard errors in parentheses.
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Nonlinear estimates

Dependent variable: $\Delta \ln P^Y_{i,t}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instruments:						
Main effect		WID, Shea, $\Delta e_{i,t}$				WID, Shea
Interaction $(\cdot\,(u_{i,t-1} - \bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17 (0.02)	0.27 (0.09)	0.28 (0.09)	0.26 (0.10)		
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.33 (0.24)	0.97 (0.31)	1.36 (0.72)	0.92 (0.66)		
R-squared	0.910	0.902	0.897	0.903		
Other controls	yes	yes	yes	yes		
Fixed effects	yes	yes	yes	yes		
First stage and instrument diagnostics†						
F Main effect		10.84	19.23	12.05		
F Interaction		16.84	6.43	3.82		
Cragg-Donald Wald F		9.08	7.76	6.67		
Hansen J (p-value)		0.409	0.380	0.407		

Notes: Driscoll-Kraay standard errors in parentheses.

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Nonlinear estimates

Dependent variable: $\Delta \ln P_{i,t}^{Y}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instruments:						
Main effect		WID, Shea, $\Delta e_{i,t}$				WID, Shea
Interaction $(\cdot\,(u_{i,t-1} - \bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17	0.27	0.28	0.26	0.27	
	(0.02)	(0.09)	(0.09)	(0.10)	(0.08)	
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.33	0.97	1.36	0.92	1.13	
	(0.24)	(0.31)	(0.72)	(0.66)	(0.33)	
R-squared	0.910	0.902	0.897	0.903	0.901	
Other controls	yes	yes	yes	yes	yes	
Fixed effects	yes	yes	yes	yes	yes	
First stage and instrument diagnostics†						
F Main effect		10.84	19.23	12.05	18.00	
F Interaction		16.84	6.43	3.82	65.87	
Cragg-Donald Wald F		9.08	7.76	6.67	6.22	
Hansen J (p-value)		0.409	0.380	0.407	0.719	

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Nonlinear estimates

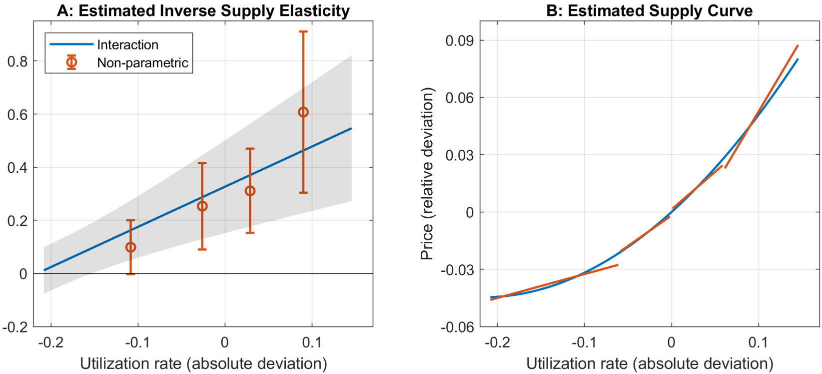
Dependent variable: $\Delta \ln P_{i,t}^{Y}$

Estimator	OLS	2SLS	2SLS	2SLS	2SLS	2SLS
Instruments:						
Main effect		WID, Shea, $\Delta e_{i,t}$				WID, Shea
Interaction $(\cdot\,(u_{i,t-1} - \bar{u}_i))$		WID	Shea	$\Delta e_{i,t}$	all	WID, Shea
$\Delta \ln Y_{i,t}$	0.17	0.27	0.28	0.26	0.27	0.26
	(0.02)	(0.09)	(0.09)	(0.10)	(0.08)	(0.09)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.33	0.97	1.36	0.92	1.13	1.13
	(0.24)	(0.31)	(0.72)	(0.66)	(0.33)	(0.33)
R-squared	0.910	0.902	0.897	0.903	0.901	0.901
Other controls	yes	yes	yes	yes	yes	yes
Fixed effects	yes	yes	yes	yes	yes	yes
First stage and instrument diagnostics[†]						
F Main effect		10.84	19.23	12.05	18.00	17.27
F Interaction		16.84	6.43	3.82	65.87	28.25
Cragg-Donald Wald F		9.08	7.76	6.67	6.22	9.02
Hansen J (p-value)		0.409	0.380	0.407	0.719	0.531

Notes: Driscoll-Kraay standard errors in parentheses.

[†]: Sanderson and Windmeijer (2016) partial F-statistics reported in paper.

Nonparametric estimates



Percentiles of utilization rate (absolute deviation)

Percentile	p1	p5	p10	p25	p50	p75	p90	p95	p99
Value	-0.21	-0.13	-0.09	-0.04	0.01	0.04	0.08	0.10	0.15

Robustness and extensions

- Inventories ▸ details
- The unit variable cost control ▸ details
- The capacity control and anticipation effects ▸ details
- Sticky prices ▸ details
- Second order approximation ▸ details
- Coefficient restrictions ▸ details
- Heterogeneity ▸ details

Roadmap

1. Model
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Conclusion

- Supply curves are convex
- The concept of capacity is operationalizable

Conclusion

- Supply curves are convex
- The concept of capacity is operationalizable
- Aggregate implications of convex supply curves
  (based on nonlinear network model in GE, see paper)
  - state-dependent fiscal multiplier
  - convex Phillips curve
  - greater welfare costs of business cycles
  - ...

Appendix

Two strategies

- Strategy 1: focus on *shock*
  1. identify shock of interest — often little variation
  2. identify "state" of interest — what is the correct "state"
  3. estimate nonlinear effects
- Strategy 2: focus on *mechanism*
  - + mechanism can be tested with different instruments
  - + model suggests "state"
  - + estimate structural (portable) object
  - − there can be other nonlinearities

Robustness and extensions

- Survey and qualitative responses ▸ details
- Markups versus marginal costs ▸ details
- The reduced form ▸ details
- Source of fluctuations ▸ details
- Partial equilibrium model ▸ details
- Aggregate implications of convex supply curves ▸ details

Monopolistic competitors

- *Production Capacity*

$$q_t = z_t F\left(k_t, \bar{v}_t\right)$$

- k_t: short-run fixed factors
- $\bar{v}_t$: maximum of variable factors the firm can employ
- z_t: productivity
- F is homogeneous of degree 1

Monopolistic competitors

- *Actual Production*

$$y_t = q_t \frac{v_t}{\bar{v}_t} = z_t F\left(\kappa_t, 1\right) v_t, \quad v_t \leq \bar{v}_t$$

- v_t: short-run variable factors
- $\kappa_t = \frac{k_t}{\bar{v}_t}$

- $v_t \leq \bar{v}_t \Rightarrow y_t \leq q_t$
- Short-run marginal costs equal average costs

Monopolistic competitors

$$V\left(k,\bar{v},z,\omega\right)=\max_{y,x,\bar{v}'}\left\{p^{y}y-p^{v}v-p^{x}x-\phi\left(x,k\right)+\frac{1}{1+r}\mathbb{E}\left[V\left(k',\bar{v}',z',\omega'\right)\right]\right\}$$

subject to

$$\begin{aligned}
y &= q\frac{v}{\bar{v}}\\
q &= zF\left(k,\bar{v}\right)\\
y &\leq q\\
k' &= \left(1-\delta\right)k+x\\
y &= \omega Y\left(\frac{p^{y}}{P^{Y}}\right)^{-\theta}
\end{aligned}$$

- $\phi\left(x,k\right)$: adjustment costs
- Note: assume flexible prices

Monopolistic competitors

- Price setting

$$p^y = \frac{\theta}{\theta - 1}\left(mc + \rho\right), \qquad \rho = 0 \quad \text{whenever} \quad y < q,$$

  - mc: marginal costs
  - ρ: multiplier on capacity constraint

- Baseline model:
  1. Flexible prices
  2. Demand shock ω i.i.d.
  3. Productivity z aggregate or industry-specific, not firm specific

$\Rightarrow$ simple aggregation

Aggregation

- There is a threshold variety $\bar{\omega}$ such that
  - $\omega \geq \bar{\omega}$: firm is capacity constrained
  - $\omega < \bar{\omega}$: unconstrained

- Industry output

$$Y\left(q_t, \bar{\omega}_t\right) = q_t \left(\left(\bar{\omega}_t\right)^{-\frac{\theta-1}{\theta}} \int_0^{\bar{\omega}_t} \omega dG\left(\omega\right) + \int_{\bar{\omega}_t}^{\infty} \left(\omega\right)^{\frac{1}{\theta}} dG\left(\omega\right) \right)^{\frac{\theta}{\theta-1}}$$

- Capacity

$$Q\left(q_t\right) := \lim_{\bar{\omega}_t \to 0} Y\left(q_t, \bar{\omega}_t\right)$$

Aggregation

- Capacity utilization

$$u_t := \frac{Y\left(q_t, \bar{\omega}_t\right)}{Q\left(q_t\right)}$$

- Properties
  1. $u_t \in [0,1]$ is only a function of $\bar{\omega}_t$: $u_t = u\left(\bar{\omega}_t\right)$
  2. $\lim_{\bar{\omega}\to 0} u\left(\bar{\omega}\right) = 1$, $\lim_{\bar{\omega}\to\infty} u\left(\bar{\omega}\right) = 0$
  3. $u' < 0$

- Note: Definition aligns with Federal Reserve Board back

The source of fluctuations

- Ghassibe and Zanetti (20): the *source* of the disturbance matters
- In our model this issue does not arise, $u_{i,t-1}$ does not depend on productivity (it cancels)
- Measured utilization rates may be affected by productivity shocks, but
  - qualitative survey evidence suggests that the utilization is mostly driven by demand
- Robustness check:
  - $u_{i,t-1} - \bar{u}_i$ can be high because demand was high, or because productivity is low
  - use inflation to infer likely source of disturbance

The source of fluctuations

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

	baseline	Price change in $t-1$	
		high	low
$\Delta \ln Y_{i,t}$	0.26 (0.09)	0.23 (0.09)	
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.13 (0.33)	1.32 (0.37)	0.77 (0.39)
R-squared	0.901	0.905	
Other controls	yes	yes	
Fixed effects	yes	yes	
First stage and instrument diagnostics			
F Main effect	17.27	19.51	
F Interaction	28.25	51.44	17.40
Cragg-Donald Wald F	9.020	6.099	
Hansen J (p-value)	0.831	0.619	

Note: Driscoll-Kraay standard errors are reported in parentheses. back

Markups versus marginal costs

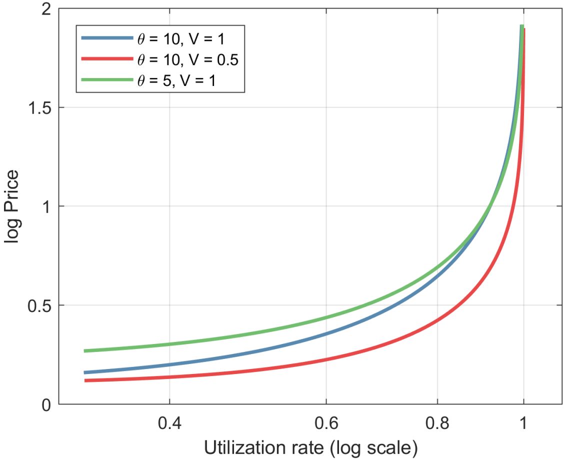
- In the model markups generate convexity
- Changes in marginal costs can also generate convexity (Bresnahan and Ramey, 94)
- Since marginal costs are not observed, our estimation cannot distinguish these channels

  ⇒ not necessarily evidence for procyclical markups

- Note:
  - unit variable cost control does *not* capture possible dependence of mc on u
  - estimation does not rely on specific channel (markups vs. marginal costs)

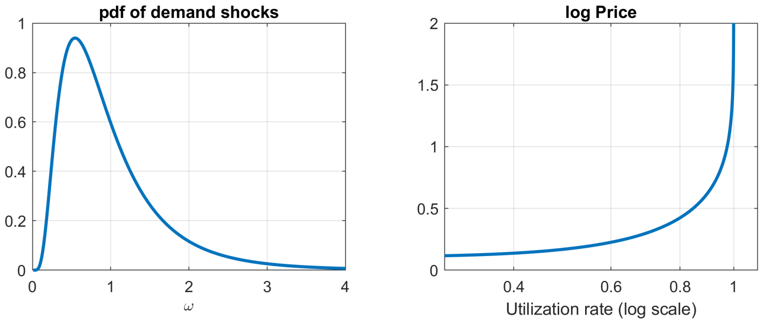
▸ details

Numerical example (log-normal)



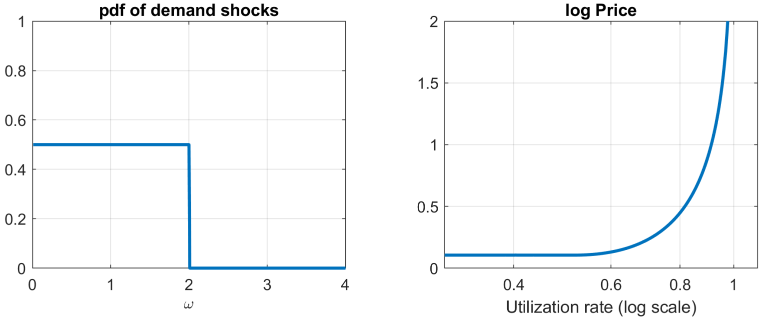
Notes: The parameterization is chosen as follows: G is log-normal with unit mean and variance V, marginal costs mc are set to 1.

Numerical example (log-normal)



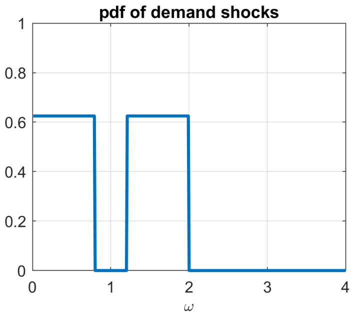
Note: G is log-normal with unit mean and unit variance. Marginal costs mc are set to 1.

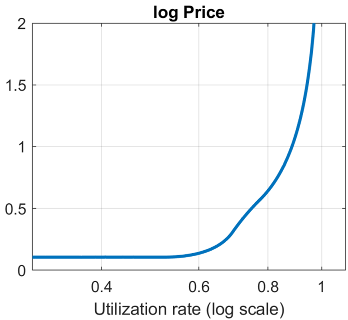
Numerical example (uniform)



Note: G is uniform between 0 and 2. Marginal costs mc are set to 1.

Numerical example (piecewise uniform)

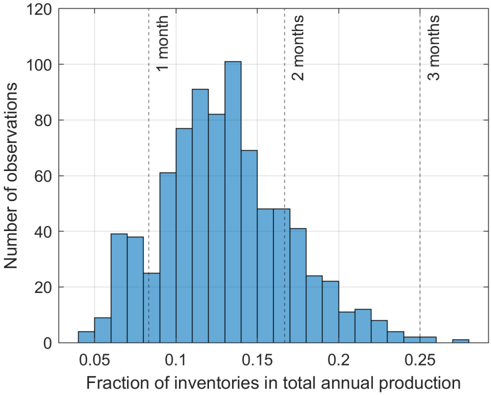




Note: G is uniform between 0 and 0.8 and 1.2 to 2. Marginal costs mc are set to 1. back

Inventories

Inventories could decouple production from sales and reduce the role of capacity constraints



Do plants draw down inventories when utilization is high?

	Correlations			
	$u_{i,t}$	$\frac{Y^{\text{inv}}_{i,t}}{Y_{i,t}}$	$\frac{\Delta Y^{\text{inv}}_{i,t}}{Y_{i,t-1}}$	$\frac{\Delta Y^{\text{inv}}_{i,t+1}}{Y_{i,t}}$
$u_{i,t}$	1.00			
$\frac{Y^{\text{inv}}_{i,t}}{Y_{i,t}}$	0.02	1.00		
$\frac{\Delta Y^{\text{inv}}_{i,t}}{Y_{i,t-1}}$	0.43	0.07	1.00	
$\frac{\Delta Y^{\text{inv}}_{i,t+1}}{Y_{i,t}}$	0.12	-0.06	0.10	1.00

Note: $u_{i,t}$ and $\frac{Y^{\text{inv}}_{i,t}}{Y_{i,t}}$ are industry-demeaned.

Do inventory holdings affect the estimates?

Dependent variable: $\Delta \ln P^Y_{i,t}$

Sample	full	full	full	$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} \leq 2/12$	$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} \geq 1/12$
$\Delta \ln Y_{i,t}$	0.26	0.27	0.27	0.31	0.30
	(0.09)	(0.08)	(0.09)	(0.11)	(0.09)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.13	1.12	1.18	1.55	1.26
	(0.33)	(0.31)	(0.30)	(0.48)	(0.31)
$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$	-0.04	-0.03	0.03		
	(0.08)	(0.08)	(0.09)		
$\Delta \ln Y_{i,t} \cdot \left(Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}\right)$		-0.33	-0.41		
		(1.05)	(1.10)		
$\Delta Y^{\text{inv}}_{i,t}/Y_{i,t-1}$			0.15		
			(0.17)		
$\Delta Y^{\text{inv}}_{i,t-1}/Y_{i,t-2}$			-0.44		
			(0.15)		
R-squared	0.901	0.900	0.903	0.900	0.872
Fixed effects	yes	yes	yes	yes	yes
Other controls	yes	yes	yes	yes	yes
Observations	819	819	819	673	719

Note: 2SLS estimates with WID and Shea instruments. ▸ back

Microdata on capacity utilization

- **Confidential census surveys**
  - before 2006: Survey of Plant Capacity (SPC)
  - 2007 onwards: Quarterly Survey of Plant Capacity (QPC)

- Plants are asked to report
  - the market value of **actual production**
  - an estimate of the market value of **full production**
    1. only current capital stock
    2. normal downtime
    3. other inputs fully available
    4. realistic and sustainable shift and work schedule
    5. same product mix

- utilization $= \frac{\text{actual production}}{\text{full production}}$

SURVEY FORM

Item 2 **VALUE OF PRODUCTION**

	$Bil.	Mil.	Thou.

A. Report market value of **actual production** for the quarter.

ACTUAL PRODUCTION . . . .

	$Bil.	Mil.	Thou.

B. Estimate the market value of production of this plant as if it had been operating at **full production capability** for the quarter.

Assume:

- only machinery and equipment **in place and ready to operate**.
- normal downtime.
- labor, materials, utilities, etc. **ARE FULLY AVAILABLE**.
- the number of shifts, hours of operation and overtime pay that can be **sustained** under **normal** conditions and a **realistic** work schedule in the long run.
- the **same product mix** as the actual production.

FULL PRODUCTION CAPABILITY. . . . .

Capacity Utilization

%

C. Divide your **actual production** estimate by your **full production estimate**. Multiply this ratio by 100 to get a percentage. . . . .

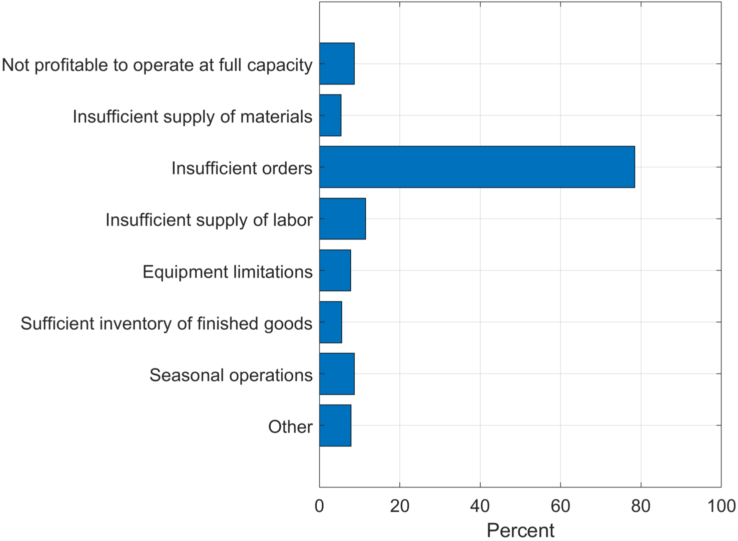
Is this a reasonable estimate of your utilization rate for this quarter? ☐ Yes ☐ No — *Review item 2A and 2B*

IBMIT

Why do plants produce below capacity?

- **Question:** If this plant's actual production in the current quarter was less than full production capability, mark (X) the primary reasons
- ... list of options ...
- Note: Multiple answers are permitted

Why do plants produce below capacity?



Notes: Data from QSPC, average over 2013q1-2018q2. back

Measurement of marginal costs

- Marginal costs are not observed

- In terms of unit variable costs, the supply curve is

$$\ln P_{i,t}^{Y} = \mathcal{M}\left(\ln u_{i,t}\right) + \Omega\left(\ln u_{i,t}\right) + \ln \mathrm{UVC}_{i,t}$$

  where Ω is a wedge between unit costs and marginal costs

- Problem: variation in u does not identify $\mathcal{M}'$, but $\mathcal{M}' + \Omega'$ (and similarly for $\mathcal{M}''$)

- **Proposition:** $\Omega' \leq 0$ and $\Omega'' \leq 0$

  $\Rightarrow$ downward bias for slope and curvature

back to model

The unit variable cost control

Dependent variable: $\Delta \ln P_{i,t}^{Y}$

	baseline	drop UVC
$\Delta \ln Y_{i,t}$	0.26 (0.09)	0.69 (0.28)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.13 (0.33)	1.85 (0.31)
$\Delta \ln \text{UVC}_{i,t}$	0.89 (0.03)	
R-squared	0.901	0.469
Other controls	yes	yes
Fixed effects	yes	yes
First stage and instrument diagnostics†		
F Main effect	17.27	16.42
F Interaction	28.25	27.80
Cragg-Donald Wald F	9.02	8.68
Hansen J (p-value)	0.531	0.297

Notes: Driscoll-Kraay standard errors in parentheses.

†: Sanderson and Windmeijer (2016) partial F-statistics reported in paper.

back

Anticipation effects

- If model is correct, future information affects $P^Y_{i,t}$ *only* through $Q_{i,t}$

$$\ln P^Y_{i,t} = \mathcal{M}\left(\ln\left(Y_{i,t}/Q_{i,t}\right)\right) + \ln mc_{i,t}$$

  $\Rightarrow$ Conditional on controlling for $Q_{i,t}$, anticipation effects do not pose problem

- If model is not correct, anticipation effects could pose problem

  $\Rightarrow$ Check if results hold up for unpredictable exchange rate shock

The capacity control

Dependent variable: $\Delta \ln P^{Y}_{i,t}$

	baseline	drop interaction	drop $Q_{i,t}$ and interaction
$\Delta \ln Y_{i,t}$	0.26 (0.09)	0.24 (0.09)	0.22 (0.07)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.13 (0.33)	0.95 (0.32)	0.82 (0.27)
$\Delta \ln Q_{i,t}$	-0.21 (0.11)	-0.19 (0.11)	
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-1.20 (0.42)		
R-squared	0.901	0.902	0.901
Other controls	yes	yes	yes
Fixed effects	yes	yes	yes
First stage and instrument diagnostics†			
F Main effect	17.27	17.14	18.10
F Interaction	28.25	28.97	31.58
Cragg-Donald Wald F	9.02	9.29	9.97
Hansen J (p-value)	0.531	0.484	0.484

Notes: Driscoll-Kraay standard errors in parentheses.

†: Sanderson and Windmeijer (2016) partial F-statistics reported in paper.

back

Instruments and identification

- **Instrument 1:** World Import Demand (WID, Hummels et al., 14)

$$\text{inst}_{i,t}^{\text{WID}} = \sum_{d} s_{d,i,t-1}^{\text{ex}} \Delta \ln Y_{d,t}$$

  - $s_{i,d,t-1}^{\text{ex}}$: sales share to country d
  - $\Delta \ln Y_{d,t}$: percent change in output in d

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  - $\Delta \ln Y_{d,t}$: percent change in output in d

- Decomposition: $\Delta \ln Y_{d,t} = \Delta \ln Y_t^{\text{com}} + \Delta \ln Y_{d,t}^{\text{spec}}$, $R^2 = 0.27$, then

$$\text{inst}_{i,t}^{\text{WID}} = \underbrace{\Delta \ln Y_t^{\text{com}} \sum_d s_{d,i,t-1}^{\text{ex}}}_{\text{time FE } \times s_{i,t-1}^{\text{ex}}} + \underbrace{\sum_d \bar{s}_{d,t-1}^{\text{ex}} \Delta \ln Y_{d,t}^{\text{spec}}}_{\text{time FE}}$$

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$$\text{inst}^{\text{WID}}_{i,t} = \underbrace{\Delta \ln Y^{\text{com}}_t \sum_d s^{\text{ex}}_{d,i,t-1}}_{\text{time FE } \times s^{\text{ex}}_{i,t-1}} + \underbrace{\sum_d \bar{s}^{\text{ex}}_{d,t-1} \Delta \ln Y^{\text{spec}}_{d,t}}_{\text{time FE}}$$

$$\underbrace{+ \sum_d \left(s^{\text{ex}}_{d,i,t-1} - \bar{s}^{\text{ex}}_{d,t-1} \right) \Delta \ln Y^{\text{spec}}_{d,t}}_{\text{4.4\% of variation, our shock}}$$

Instruments and identification

- **Instrument 2:** (Shea, 93a,b)

  Material purchases of industry j are a good instrument for output of industry i if

  (1) industry j demands a large share of i's output

  (2) materials from i constitute a small share of j's costs

  (3) i's cost share from j is small

Instruments and identification

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  Material purchases of industry j are a good instrument for output of industry i if

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  (3) i's cost share from j is small

- Formally,

$$\text{inst}_{i,t}^{\text{Shea}} = \sum_j s_{j,i,t-1}^{M} \mathbb{1}\{(1),\ (2),\ (3)\ \text{hold}\} \, \Delta \ln M_{j,t}$$

  - $s_{j,i,t-1}^{\text{M}}$: sales share to industry j
  - $\Delta \ln M_{j,t}$: material bundle of industry j

- Note: takes direct and indirect linkages into account

Instruments and identification

- **Instrument 3:** Effective exchange rate depreciation

$$\Delta e_{i,t} = \sum_{d} s^{\text{ex}}_{d,i,t-1} \Delta \ln \mathcal{E}_{d,t}$$

  - $s^{\text{ex}}_{d,i,t-1}$: sales share to country d
  - $\Delta \ln \mathcal{E}_{d,t}$: percent depreciation in bilateral exchange rate

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- Decomposition: $\Delta \ln \mathcal{E}_{d,t} = \Delta \mathcal{E}^{\text{com}}_t + \Delta \ln \mathcal{E}^{\text{spec}}_{d,t}$, $R^2 = 0.28$, then

$$\Delta e_{i,t} = \underbrace{\Delta \ln \mathcal{E}^{com}_t \times \sum_d s^{\text{ex}}_{d,i,t-1}}_{\text{time FE } \times s^{\text{ex}}_{i,t-1}} + \underbrace{\sum_d \bar{s}^{\text{ex}}_{d,t-1} \Delta \ln \mathcal{E}^{spec}_{d,t}}_{\text{time FE}}$$

back

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$$\underbrace{+ \sum_d \left(s^{\text{ex}}_{d,i,t-1} - \bar{s}^{\text{ex}}_{d,t-1} \right) \Delta \ln \mathcal{E}^{spec}_{d,t}}_{\text{6.7\% of variation, our shock}}$$

back

Sticky prices

- When prices are sticky...
  - prices cannot adjust to equate the quantity demanded to supply for capacity constrained plants
  - a shadow prices clears the market and there is rationing
  - measured prices are not allocative

Sticky prices

- When prices are sticky...
  - prices cannot adjust to equate the quantity demanded to supply for capacity constrained plants
  - a shadow prices clears the market and there is rationing
  - measured prices are not allocative

- Implications for quantities are unchanged
  - low (high) initial utilization rate $\Rightarrow$ large (small) production response to demand shock
  - test prediction by estimation the reduced form

Reduced form: demand

- Domestic final

$$C_{i,t} = \omega^C_{i,t} C_t \left(\frac{P^Y_{i,t}}{P^C_t} \right)^{-\sigma} \qquad I_{j,i,t} = \omega^I_{j,i,t} I_{j,t} \left(\frac{P^Y_{i,t}}{P^I_{j,t}} \right)^{-\sigma}$$

- Domestic intermediate downstream

$$M_{j,i,t} = \omega^M_{j,i,t} M_{j,t} \left(\frac{P^Y_{i,t}}{P^M_{j,t}} \right)^{-\sigma}$$

- Exports to foreign countries

$$EX_{d,i,t} = \omega^{\text{ex}}_{d,i,t} EX_{d,t} \left(\frac{P^{Y,*}_{d,i,t}}{P^{\text{ex},*}_{d,t}} \right)^{-\sigma}$$

- $\mathcal{E}_{d,t}$: nominal exchange rate in USD per unit of foreign currency, $(P^Y_{i,t} = \mathcal{E}_{d,t} P^{Y,*}_{d,i,t})$

Reduced form: market clearing

- As in the use tables

$$Y_{i,t} + IM_{i,t} = \sum_j M_{j,i,t} + C_{i,t} + \sum_j I_{j,i,t} + G_{i,t} + \sum_d EX_{d,i,t} + \Delta Y_{i,t}^{\text{inv}}$$

- where
  - $IM_{i,t}$: Imports
  - $M_{j,i,t}$: Materials shipments to industry j
  - $C_{i,t}$: Consumption
  - $I_{j,i,t}$: Category j investment (equipment, structures)
  - $G_{i,t}$: Government purchases
  - $EX_{d,i,t}$: Exports to country d
  - $\Delta Y_{i,t}^{\text{inv}}$: Changes in inventories

Reduced form: observable demand shifters

- Observable demand shifter: market size change

$$\Delta\xi_{i,t} := \sum_j s^M_{j,i,t-1}\Delta\ln M_{j,t} + s^C_{i,t-1}\Delta\ln C_t + \sum_j s^I_{j,i,t-1}\Delta\ln I_{j,t} + s^G_{i,t-1}\Delta\ln G_{i,t} + \sum_d s^{\text{ex}}_{d,i,t-1}\Delta\ln EX_{d,t}$$

- Observable demand shifter: price change

$$\Delta\pi_{i,t} := \sum_j s^M_{j,i,t-1}\Delta\ln P^M_{j,t} + s^C_{i,t-1}\Delta\ln P^C_t + \sum_j s^I_{j,i,t-1}\Delta\ln P^I_{j,t} + \sum_d s^{\text{ex}}_{d,i,t-1}\Delta\ln P^{\text{ex},*}_{d,t}$$

- Observable demand shifter: effective exchange rate change

$$\Delta e_{i,t} := \sum_d s^{\text{ex}}_{d,i,t-1}\Delta\ln \mathcal{E}_{d,t}$$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_\xi \left(\ln u_{i,t-1}\right) \Delta\xi_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_\xi \left(\ln u_{i,t-1}\right) \Delta\xi_{i,t} + \beta_\pi \left(\ln u_{i,t-1}\right) \Delta\pi_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_\xi \left(\ln u_{i,t-1}\right) \Delta\xi_{i,t} + \beta_\pi \left(\ln u_{i,t-1}\right) \Delta\pi_{i,t} + \beta_e \left(\ln u_{i,t-1}\right) \Delta e_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_e > 0$, $\beta'_e < 0$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_\xi \left(\ln u_{i,t-1}\right) \Delta\xi_{i,t} + \beta_\pi \left(\ln u_{i,t-1}\right) \Delta\pi_{i,t} + \beta_e \left(\ln u_{i,t-1}\right) \Delta e_{i,t} + \beta_Q \left(\ln u_{i,t-1}\right) \Delta \ln Q_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_e > 0$, $\beta'_e < 0$
- $\Delta \ln Q_{i,t}$: change in capacity, $\beta_Q > 0$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_{\xi}\left(\ln u_{i,t-1}\right)\Delta\xi_{i,t} + \beta_{\pi}\left(\ln u_{i,t-1}\right)\Delta\pi_{i,t} + \beta_{e}\left(\ln u_{i,t-1}\right)\Delta e_{i,t}$$
$$+\ \beta_{Q}\left(\ln u_{i,t-1}\right)\Delta \ln Q_{i,t} + \beta_{mc}\left(\ln u_{i,t-1}\right)\Delta \ln mc_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_{\xi} > 0$, $\beta'_{\xi} < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_{\pi} > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_{e} > 0$, $\beta'_{e} < 0$
- $\Delta \ln Q_{i,t}$: change in capacity, $\beta_{Q} > 0$
- $\Delta \ln mc_{i,t}$: change in marginal costs, $\beta_{mc} < 0$

Reduced form

$$\Delta \ln Y_{i,t} = \beta_\xi (\ln u_{i,t-1}) \Delta\xi_{i,t} + \beta_\pi (\ln u_{i,t-1}) \Delta\pi_{i,t} + \beta_e (\ln u_{i,t-1}) \Delta e_{i,t}$$
$$+ \; \beta_Q (\ln u_{i,t-1}) \Delta \ln Q_{i,t} + \beta_{mc} (\ln u_{i,t-1}) \Delta \ln mc_{i,t}$$
$$+ \; \beta_{\text{IM}} (\ln u_{i,t-1}) \frac{\Delta IM_{i,t}}{Y_{i,t-1}}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_e > 0$, $\beta'_e < 0$
- $\Delta \ln Q_{i,t}$: change in capacity, $\beta_Q > 0$
- $\Delta \ln mc_{i,t}$: change in marginal costs, $\beta_{mc} < 0$
- $\frac{\Delta IM_{i,t}}{Y_{i,t-1}}$: change in imports, $\beta_{\text{IM}} < 0$

Reduced form

$$
\begin{aligned}
\Delta \ln Y_{i,t} = {} & \beta_\xi (\ln u_{i,t-1}) \Delta\xi_{i,t} + \beta_\pi (\ln u_{i,t-1}) \Delta\pi_{i,t} + \beta_e (\ln u_{i,t-1}) \Delta e_{i,t} \\
& + \beta_Q (\ln u_{i,t-1}) \Delta \ln Q_{i,t} + \beta_{mc} (\ln u_{i,t-1}) \Delta \ln mc_{i,t} \\
& + \beta_{\text{IM}} (\ln u_{i,t-1}) \frac{\Delta IM_{i,t}}{Y_{i,t-1}} + \beta_{\text{inv}} (\ln u_{i,t-1}) \frac{\Delta Y^{\text{inv}}_{i,t} - \Delta Y^{\text{inv}}_{i,t-1}}{Y_{i,t-1}}
\end{aligned}
$$

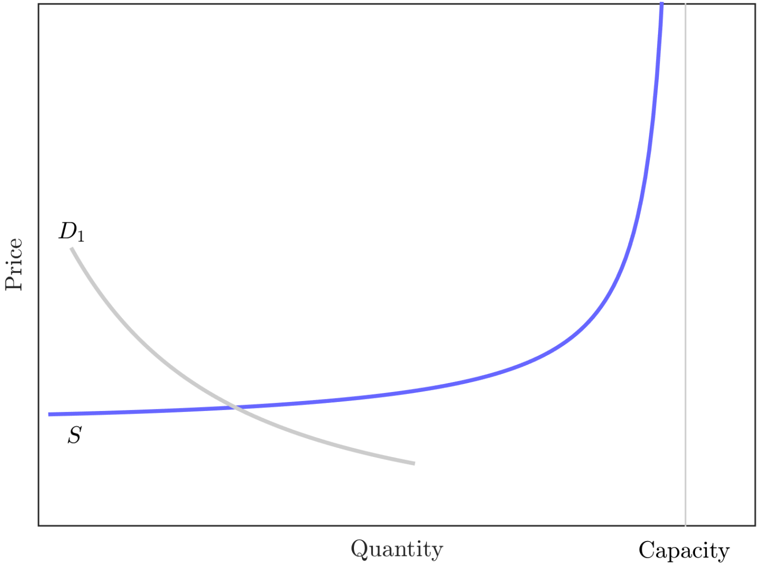
- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_e > 0$, $\beta'_e < 0$
- $\Delta \ln Q_{i,t}$: change in capacity, $\beta_Q > 0$
- $\Delta \ln mc_{i,t}$: change in marginal costs, $\beta_{mc} < 0$
- $\frac{\Delta IM_{i,t}}{Y_{i,t-1}}$: change in imports, $\beta_{\text{IM}} < 0$
- $\frac{\Delta Y^{\text{inv}}_{i,t} - \Delta Y^{\text{inv}}_{i,t-1}}{Y_{i,t-1}}$: change in change in inventories, $\beta_{\text{inv}} > 0$

Reduced form

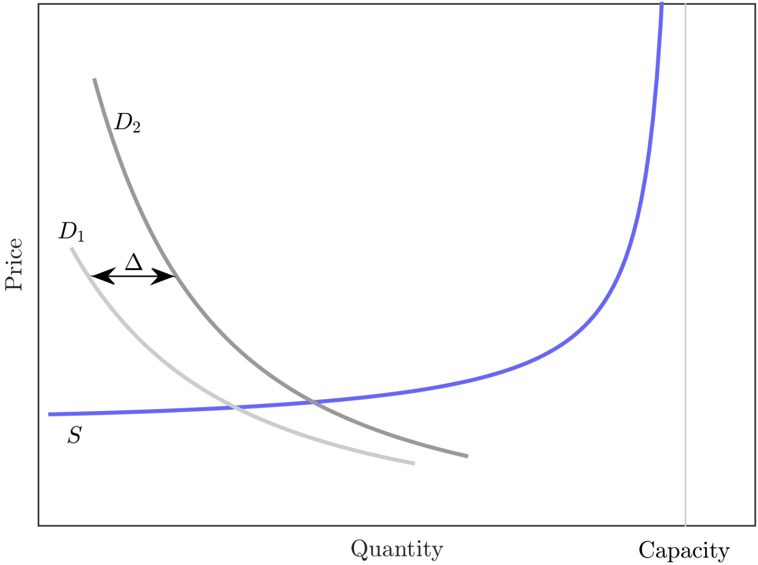
$$\Delta \ln Y_{i,t} = \beta_\xi \left(\ln u_{i,t-1}\right) \Delta\xi_{i,t} + \beta_\pi \left(\ln u_{i,t-1}\right) \Delta\pi_{i,t} + \beta_e \left(\ln u_{i,t-1}\right) \Delta e_{i,t}$$
$$+ \ \beta_Q \left(\ln u_{i,t-1}\right) \Delta \ln Q_{i,t} + \beta_{mc} \left(\ln u_{i,t-1}\right) \Delta \ln mc_{i,t}$$
$$+ \ \beta_{\text{IM}} \left(\ln u_{i,t-1}\right) \frac{\Delta IM_{i,t}}{Y_{i,t-1}} + \beta_{\text{inv}} \left(\ln u_{i,t-1}\right) \frac{\Delta Y^{\text{inv}}_{i,t} - \Delta Y^{\text{inv}}_{i,t-1}}{Y_{i,t-1}} + \omega^Y_{i,t}$$

- $\Delta\xi_{i,t}$: change in market size, $\beta_\xi > 0$, $\beta'_\xi < 0$
- $\Delta\pi_{i,t}$: change in prices, $\beta_\pi > 0$
- $\Delta e_{i,t}$: change in effective exchange rate, $\beta_e > 0$, $\beta'_e < 0$
- $\Delta \ln Q_{i,t}$: change in capacity, $\beta_Q > 0$
- $\Delta \ln mc_{i,t}$: change in marginal costs, $\beta_{mc} < 0$
- $\frac{\Delta IM_{i,t}}{Y_{i,t-1}}$: change in imports, $\beta_{\text{IM}} < 0$
- $\frac{\Delta Y^{\text{inv}}_{i,t} - \Delta Y^{\text{inv}}_{i,t-1}}{Y_{i,t-1}}$: change in change in inventories, $\beta_{\text{inv}} > 0$
- $\omega^Y_{i,t}$: error

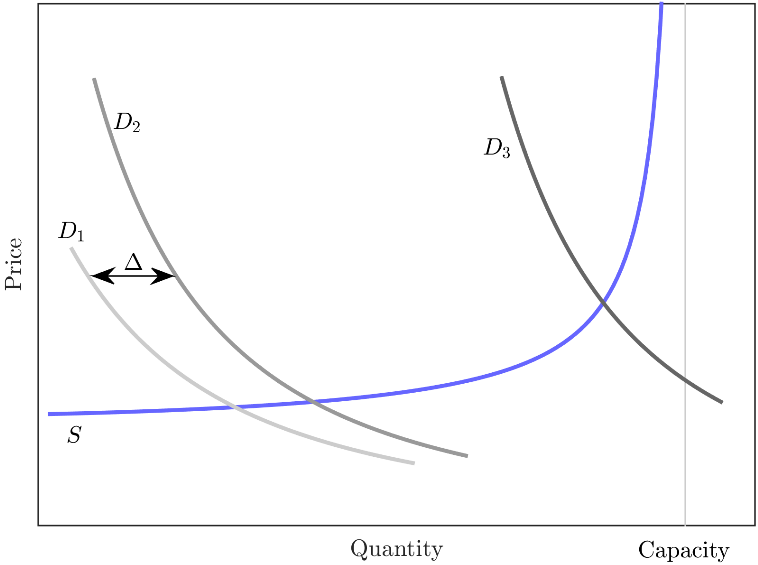
Intuition



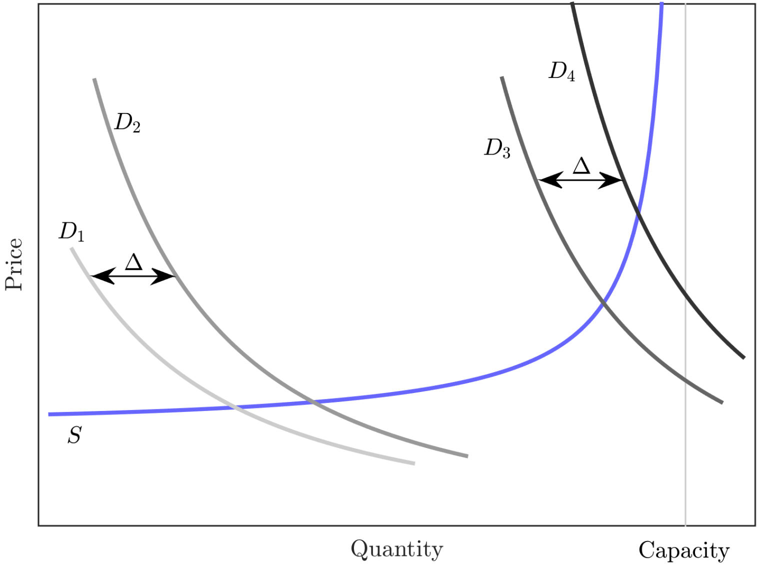
Intuition



Intuition



Intuition



Estimates of the reduced form

Dependent variable: $\Delta \ln Y_{i,t}$

Estimator	OLS	OLS	OLS	2SLS	2SLS	2SLS
Instrument(s)				WID	Shea	WID, Shea
$\Delta\xi_{i,t}$	0.89	0.81	0.77	0.60	0.87	0.85
	(0.08)	(0.07)	(0.11)	(0.42)	(0.13)	(0.13)
$\Delta\pi_{i,t}$	-0.03	-0.03	-0.10	-0.07	-0.12	-0.12
	(0.11)	(0.11)	(0.12)	(0.13)	(0.12)	(0.12)
$\Delta e_{i,t}$	1.94	1.83	0.94	1.17	0.82	0.84
	(0.60)	(0.48)	(1.05)	(1.23)	(1.01)	(1.01)
$\Delta \ln Q_{i,t}$	0.69	0.72	0.64	0.67	0.63	0.63
	(0.07)	(0.06)	(0.07)	(0.10)	(0.07)	(0.07)
$\Delta \ln \mathrm{UVC}_{i,t}$	-0.08	-0.07	-0.10	-0.10	-0.10	-0.10
	(0.05)	(0.06)	(0.04)	(0.05)	(0.04)	(0.04)
$\left(\Delta Y_{i,t}^{\text{inv}} - \Delta Y_{i,t-1}^{\text{inv}}\right)/Y_{i,t-1}$		1.00	0.89	0.92	0.87	0.87
		(0.14)	(0.15)	(0.18)	(0.15)	(0.15)
$\Delta IM_{i,t}/Y_{i,t-1}$		-0.10	0.04	0.12	0.00	0.01
		(0.08)	(0.09)	(0.19)	(0.09)	(0.09)
R-squared	0.691	0.735	0.826	0.824	0.826	0.826
Fixed Effects	no	no	yes	yes	yes	yes
First stage and instrument diagnostics						
F Main effect				7.23	288.86	159.92
Hansen J (p-value)						0.567

Note: Driscoll-Kraay standard errors are reported in parentheses.

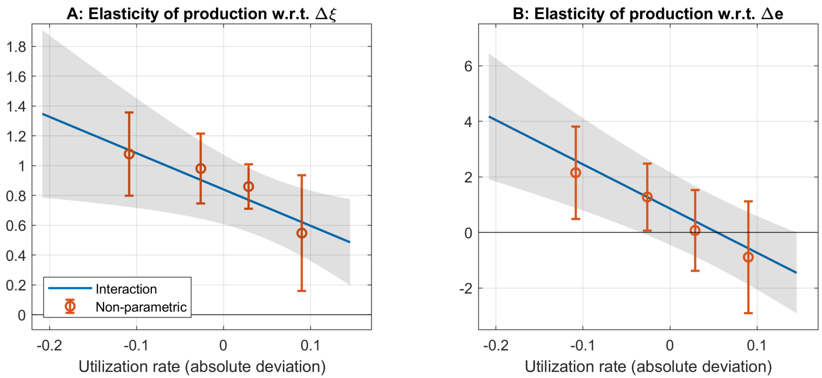
Estimates of the nonlinear reduced form

Dependent variable: $\Delta \ln Y_{i,t}$

Estimator	OLS	2SLS	2SLS	2SLS
Instrument(s): Main effect		WID, Shea		
Instrument(s): Interaction ($\cdot (u_{i,t-1} - \bar{u}_i)$)		WID	Shea	WID, Shea
$\Delta\xi_{i,t}$	0.75	0.82	0.83	0.82
	(0.09)	(0.14)	(0.13)	(0.13)
$\Delta\xi_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-1.78	-4.49	-2.89	-3.57
	(0.61)	(1.02)	(1.59)	(0.95)
$\Delta e_{i,t}$	0.50	0.30	0.36	0.34
	(1.02)	(0.90)	(0.91)	(0.90)
$\Delta e_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-20.28	-20.76	-20.61	-20.67
	(5.30)	(5.93)	(5.45)	(5.61)
R-squared	0.846	0.840	0.845	0.843
Other controls	yes	yes	yes	yes
Fixed Effects	yes	yes	yes	yes
First stage and instrument diagnostics				
F Main effect		115.26	140.27	109.54
F Interaction		14.33	16.12	18.31
Cragg-Donald Wald F		28.77	39.33	38.28
Hansen J (p-value)		0.447	0.442	0.559

Note: Driscoll-Kraay standard errors are reported in parentheses.

Nonparametric estimates

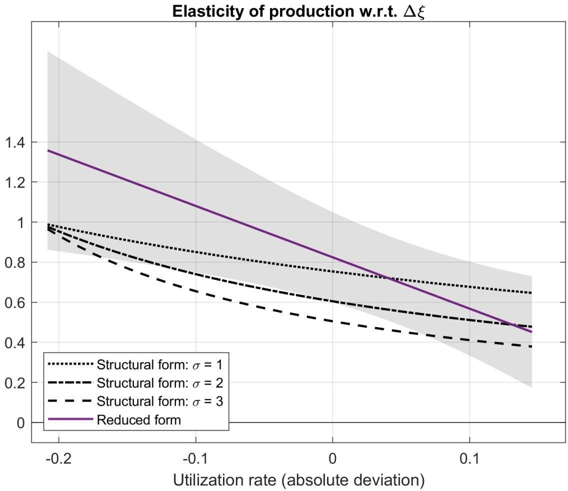


Percentiles of utilization rate (absolute deviation)

Percentile	p1	p5	p10	p25	p50	p75	p90	p95	p99
Value	-0.21	-0.13	-0.09	-0.04	0.01	0.04	0.08	0.10	0.15

back to robustness   back to further robustness

Are the estimates of reduced and structural form consistent with one another?



Note: σ is the demand elasticity.

Second order approximation

Specification: $\Delta \ln P^{Y}_{i,t} = \beta_0 + \beta_1 \Delta \ln Y_{i,t} + \beta_2 \left(\Delta \ln Y_{i,t}\right)^2 + \text{controls} + \varepsilon_{i,t}$

Estimator	2SLS	2SLS	2SLS
Instruments: Main effect		WID, Shea	
Instruments: Squared term		WID, Shea	
$\Delta \ln Y_{i,t}$	0.50	0.18	0.20
	(0.37)	(0.12)	(0.12)
$\left(\Delta \ln Y_{i,t}\right)^2$	-2.90	-0.88	-0.92
	(1.41)	(0.60)	(0.67)
$\Delta \ln Q_{i,t}$			-0.14
			(0.11)
$\Delta \ln \text{UVC}_{i,t}$		0.89	0.90
		(0.03)	(0.04)
R-squared	0.343	0.900	0.901
Fixed Effects	yes	yes	yes
First stage and instrument diagnostics			
F Main effect	9.81	12.57	17.44
F Squared term	2.47	2.44	2.45
Cragg-Donald Wald F	5.61	5.87	3.94
SW F Main effect	13.27	19.80	23.77
SW F Squared term	3.30	3.32	3.29
Hansen J (p-value)	0.918	0.960	0.948

Note: Driscoll-Kraay standard errors are reported in parentheses. back

Coefficient restrictions

Specification

$$
\begin{aligned}
\Delta \ln P^{Y}_{i,t} \;=\; & \alpha + \beta_Y \Delta \ln Y_{i,t} + \beta_{Yu} \Delta \ln Y_{i,t} \cdot (u_{i,t-1} - u_i) + \beta_u \,(u_{i,t-1} - u_i) \\
& + \beta_Q \Delta \ln Q_{i,t} + \beta_{Qu} \Delta \ln Q_{i,t} \cdot (u_{i,t-1} - u_i) + \beta_{\text{UVC}} \Delta \ln \text{UVC}_{i,t} + \varepsilon_{i,t}
\end{aligned}
$$

Individual tests

H_0 :	p-value
$\beta_Y + \beta_Q = 0$	0.302
$\beta_{Yu} + \beta_{Qu} = 0$	0.847
$\beta_u = 0$	0.593
$\beta_{\text{UVC}} = 1$	0.000

Note: Wald tests based on Driscoll-Kraay standard errors.

Coefficient restrictions

Specification
$$\Delta \ln P^{Y}_{i,t} = \alpha + \beta_Y \Delta \ln Y_{i,t} + \beta_{Yu} \Delta \ln Y_{i,t} \cdot (u_{i,t-1} - u_i) + \beta_u (u_{i,t-1} - u_i) + \beta_Q \Delta \ln Q_{i,t} + \beta_{Qu} \Delta \ln Q_{i,t} \cdot (u_{i,t-1} - u_i) + \beta_{\text{UVC}} \Delta \ln \text{UVC}_{i,t} + \varepsilon_{i,t}$$

Joint tests

H_0 :	p-value
Joint test 1	0.000
$\beta_Y + \beta_Q = 0$	
$\beta_{Yu} + \beta_{Qu} = 0$	
$\beta_u = 0$	
$\beta_{\text{UVC}} = 1$	
Joint test 2	0.350
$\beta_Y + \beta_Q = 0$	
$\beta_{Yu} + \beta_{Qu} = 0$	
$\beta_u = 0$	

Note: Wald tests based on Driscoll-Kraay standard errors. back

Heterogeneity

Dependent variable: $\Delta \ln P^Y_{i,t}$

	By durability		By average utilization rate	
	nondurable	durable	low	high
$\Delta \ln Y_{i,t}$	0.16	0.20	0.26	0.21
	(0.07)	(0.06)	(0.07)	(0.10)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.15	0.82	1.04	1.29
	(0.39)	(0.37)	(0.31)	(0.45)
R-squared	0.907		0.905	
Other controls	yes		yes	
Fixed effects	yes		yes	
First stage and instrument diagnostics				
F Main effect	27.03	116.29	68.42	32.10
F Interaction	54.36	29.94	47.45	10.09
Cragg-Donald Wald F	7.681		4.456	
Hansen J (p-value)	0.714		0.849	

Note: Driscoll-Kraay standard errors are reported in parentheses. back

Aggregate implications of convex supply curves

1. Government expenditure multiplier $\frac{\mathrm{d}Y}{\mathrm{d}G}$
   - becomes state-dependent

2. Slope of Phillips curve
   - $\frac{mc}{P_Y}$ convex function of output (explain missing disinflation)

3. Welfare costs of business cycles
   - shocks affect mean of consumption and hours

4. Many more ...

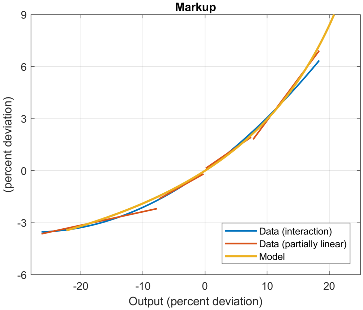
Nonlinear production network

- Final consumer
  - consumes (isoelastic utility, nested CES)
  - supplies labor (separable isoelastic disutility)
- Many industries
  1. capacity industries: markup increasing and convex
  2. non-capacity industries: markup constant

  - hire labor, buy intermediates
  - produce output
- Demand shocks (wedge) drives business cycle

Baseline calibration

- 45 capacity industries
  - e.g. Manufacturing, Construction, Air transportation
- 26 non-capacity industries
  - e.g. Legal services, Government
- Key parameters
  - Frisch labor supply elasticity $\eta = 2$ (Hall, 09)
  - Elasticities of substitution $\varepsilon = 0.05$ (Boehm et al. 19, others)



Aggregation

Overall curvature of aggregate supply determined by

1. Accumulation of markups (Convexity $\uparrow$)
   - Net markups are additive in input-output networks
2. Substitution (Convexity $\downarrow$)
   - Evidence: very limited substitution at high frequencies
3. Heterogeneity in nonlinear aggregation (Convexity $\uparrow$)
   - Fairly limited (due to limited substitution)

State-dependent expenditure multiplier

	Initial output relative to steady state (in percent)					Difference
	-10	-5	0	5	10	-10/+10
Calibration	Government expenditure multiplier					
Baseline	0.68	0.65	0.63	0.59	0.55	0.12
Elasticity of substitution 0.5	0.68	0.66	0.64	0.63	0.61	0.07
22 capacity industries	0.72	0.71	0.69	0.67	0.64	0.08
66 capacity industries	0.62	0.59	0.56	0.51	0.46	0.16
Frisch labor supply elasticity 1	0.56	0.54	0.52	0.50	0.47	0.09
Frisch labor supply elasticity 5	0.77	0.74	0.71	0.67	0.62	0.15

Slope of Phillips curve

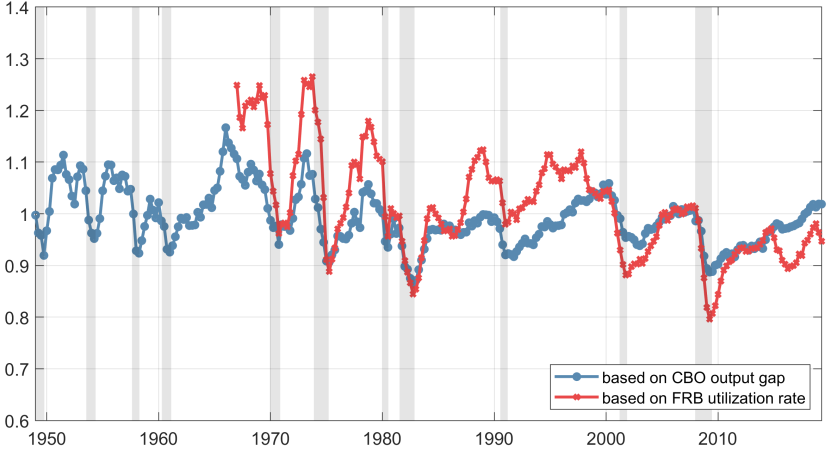
- Define partial elasticity

$$\left.\frac{\partial \ln \frac{mc_t}{P_t^Y}}{\partial \ln Y_t}\right|_{MU=const}$$

  - does not impose constant markup of aggregating firm
  - does not impose output market clearing
  - holds marginal utility constant

- Well-defined object in static model
- Key determinant of slope of Phillips curve

Slope of Phillips curve



Welfare costs of business cycles

- Calibration
  - Demand shock lognormal, calibrate $\text{sd}[\ln C] = 0.032$ (Lucas, 87)
- Results:
  - Consumption and hours both mildly left-skewed

Model/calibration	$\frac{\mathbb{E}[C]-C_{ss}}{C_{ss}}$ (in percent)	$\frac{\mathbb{E}[n]-n_{ss}}{n_{ss}}$ (in percent)	Welfare costs (in percent)
Baseline	-0.097	-0.076	0.119
Elasticity of substitution 0.5	-0.077	-0.059	0.115
22 capacity industries	-0.071	-0.055	0.107
66 capacity industries	-0.129	-0.101	0.135
Frisch labor supply elasticity 1	-0.114	-0.090	0.139
Frisch labor supply elasticity 5	-0.088	-0.068	0.107
Lucas (87)	-	-	0.068

back