Are supply curves convex? Implications for state-dependent responses to shocks

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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 views expressed are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System. The contribution of Pandalai-Nayar has been prepared under the Lamfalussy Fellowship Program sponsored by the European Central Bank.
Motivation

- **Question:** Are responses to demand shocks state dependent?
  - Average vs. conditional policy effects

- Evidence: Auerbach and Gorodnichenko (12), Tenreyro and Thwaites (16)

- Theoretically possible, multiple candidate mechanisms

- Concerns:
  - Robustness, e.g. Ramey and Zubairy (14), Santoro et al. (14)
  - Little to no structure

- Identification

- Our approach:
  - Commit to one mechanism: convex supply curves
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Motivation

Diagram showing the relationship between price, quantity, and capacity.
Motivation

The diagram illustrates the relationship between price, quantity, and capacity. The curves labeled $D_1$, $D_2$, $D_3$, and $D_4$ represent different demand scenarios. The vertical line on the right represents capacity, and the horizontal line at the bottom represents quantity. The price axis is on the left.

The shift arrows, labeled $\Delta$, indicate changes in demand or supply conditions. The curve $S$ represents supply.

The graph shows how changes in demand ($D_1$ to $D_4$) can impact the market equilibrium, with the price and quantity adjusting to accommodate the new demand levels.
Related Literature

• **State-dependent effects of stabilization policy**
  Auerbach and Gorodnichenko (12, 13a, 13b), Michaillat (14), Owyang, Ramey, and Zubairy (13), Ramey and Zubairy (forthcoming), Santoro et al. (14), Tenreyro and Thwaites (16), Jorda, Schularick, and Taylor (17)

• **Capacity/capital utilization**
  • Theory: Greenwood, Hercovitz, and Huffman (88), Cooley, Hansen, and Prescott (95), Fagnart, Licandro, and Portier (97)
  • Empirics: Morin and Stevens (04), Bansak, Morin, and Starr (07), Lein and Koeberl (09, 11), Lein (10), Shapiro (89), Stock and Watson (99)

• **Exchange rate shocks**
  Gopinath and Rigobon (08), Amiti, Itskhoki and Konings (14)
1. Motivation

2. Model

3. Estimation

4. Direct evidence on rationing

5. Conclusion
Model

- Main assumption: Putty clay capacity limit $Q_{i,t}$

Evidence
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Convexity: markup adjustments, rationing, shift premia, etc.
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- Observable concept of capacity utilization $u_{i,t} = \frac{X_{i,t}}{Q_{i,t}}$
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- Sufficient statistics estimating equation

- Object of analysis: Industry
Equilibrium

- Supply of industry $i$

$$\ln P_{i,t} = \Xi(u_{i,t}) + \ln \frac{w_{i,t}L_{i,t}}{X_{i,t}}$$
EQUILIBRIUM

• Supply of industry $i$

$$\ln P_{i,t} = \Xi (u_{i,t}) + \ln \frac{w_{i,t}L_{i,t}}{X_{i,t}}$$

• Demand from country $n$

$$X_{i,n,t} = \omega_{i,n,t}X_{n,t} \left[ \frac{P_{i,n,t}^{*}}{P_{n,t}^{*}} \right]^{-\sigma}$$
**Equilibrium**

- **Supply of industry** $i$
  \[
  \ln P_{i,t} = \Xi(w_{i,t}) + \ln \frac{w_{i,t}L_{i,t}}{X_{i,t}}
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- **Exchange rate**
  \[
  P_{i,n,t} = \varepsilon_{n,t}^{*}P_{i,n,t}^{*}
  \]
**EQUILIBRIUM**

- Supply of industry $i$

  $$\ln P_{i,t} = \Xi (u_{i,t}) + \ln \frac{w_{i,t}L_{i,t}}{X_{i,t}}$$

- Demand from country $n$

  $$X_{i,n,t} = \omega_{i,n,t}X_{n,t} \left[ \frac{P^*_{i,n,t}}{P^*_n} \right]^{-\sigma}$$

- Exchange rate

  $$P_{i,n,t} = \mathcal{E}_{n,t}P^*_{i,n,t}$$

- Market clearing

  $$X_{i,t} = G_{i,t} + \sum_n X_{i,n,t}$$
**Shocks**

- Effective exchange rate depreciation of industry $i$
  \[ \Delta e_{i,t} := \sum_{n} s_{i,n,t-1} \Delta \ln E_{n,t} \]

- $s_{i,n,t}$: sales share to country $n$
- $n = 0$ is the U.S. (with $\Delta \ln E_{0,t} = 0$)
**Shocks**

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- Defense spending shock

$$\Delta g_{i,t} := \frac{G_{i,t} - G_{i,t-1}}{X_{i,t-1}}$$

- Use Bartik-type instrument with aggregate defense spending
1. Motivation
2. Model
3. Data and Estimation
4. Conclusion
Estimation

Baseline specification

\[ \Delta \ln X_{i,t} = \beta_e \Delta e_{i,t} + \beta_{eu} \Delta e_{i,t} \cdot u_{i,t-1} + \beta_u u_{i,t-1} \]

\[ + \text{ controls} + \omega_{i,t}^X \]
Estimation

Baseline specification

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• If \( \beta_{eu} < 0 \) the supply curve is convex
**Estimation**

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- Controls include
  1. Market size and prices
  2. Unit costs
  3. Capacity
  4. Interactions with utilization
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- If \( \beta_{eu} < 0 \) the supply curve is convex

- Controls include
  1. Market size and prices
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- Identification
  - \( \beta_u \) will in general be biased, \( \beta_{eu} \) won’t
  - Next turn to \( \Delta e_{i,t} \)
Identification

Purification of $\Delta e_{i,t}$

1. Control for cost changes (Amiti et al., 14)
Purification of $\Delta e_{i,t}$

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2. Decomposition ($R^2$ of 28.3 percent)

$$\Delta \ln \mathcal{E}_{n,t} = \Delta \ln \mathcal{E}_{t}^{com} + \Delta \ln \mathcal{E}_{n,t}^{spec}$$
IDENTIFICATION

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$$
\Delta \ln \mathcal{E}_{n,t} = \Delta \ln \mathcal{E}^{com}_t + \Delta \ln \mathcal{E}^{spec}_{n,t}
$$

Then

$$
\Delta e_{i,t} = \underbrace{\Delta \ln \mathcal{E}^{com}_t \times (1 - s_{i,0,t-1})}_{\text{time FE} \times (1 - s_{i,0,t-1})}
$$
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Then

$$\Delta e_{i,t} = \Delta \ln \mathcal{E}_{t}^{com} \times (1 - s_{i,0,t-1}) + \sum_{n=1}^{N} \bar{s}_{n,t-1} \Delta \ln \mathcal{E}_{n,t}^{spec}$$
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Then

$$\Delta e_{i,t} = \Delta \ln \varepsilon_{t}^{com} \times (1 - s_{i,0,t-1}) \underbrace{\text{time FE } \times (1 - s_{i,0,t-1})}_{\text{time FE}} + \sum_{n=1}^{N} \bar{s}_{n,t-1} \Delta \ln \varepsilon_{n,t}^{spec}$$

$$+ \sum_{n=1}^{N} (s_{i,n,t-1} - \bar{s}_{n,t-1}) \Delta \ln \varepsilon_{n,t}^{spec}$$

our shock
## Results: Quantities

Dependent variable $\Delta \ln X_{i,t}$

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
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<tbody>
<tr>
<td>$\Delta e_{i,t}$</td>
<td>2.79***</td>
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<tr>
<td></td>
<td>(0.75)</td>
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</tr>
<tr>
<td>$\Delta e_{i,t} \times u_{i,t-1}$</td>
<td>-22.30**</td>
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<tr>
<td></td>
<td>(9.43)</td>
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<tr>
<td>$u_{i,t-1}$</td>
<td>-0.04</td>
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<tr>
<td></td>
<td>(0.09)</td>
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</tr>
</tbody>
</table>

Baseline controls | yes

Observations | 819
R-squared | 0.554
Industry FE | no
Time FE | no
Time FE $\times (1 - s_{i,0,t-1})$ | no
Higher order controls | no

Note: Driscoll-Kraay standard errors. Significance: *** p<0.01, ** p<0.05, * p<0.1.
**Interpreting of the interaction term**

Dependent Variable: $\Delta \ln X_{i,t}$

<table>
<thead>
<tr>
<th>Percentile</th>
<th>Utilization rate</th>
<th>Elasticity w.r.t. $\Delta e_{i,t}$</th>
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<tr>
<td>$10^{th}$</td>
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<td>$25^{th}$</td>
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<td>$50^{th}$</td>
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<td>$75^{th}$</td>
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<tr>
<td>$90^{th}$</td>
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<tr>
<td>$u_{i,t-1}$</td>
<td>-0.04</td>
<td>-0.09</td>
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<td>(0.08)</td>
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<td><strong>Higher order controls</strong></td>
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<td>(6.34)</td>
<td>(7.19)</td>
</tr>
<tr>
<td>$u_{i,t-1}$</td>
<td>-0.04</td>
<td>-0.09</td>
<td>-0.16</td>
<td>-0.18**</td>
<td>-0.23**</td>
</tr>
<tr>
<td></td>
<td>(0.09)</td>
<td>(0.08)</td>
<td>(0.10)</td>
<td>(0.09)</td>
<td>(0.08)</td>
</tr>
</tbody>
</table>

Baseline controls     yes    yes    yes    yes    yes

Observations          819    819    819    819    819
R-squared             0.554  0.569  0.679  0.714  0.735
Industry FE           no     yes    yes    yes    yes
Time FE               no     no     yes    yes    yes
Time FE $\times (1 - s_{i,0,t-1})$ no     no     no     yes    yes
Higher order controls no     no     no     no     yes

Note: Driscoll-Kraay standard errors. Significance: *** p<0.01, ** p<0.05, * p<0.1.
## Results: Prices

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

<table>
<thead>
<tr>
<th></th>
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<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta e_{i,t}$</td>
<td>-0.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.24)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\Delta e_{i,t} \times u_{i,t-1}$</td>
<td>4.89**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1.74)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$u_{i,t-1}$</td>
<td>-0.06*</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Baseline controls: yes

Observations: 819

R-squared: 0.906

Industry FE: no

Time FE: no

Time FE $\times (1 - s_{i,0,t-1})$: no

Higher order controls: no

Note: Driscoll-Kraay standard errors. Significance: *** $p<0.01$, ** $p<0.05$, * $p<0.1$. 
## Results: Prices

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta e_{i,t}$</td>
<td>-0.12</td>
<td>-0.13</td>
<td>-0.13</td>
<td>0.25</td>
<td>-1.69*</td>
</tr>
<tr>
<td></td>
<td>(0.24)</td>
<td>(0.23)</td>
<td>(0.21)</td>
<td>(0.74)</td>
<td>(0.93)</td>
</tr>
<tr>
<td>$\Delta e_{i,t} \times u_{i,t-1}$</td>
<td>4.89**</td>
<td>4.53**</td>
<td>5.99***</td>
<td>5.66***</td>
<td>5.10**</td>
</tr>
<tr>
<td></td>
<td>(1.74)</td>
<td>(1.78)</td>
<td>(1.97)</td>
<td>(1.66)</td>
<td>(1.93)</td>
</tr>
<tr>
<td>$u_{i,t-1}$</td>
<td>-0.06*</td>
<td>-0.07**</td>
<td>-0.04</td>
<td>-0.04</td>
<td>-0.01</td>
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<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.04)</td>
</tr>
</tbody>
</table>

Baseline controls | yes | yes | yes | yes | yes | yes |

Observations | 819 | 819 | 819 | 819 | 819 | 819 |

R-squared | 0.906 | 0.908 | 0.921 | 0.927 | 0.932 |

Industry FE | no | yes | yes | yes | yes |

Time FE | no | no | yes | yes | yes |

Time FE $\times (1 - s_{i,0,t-1})$ | no | no | no | yes | yes |

Higher order controls | no | no | no | no | yes |

Note: Driscoll-Kraay standard errors. Significance: *** p<0.01, ** p<0.05, * p<0.1.
Outline

1. Motivation
2. Model
3. Data and Estimation: Extension to defense spending
4. Conclusion
Note: Shaded areas are one standard error bands, clustered by industry
CONCLUSION

- Structural model with capacity constraints
Conclusion

- Structural model with capacity constraints
- Sufficient statistics approach to estimation
CONCLUSION

- Structural model with capacity constraints
- Sufficient statistics approach to estimation
- Responses to demand shocks are highly state dependent
Conclusion

- Structural model with capacity constraints
- Sufficient statistics approach to estimation
- Responses to demand shocks are highly state dependent
- Evidence consistent with convex supply curves
Conclusion

- Structural model with capacity constraints
- Sufficient statistics approach to estimation
- Responses to demand shocks are highly state dependent
- Evidence consistent with convex supply curves
- Implications for stabilization policy?
## Survey Form

### Item 2  VALUE OF PRODUCTION

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

**ACTUAL PRODUCTION.** ................................................

###  $\text{\textdollar}Bil. \quad \text{Mil.} \quad \text{Thou.}$

**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.** ......................................

###  $\text{\textdollar}Bil. \quad \text{Mil.} \quad \text{Thou.}$

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

###  $\text{\textdollar}Bil. \quad \text{Mil.} \quad \text{Thou.}$

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

---

[Back]
NONPARAMETRIC ESTIMATION: QUANTITIES

![Graph showing exchange rate coefficient vs. tercile of utilization.](image)
### Results: Quantities

<table>
<thead>
<tr>
<th>RHS Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sum_n s_{i,n,t-1} \Delta \ln \mathcal{E}_{n,t}$</td>
<td>2.22***</td>
<td>0.48</td>
<td>0.83</td>
<td>2.20***</td>
</tr>
<tr>
<td></td>
<td>(0.60)</td>
<td>(0.80)</td>
<td>(0.80)</td>
<td>(0.57)</td>
</tr>
<tr>
<td>$\sum_n s_{i,n,t-1} \Delta \ln \mathcal{E}<em>{n,t} \cdot u</em>{i,t-1}$</td>
<td>-16.32***</td>
<td>-32.12***</td>
<td>-30.08***</td>
<td>-17.32***</td>
</tr>
<tr>
<td></td>
<td>(5.48)</td>
<td>(5.70)</td>
<td>(5.40)</td>
<td>(5.43)</td>
</tr>
<tr>
<td>$\Delta \ln q_{i,t}$</td>
<td>0.98***</td>
<td></td>
<td></td>
<td>0.99***</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td></td>
<td></td>
<td>(0.05)</td>
</tr>
<tr>
<td>$\Delta \ln q_{i,t} \cdot u_{i,t-1}$</td>
<td>-0.54</td>
<td></td>
<td></td>
<td>-0.38</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td></td>
<td></td>
<td>(0.55)</td>
</tr>
<tr>
<td>$\Delta \ln m_{ci,t}$</td>
<td>-0.03</td>
<td></td>
<td>-0.17***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td></td>
<td>(0.05)</td>
<td></td>
</tr>
<tr>
<td>$\Delta \ln m_{ci,t} \cdot u_{i,t-1}$</td>
<td>-0.55</td>
<td></td>
<td>-0.64</td>
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</tr>
<tr>
<td></td>
<td>(0.56)</td>
<td></td>
<td>(0.86)</td>
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</tr>
</tbody>
</table>

Other variables: yes, yes, yes, yes

Observations: 819, 819, 819, 819
R-squared: 0.62, 0.37, 0.39, 0.62
Industry FE: no, no, no, no
Time FE: no, no, no, no

Driscoll-Kraay standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.
## Results: Quantities

<table>
<thead>
<tr>
<th>RHS Variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ \sum_n s_{i,n,t-1} \Delta \ln \varepsilon_{n,t} ]</td>
<td>0.85</td>
<td>-0.16</td>
<td>-0.15</td>
<td>0.89</td>
</tr>
<tr>
<td></td>
<td>(0.81)</td>
<td>(0.81)</td>
<td>(0.78)</td>
<td>(0.83)</td>
</tr>
<tr>
<td>[ \sum_n s_{i,n,t-1} \Delta \ln \varepsilon_{n,t} \cdot u_{i,t-1} ]</td>
<td>-16.62***</td>
<td>-22.33***</td>
<td>-21.21***</td>
<td>-16.97***</td>
</tr>
<tr>
<td></td>
<td>(4.36)</td>
<td>(6.86)</td>
<td>(6.78)</td>
<td>(4.43)</td>
</tr>
<tr>
<td>[ \Delta \ln q_{i,t} ]</td>
<td>0.96***</td>
<td></td>
<td></td>
<td>0.97***</td>
</tr>
<tr>
<td></td>
<td>(0.11)</td>
<td></td>
<td></td>
<td>(0.11)</td>
</tr>
<tr>
<td>[ \Delta \ln q_{i,t} \cdot u_{i,t-1} ]</td>
<td></td>
<td>-0.57</td>
<td></td>
<td>-0.48</td>
</tr>
<tr>
<td></td>
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<td>(0.71)</td>
<td></td>
<td>(0.66)</td>
</tr>
<tr>
<td>[ \Delta \ln mc_{i,t} ]</td>
<td></td>
<td>-0.06**</td>
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<td>-0.11**</td>
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<tr>
<td></td>
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<td>(0.03)</td>
<td></td>
<td>(0.04)</td>
</tr>
<tr>
<td>[ \Delta \ln mc_{i,t} \cdot u_{i,t-1} ]</td>
<td></td>
<td>-0.36</td>
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<td>-0.63</td>
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<td>(0.45)</td>
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<td>(0.64)</td>
</tr>
</tbody>
</table>

Other variables: yes, yes, yes, yes

Observations: 819, 819, 819, 819
R-squared: 0.70, 0.61, 0.61, 0.70
Industry FE: yes, yes, yes, yes
Time FE: yes, yes, yes, yes

Driscoll-Kraay standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1.
CROSS-SECTIONAL DISTRIBUTION OF UTILIZATION

![Graph showing cross-sectional distribution of utilization with density on the y-axis and utilization rate on the x-axis. The graph includes lines for 2007, 2009, and 2011.]
Data

- Sample
  - Manufacturing 3-digit NAICS industries (21)
  - Old OECD countries
  - 1972 - 2011
Data

• Sample
  • Manufacturing 3-digit NAICS industries (21)
  • Old OECD countries
  • 1972 - 2011

• Penn World Tables: exchange rates, GDP, deflator

• Federal Reserve Board: capacity, utilization

• NBER CES Manufacturing Industry Database: prices, sales, inventories, unit cost:

\[
\frac{wL}{X} = \frac{\text{Production Wages + Material Cost + Energy Cost}}{\text{Output}}
\]
Data

- Sample
  - Manufacturing 3-digit NAICS industries (21)
  - Old OECD countries
  - 1972 - 2011

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- NBER CES Manufacturing Industry Database: prices, sales, inventories, unit cost:
  \[
  \frac{wL}{X} = \frac{\text{Production Wages} + \text{Material Cost} + \text{Energy Cost}}{\text{Output}}
  \]

- Peter Schott’s website: exports