Online Appendix

for

Convex Supply Curves

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Table of Contents

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A Appendix: Data

A.1 Capacity utilization at the plant level

This appendix discusses background information on the Quarterly Survey of Plant Capacity Utilization (QSPC) and basic facts on plants' capacity utilization using public use data.

Background The survey is conducted by the US Census Bureau and funded jointly by the Federal Reserve Board and the Department of Defense. The sample is drawn from all US manufacturing and publishing plants with 5 or more production employees. Among other things, establishments are asked about the market value of their *actual production* and the estimated market value of their *full production capacity*. Respondents are asked to construct the full capacity estimate under the following assumptions: 1) only the current functional machinery and equipment is available, 2) normal downtime, 3) labor, materials, and other non-capital inputs are fully available, 4) a realistic and sustainable shift and work schedule, and 5) that the establishment produces the same product mix as its current production. Figure A1 shows the question on the survey form. The current survey form of the Quarterly Survey of Plant Capacity Utilization is available at `https://www2.census.gov/programs-surveys/qpc/technical-documentation/questionnaires/form-mq-c2-worksheet-final-after-omb-approval.pdf`. Capacity utilization rates are then obtained by dividing the market value of actual production by the estimate of full capacity production.

Why do plants produce below capacity? The survey also contains questions on why establishments produce at levels below their capacity. As Figure A1 shows, respondents of the QSPC are asked: "If this plant's actual production in the current quarter was less than full production capacity, mark (X) the primary reasons." Possible answers include "Insufficient supply of materials", "Insufficient orders", "Insufficient supply of local labor force/skills", and others. Multiple answers are permitted. It turns out that the vast majority of plants produce below capacity because they are not able to sell their products. For the time period from 2013q1 to 2018q4, 78 percent of plant managers cite insufficient orders as the main reason for producing below capacity. The second most cited option is chosen by 12 percent of respondents (insufficient supply of local labor force/skills). These responses are summarized in Figure A2. This evidence is consistent with our model, in which plants produce below capacity in equilibrium because they cannot sell more of their product at the desired price. For information on the data, see US Census Bureau (2013-2018) and US Census Bureau (2006, p. A-3).

A.2 Data for industry-level analysis

Sample Our baseline sample is annual and includes all 21 3-digit NAICS manufacturing industries. It ranges from 1972 to 2011.

Industrial production, capacity, and capacity utilization The series for industrial production, capacity, and capacity utilization are obtained from the Federal Reserve Board and available at `https://www.federalreserve.gov/releases/g17/ipdisk/alltables.txt` (see also Federal Reserve Board, 1972-2011). Table A1 provides summary statistics of the utilization rate by NAICS

Page 2

Item 2 **VALUE OF PRODUCTION**

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 . . . .

$Bil.	Mil.	Thou.

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

Capacity Utilization %

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

Item 3 **ACTUAL AND FULL PRODUCTION COMPARISONS**

A. FULL PRODUCTION CAPABILITY: CURRENT QUARTER VS PREVIOUS QUARTER

If your estimate of current quarter **full production capability** has changed compared to the previous quarter, mark (X) the primary reasons.

- ☐ Building capital expenditures
- ☐ Machinery capital expenditures – *Include new, replaced, or enhanced machinery*
- ☐ Building retirements
- ☐ Machinery retirements
- ☐ Price changed but product mix is the same
- ☐ Revised estimation assumption with no change in plant or operations
- ☐ Change in method of operation
- ☐ Change in product mix or product specifications
- ☐ Change in material input
- ☐ Other – *Specify*

B. ACTUAL OPERATIONS VS FULL PRODUCTION CAPABILITY

If this plant's **actual** production in the current quarter was **less** than **full production capability**, mark (X) the primary reasons.

- ☐ Not most profitable to operate at full production capability
- ☐ Insufficient supply of materials
- ☐ Insufficient orders
- ☐ Insufficient supply of local labor force/skills
- ☐ Lack of sufficient fuel or electric energy
- ☐ Equipment limitations
- ☐ Storage limitations
- ☐ Logistics/transportation constraints
- ☐ Sufficient inventory of finished goods on hand
- ☐ Strike or work stoppage
- ☐ Seasonal operations
- ☐ Environmental restrictions
- ☐ Other – *Specify*

CONTINUE WITH **Item 4** *ON PAGE 3.*

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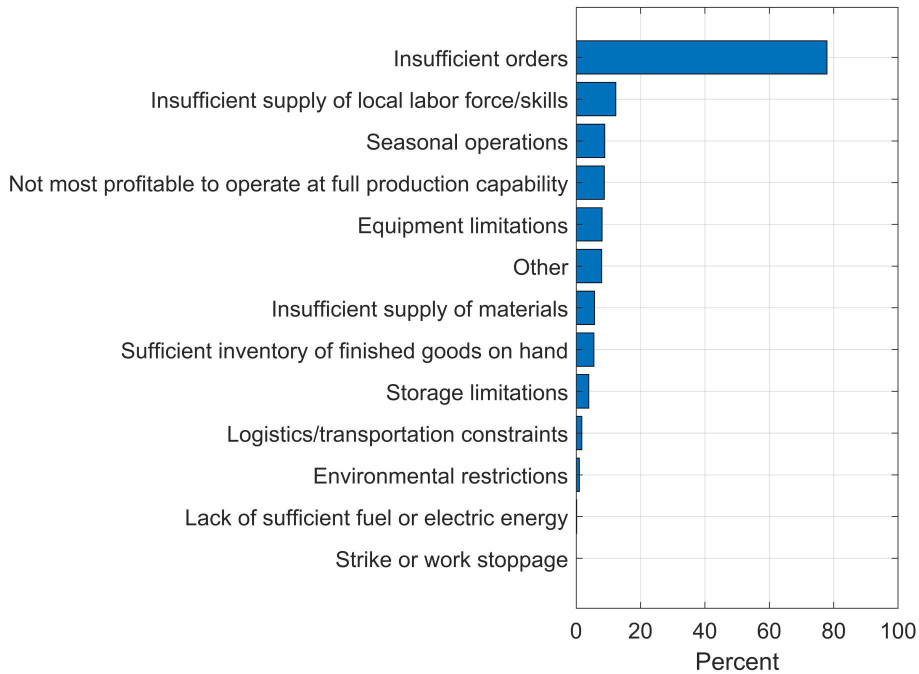
Figure A1: Page 2 of survey form of the Quarterly Survey of Plant Capacity

3-digit industry.

NBER-CES manufacturing industry database Data on prices, sales, production worker wages, material costs, energy costs, inventories, and nonproduction worker salaries and wages



Notes: The data are from public use data of the QSPC of the US Census Bureau and are averaged from 2013q1 to 2018q4.

Figure A2: Why do plants produce below capacity?

are from the NBER-CES Manufacturing Industry Database. For a description of these data, see Bartelsman and Gray (1996) and Becker et al. (2016). The database is available at `http://www.nber.org/nberces/` (see also NBER-CES, 1972-2011).

BEA Input-Output Accounts Cost shares, sales shares, changes in government purchases, and changes in imports are constructed from the BEA's Input-Output accounts. Data from 1997 to today is available from the BEA website at `https://www.bea.gov/industry/input-output-accounts-data` (see also Bureau of Economic Analysis, 1997-2016b). Historical data is available under the tab `Historical Make-Use Tables` (see Bureau of Economic Analysis, 1947-1996).

BEA National Income and Product Accounts We use quantity and price indexes on personal consumption expenditures, equipment investment, and nonresidential fixed investment from the BEA's National Income and Product Accounts. These data are available at `https://www.bea.gov/national/nipaweb/DownSS2.asp` (see also Bureau of Economic Analysis, 1930-2017).

BEA Industry Accounts Data on quantity and price indexes of downstream industries' material use from the BEA's Industry Accounts. Data from 1997 to today is available at `https://apps.bea.gov/iTable/iTable.cfm?reqid=56&step=2&isuri=1#reqid=56&step=2&isuri=1` (see also Bureau of Economic Analysis, 1997-2016a). Historical data is available at `https://www.bea.gov/industry/historical-industry-accounts-data` (see also Bureau of Economic Analysis, 1947-1997). Note that since these downstream industries are not necessarily in the manufacturing sector, they are not necessarily covered by the NBER-CES manufacturing industry database.

UN Statistics Division Real GDP, the GDP deflator, both in local currency, and the nominal exchange rate are from the United Nation's Statistics Division. These data are available at `https://unstats.un.org/unsd/snaama/Downloads` (see also UN Statistics Division, 1972-2011a,-,-,-).

US export data The data on exports are from the US Census and are available on Peter Schott's website `http://faculty.som.yale.edu/peterschott/sub_international.htm` (see also US Census Bureau and Peter Schott, 1972-2015) and used in Schott (2008). The data are available with SIC industry codes between 1972 and 1997, and with NAICS industry codes thereafter. We use the NBER-CES SIC4 to NAICS6 concordance based on sales weights to convert the SIC codes into NAICS equivalents and then aggregate to the 3-digit NAICS level. To ensure high data quality, we limit ourselves to countries that joined the Organisation for Economic Co-operation and Development (OECD) prior to year 2000 when constructing the sales shares to foreign countries $s_{j,i,t}$ for $j \in \mathcal{J}^F$. These are Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, the Republic of Korea, Luxembourg, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States (see also Organisation for Economic Co-operation and Development, 2019).

Further data, identifiers, concordances and classifications Replication of the results further requires

- A concordance of 1987 SIC codes to 1997 NAICS codes (see NBER-CES, 1997)
- Country identifiers and names (see US Census Bureau, 2021; Penn World Table version 10.0, 2021)
- A NAICS classification of durable goods producing industries (see Bureau of Labor Statistics, n.d.)

We provide details on the data and how to obtain them in the replication package for the paper Boehm and Pandalai-Nayar (2022).

Industry	NAICS	p10	Median	p90	Mean	S.D.	Skewness	Kurtosis	Durable
				(utilization rates in percent)					
Food	311	79.2	82.1	85.2	82.3	2.5	0.3	2.5	no
Beverage and Tobacco Products	312	69.4	79.2	82.9	77.3	5.3	-0.5	2.0	no
Textile Mills	313	68.2	82.0	89.5	79.8	8.6	-0.8	3.2	no
Textile Product Mills	314	71.7	81.9	90.4	81.0	8.0	-0.8	3.4	no
Apparel	315	72.1	80.7	85.0	79.7	4.7	-0.5	2.4	no
Leather and Allied Products	316	58.8	75.0	82.1	72.8	9.0	-1.2	3.7	no
Wood Products	321	63.6	79.3	85.3	77.0	8.5	-1.3	4.7	yes
Paper	322	80.8	87.7	91.3	87.0	4.2	-0.3	2.5	no
Printing and Related Support Activities	323	72.1	83.1	89.0	81.3	7.6	-1.0	4.0	no
Petroleum and Coal Products	324	77.3	86.9	92.7	85.7	5.9	-0.7	2.7	no
Chemicals	325	71.6	77.7	83.2	77.6	4.5	-0.4	2.4	no
Plastics and Rubber Products	326	70.0	83.8	89.5	82.1	7.5	-1.0	3.5	no
Nonmetallic Mineral Products	327	62.2	77.1	84.2	75.3	9.4	-1.7	5.5	yes
Primary Metals	331	68.7	80.4	89.6	79.6	9.4	-0.8	3.6	yes
Fabricated Metal Products	332	71.9	77.6	84.8	77.5	5.7	-0.1	3.1	yes
Machinery	333	67.7	79.2	87.0	77.9	7.8	-0.3	2.5	yes
Computer and Electronic Product	334	70.5	79.2	84.6	78.5	5.8	-1.1	4.3	yes
Electrical Equipment, Appliances, and Components	335	73.0	82.6	90.6	82.5	6.7	-0.2	2.6	yes
Transportation Equipment	336	66.5	75.7	81.3	74.5	6.1	-1.0	4.1	yes
Furniture and Related Products	337	68.1	78.1	84.1	77.0	7.4	-0.2	3.9	yes
Miscellaneous	339	72.9	77.1	79.7	76.3	3.1	-0.6	3.2	yes
All		69.9	79.9	88.6	79.2	7.6	-0.8	4.6	

Notes: The data are from the Federal Reserve Board and the sample ranges from 1972-2011.

Table A1: Summary statistics of utilization rates by 3-digit NAICS manufacturing industries

B Appendix: Model

In this appendix we provide details on the model in Section 2, including the proofs of all results. To improve the readability of this appendix, we often restate equations from the main text.

As noted in the text we assume throughout that $\theta > 1$, that $\alpha \in (0,1)$, that $\mathbb{E}_\omega[\omega] = 1$, and that $\mathbb{E}_\omega\left[\omega^2\right] < \infty$. We will make use of these conditions below.

Further, for the proofs in this appendix, the following limits are useful. Using L'Hôspital's rule, we have

$$\lim_{\bar{\omega}_t \to 0} \frac{\int_0^{\bar{\omega}_t} \omega dG(\omega)}{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}} = \lim_{\bar{\omega}_t \to 0} \frac{\bar{\omega}_t g(\bar{\omega}_t)}{\frac{\theta-1}{\theta}(\bar{\omega}_t)^{-\frac{1}{\theta}}} = \frac{\theta}{\theta-1} \lim_{\bar{\omega}_t \to 0} \bar{\omega}_t^{1+\frac{1}{\theta}} g(\bar{\omega}_t) = 0, \tag{B1}$$

$$\lim_{\bar{\omega}_t \to \infty} (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) = \lim_{\bar{\omega}_t \to \infty} \frac{-(\bar{\omega}_t)^{\frac{1}{\theta}} g(\bar{\omega}_t)}{-\frac{\theta-1}{\theta}(\bar{\omega}_t)^{-\frac{\theta-1}{\theta}-1}} = \frac{\theta}{\theta-1} \lim_{\bar{\omega}_t \to \infty} (\bar{\omega}_t)^2 g(\bar{\omega}_t) = 0, \tag{B2}$$

where g is the pdf of G.

B.1 Agreggating firm

A competitive aggregating firm uses a unit continuum of varieties, indexed ℓ, as inputs into a constant elasticity of substitution aggregator with elasticity $\theta > 1$. Taking prices as given, the aggregating firm solves

$$\max_{\{y_{\ell t}\}} P_t^Y Y_t - \int_0^1 p_{\ell t}^y y_{\ell t} d\ell,$$

where the maximization is subject to the production function

$$Y_t = \left(\int_0^1 \omega_{\ell t}^{\frac{1}{\theta}} y_{\ell t}^{\frac{\theta-1}{\theta}} d\ell\right)^{\frac{\theta}{\theta-1}}.$$

Plugging the production function into the objective gives

$$\max_{\{y_{\ell t}\}} P_t^Y \left(\int_0^1 \omega_{\ell t}^{\frac{1}{\theta}} y_{\ell t}^{\frac{\theta-1}{\theta}} d\ell\right)^{\frac{\theta}{\theta-1}} - \int_0^1 p_{\ell t}^y y_{\ell t} d\ell,$$

and the first order necessary conditions for optimality are

$$y_{\ell t} = \omega_{\ell t} Y_t \left(\frac{p_{\ell t}^y}{P_t^Y}\right)^{-\theta},$$

for all ℓ, where the industry's price index is

$$P_t^Y = \left(\int_0^1 \omega_{\ell t} \left(p_{\ell t}^y\right)^{1-\theta} d\ell\right)^{\frac{1}{1-\theta}}.$$

These two equations are the demand functions (2) and the price index (3) in the text, which are restated here for convenience.

B.2 Intermediate goods producers

Production and capacity Intermediate goods producers operate the production function

$$y_{\ell t} = q_{\ell t} \min \{v_{\ell t}, 1\},$$

where $v_{\ell t}$ is a variable input bundle including, for instance, labor and materials. Further, $q_{\ell t}$ is capacity and takes the form

$$q_{\ell t} = z_t k_{\ell t}^{\alpha},$$

where z_t is productivity and $k_{\ell t}$ the firm's capital stock. We assume that $\alpha \in (0, 1)$ and that productivity z_t is common across plants.

Firm problem As noted in the text, we abstract for simplicity from uncertainty over the common exogenous state variables z_t, the price index of variable inputs p_t^v, and the price of investment goods p_t^x, as well as the industry-level aggregates P_t^Y and Y_t. Hence, all these variables should be viewed as known sequences that potentially vary over time. The idiosyncratic i.i.d. demand shock $\omega_{\ell t}$ is observed at the beginning of each period, i.e. before any decisions are made, and we denote the expectation over its distribution G by $E_\omega[\cdot]$. Firms own their capital stock $k_{\ell t}$ and discount future profits at rate r. They compete monopolistically and maximize the present value of profits,

$$\max_{\{p_{\ell t}^y, y_{\ell t}, v_{\ell t}, x_{\ell t}, k_{\ell t}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t E_\omega \left[p_{\ell t}^y y_{\ell t} - p_t^v v_{\ell t} - p_t^x x_{\ell t}\right],$$

where the maximization is subject to

$$\begin{aligned} k_{\ell t+1} &= (1-\delta) k_{\ell t} + x_{\ell t}, \\ y_{\ell t} &= \omega_{\ell t} Y_t \left(\frac{p_{\ell t}^y}{P_t^Y}\right)^{-\theta}, \\ y_{\ell t} &= q_{\ell t} \min \{v_{\ell t}, 1\}, \\ q_{\ell t} &= z_t k_{\ell t}^{\alpha}. \end{aligned}$$

It is convenient to solve this problem in three steps. We first solve the cost minimization problem of the firm. In a second step we solve for the optimal price $p_{\ell t}^y$. These first two steps are static optimization problems and hold the predetermined capital stock $k_{\ell t}$ fixed. We then plug the optimal price back into the objective and solve for the optimal capital stock $k_{\ell t+1}$.

Step 1: Cost minimization For a given level of capital $k_{\ell t}$ and hence $q_{\ell t}$, each firm ℓ minimizes costs

$$\min_{v_{\ell t}} p_t^v v_{\ell t}$$

subject to the production function

$$y_{\ell t} = q_{\ell t} \min \{v_{\ell t}, 1\}.$$

Notice that no solution exists for $y_{\ell t} > q_{\ell t}$. For $y_{\ell t} \leq q_{\ell t}$ optimality requires that $y_{\ell t} = q_{\ell t} v_{\ell t}$ so that short-run total costs are

$$C\left(p_t^v, y_{\ell t}, q_{\ell t}\right) = p_t^v \frac{y_{\ell t}}{q_{\ell t}}.$$

Short-run marginal costs for $y_{\ell t} < q_{\ell t}$ are

$$mc_{\ell t} = \frac{p_t^v}{z_t k_{\ell t}^{\alpha}}.$$

This equation delivers expression (9) in the text.

Notice that marginal costs (9) for $y_{\ell t} = q_t$ are not defined because the derivative (the limit from above) does not exist at this point. We will often write total costs for both constrained and unconstrained firms as $C\left(p_t^v, y_{\ell t}, q_{\ell t}\right) = mc_{\ell t} y_{\ell t}$ below. Economically speaking, this definition sets the marginal cost of constrained firms to the cost of producing the last unit of output before becoming capacity constrained. Its main use below is that this simplifies the notation since we can write $mc_{\ell t}$ instead of $\frac{p_t^v}{z_t k_{\ell t}^{\alpha}}$ for all firms.

Step 2: Optimal price setting For firm ℓ with capital stock $k_{\ell t}$ flow profits are $\pi_{\ell t} = p_{\ell t}^y y_{\ell t} - p_t^v v_{\ell t} = \left(p_{\ell t}^y - mc_{\ell t}\right) y_{\ell t}$ (see step 1). The firm solves the problem

$$\max_{p_{\ell t}^y, y_{\ell t}} \left(p_{\ell t}^y - mc_{\ell t}\right) y_{\ell t}$$

where the maximization is subject to the constraints

$$\begin{aligned} y_{\ell t} &= \omega_{\ell t} Y_t \left(\frac{p_{\ell t}^y}{P_t^Y}\right)^{-\theta}, \\ y_{\ell t} &\leq q_{\ell t}. \end{aligned}$$

The Lagrangian is

$$\mathcal{L} = \left(p_{\ell t}^y - mc_{\ell t}\right) \omega_{\ell t} Y_t \left[\frac{p_{\ell t}^y}{P_t^Y}\right]^{-\theta} + \lambda_{\ell t} \left(q_{\ell t} - \omega_{\ell t} Y_t \left[\frac{p_{\ell t}^y}{P_t^Y}\right]^{-\theta}\right),$$

and optimality requires that

$$p_{\ell t}^y = \frac{\theta}{\theta - 1} \left(mc_{\ell t} + \lambda_{\ell t}\right),$$

where complementary slackness implies that the multiplier $\lambda_{\ell t} \geq 0$ satisfies

$$\lambda_{\ell t} = \begin{cases} 0 & \text{if} \quad y_{\ell t} < q_{\ell t} \\ \frac{\theta-1}{\theta} P_t^Y \left(\frac{\omega_{\ell t} Y_t}{q_{\ell t}}\right)^{\frac{1}{\theta}} - mc_{\ell t} & \text{if} \quad y_{\ell t} = q_{\ell t} \end{cases}. \tag{B3}$$

These expressions deliver equation (8) in the text.

Flow profits are then

$$
\begin{aligned}
\pi_{\ell t} &= \left(p^y_{\ell t} - mc_{\ell t}\right) y_{\ell t} \\
&= \left(\frac{1}{\theta-1} mc_{\ell t} + \frac{\theta}{\theta-1}\lambda_{\ell t}\right)\omega_{\ell t} Y_t \left[\frac{p^y_{\ell t}}{P^Y_t}\right]^{-\theta} \\
&= \left(\frac{\theta-1}{\theta}\right)^{\theta-1} \frac{1}{\theta}\left(mc_{\ell t} + \theta\lambda_{\ell t}\right)\omega_{\ell t} Y_t \left[\frac{mc_{\ell t}+\lambda_{\ell t}}{P^Y_t}\right]^{-\theta}.
\end{aligned}
$$

Next we distinguish cases. If the capacity constraint for variety ℓ does not bind, then $\lambda_{\ell t} = 0$, and flow profits are

$$
\begin{aligned}
\pi_{\ell t} &= \frac{1}{\theta}\left[\frac{\theta}{\theta-1} mc_{\ell t}\right]^{1-\theta} \omega_{\ell t} Y_t \left(P^Y_t\right)^{\theta} \\
&= \frac{1}{\theta}\left[\frac{\theta}{\theta-1} p^v_t\right]^{1-\theta} \left(z_t k^{\alpha}_{\ell t}\right)^{\theta-1} \omega_{\ell t} Y_t \left(P^Y_t\right)^{\theta}.
\end{aligned}
$$

If the capacity constraint for variety ℓ does bind, then

$$
\begin{aligned}
\pi_{\ell t} &= \left(P^Y_t \left(\frac{\omega_{\ell t} Y_t}{q_{\ell t}}\right)^{\frac{1}{\theta}} - mc_{\ell t}\right) q_{\ell t} \\
&= \left(z_t k^{\alpha}_{\ell t}\right)^{1-\frac{1}{\theta}} \left(\omega_{\ell t} Y_t\right)^{\frac{1}{\theta}} P^Y_t - p^v_t.
\end{aligned}
$$

In what follows, we denote the expectation over profits prior to the materialization of $\omega_{\ell t}$ by $E_\omega\left[\pi\left(p^v_t, P^Y_t, Y_t, z_t, k_{\ell t}, \omega_{\ell t}\right)\right]$.

Step 3: The user cost equation Next, return to the firm's dynamic problem, which we can now write as

$$
\max_{\{x_{\ell t}, k_{\ell t}\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left(E_\omega\left[\pi\left(p^v_t, P^Y_t, Y_t, z_t, k_{\ell t}, \omega_{\ell t}\right)\right] - p^x_t x_{\ell t}\right)
$$

and the maximization is subject to

$$
k_{\ell t+1} = (1-\delta) k_{\ell t} + x_{\ell t}.
$$

The current value Lagrangian is

$$
\mathcal{L} = \sum_{t=0}^{\infty} \left(\frac{1}{1+r}\right)^t \left(\left(E_\omega\left[\pi\left(p^v_t, P^Y_t, Y_t, z_t, k_{\ell t}, \omega_{\ell t}\right)\right] - p^x_t x_{\ell t}\right) + \gamma_{\ell t}\left((1-\delta) k_{\ell t} + x_{\ell t} - k_{\ell t+1}\right)\right)
$$

and the first order necessary conditions are

$$
\begin{aligned}
\gamma_{\ell t} &= \frac{1}{1+r}\left(\frac{\partial E_\omega\left[\pi\left(p^v_{t+1}, P^Y_{t+1}, Y_{t+1}, z_{t+1}, k_{\ell t+1}, \omega_{\ell t+1}\right)\right]}{\partial k_{\ell t+1}} + (1-\delta)\gamma_{\ell t+1}\right), \\
p^x_t &= \gamma_{\ell t},
\end{aligned}
$$

as well as the transversality condition

$$\lim_{t\to\infty}\left(\frac{1}{1+r}\right)^t \gamma_{\ell t} k_{\ell t} = 0.$$

Together these equations imply that

$$p_t^x = \frac{1}{1+r}\left(\frac{\partial E_\omega\left[\pi\left(p_{t+1}^v, P_{t+1}^Y, Y_{t+1}, z_{t+1}, k_{\ell t+1}, \omega_{\ell t+1}\right)\right]}{\partial k_{\ell t+1}} + (1-\delta)\, p_{t+1}^x\right),$$

which is equation (7) in the text. Notice that flow profits are identical *in expectation*. Firms face the same prices p_{t+1}^v and P_{t+1}^Y, they face the same level of industry output Y_{t+1}, they have the same productivity z_{t+1}. Further, the demand shock $\omega_{\ell t}$ is i.i.d. over time and across firms, so that its current materialization is not informative about idiosyncratic demand $\omega_{\ell t+1}$ in the next period. Hence, it is "integrated out", that is, $E_\omega\left[\pi\left(p_{t+1}^v, P_{t+1}^Y, Y_{t+1}, z_{t+1}, k_{\ell t+1}, \omega_{\ell t+1}\right)\right]$ does not depend on $\omega_{\ell t}$. This implies that all firms will choose identical capital stocks $k_{\ell t+1} = k_{t+1}$ for all ℓ. As noted in the text, this, in turn, implies that all firms have identical levels of capacity and identical marginal costs, $q_{\ell t} = q_t$ and $mc_{\ell t} = mc_t$ for all ℓ.

The threshold variety $\bar{\omega}_t$ Next, consider the threshold variety $\bar{\omega}_t$ at which an intermediate goods producer becomes capacity constrained. From equation (B3) it follows that $\bar{\omega}_t$ satisfies

$$\bar{\omega}_t = \frac{q_t}{Y_t}\left(\frac{\frac{\theta}{\theta-1} mc_t}{P_t^Y}\right)^\theta = \frac{z_t k_t^\alpha}{Y_t}\left(\frac{\frac{\theta}{\theta-1}\frac{p_t^v}{z_t k_t^\alpha}}{P_t^Y}\right)^\theta, \tag{B4}$$

where we used the fact that $k_{\ell t}$, $q_{\ell t}$ and $mc_{\ell t}$ are identical across producers. For varieties $\omega_{\ell t} < \bar{\omega}_t$ the capacity constraint does not bind and for varieties $\omega_{\ell t} \geq \bar{\omega}_t$ the capacity constraint binds.

Expected firm profits and the optimal choice of k_{t+1} We next return to the expectation over the profit function, which we denote for convenience by π_t^e, and is given by

$$\begin{aligned}
\pi_t^e &= E_\omega\left[\pi\left(p_t^v, P_t^Y, Y_t, z_t, k_t, \omega_{\ell t}\right)\right] \\
&= \int_0^\infty \pi\left(p_t^v, P_t^Y, Y_t, z_t, k_t, \omega\right) dG(\omega) \\
&= \int_0^{\bar{\omega}_t}\left[\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta}\left(z_t k_t^\alpha\right)^{\theta-1}\omega Y_t\left(P_t^Y\right)^\theta\right] dG(\omega) + \int_{\bar{\omega}_t}^\infty\left[\left(z_t k_t^\alpha\right)^{1-\frac{1}{\theta}}\left(\omega Y_t\right)^{\frac{1}{\theta}} P_t^Y - p_t^v\right] dG(\omega) \\
&= \frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta}\left(z_t k_t^\alpha\right)^{\theta-1} Y_t\left(P_t^Y\right)^\theta \int_0^{\bar{\omega}_t}\omega dG(\omega) \\
&+ \left(z_t k_t^\alpha\right)^{1-\frac{1}{\theta}}\left(Y_t\right)^{\frac{1}{\theta}} P_t^Y \int_{\bar{\omega}_t}^\infty \omega^{\frac{1}{\theta}} dG(\omega) - p_t^v\left(1 - G\left(\bar{\omega}_t\right)\right).
\end{aligned} \tag{B5}$$

The partial derivative of π_t^e with respect to k_t is

$$\frac{\partial \pi_t^e}{\partial k_t} = \alpha(\theta-1)\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1}k_t^{\alpha(\theta-1)-1}Y_t\left(P_t^Y\right)^\theta \int_0^{\bar{\omega}_t}\omega dG(\omega)$$
$$+\alpha\left(1-\frac{1}{\theta}\right)z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1}(Y_t)^{\frac{1}{\theta}}P_t^Y\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)$$
$$+\left(\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1}k_t^{\alpha(\theta-1)}Y_t\left(P_t^Y\right)^\theta\bar{\omega}_t - z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)}(Y_t)^{\frac{1}{\theta}}P_t^Y\bar{\omega}_t^{\frac{1}{\theta}}+p_t^v\right)g(\bar{\omega}_t)\frac{\partial\bar{\omega}_t}{\partial k_t}.$$

Plugging in the threshold variety $\bar{\omega}_t$ (equation (B4)) leads to cancellation of the last term so that

$$\frac{\partial \pi_t^e}{\partial k_t} = \alpha(\theta-1)\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1}k_t^{\alpha(\theta-1)-1}Y_t\left(P_t^Y\right)^\theta \int_0^{\bar{\omega}_t}\omega dG(\omega) \tag{B6}$$
$$+\alpha\left(1-\frac{1}{\theta}\right)z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1}(Y_t)^{\frac{1}{\theta}}P_t^Y\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega).$$

Since we assumed that $\theta > 1$, expected profits are increasing in capital.

Next, return to the optimal choice of the capital stock. In particular, rewrite equation (7) as

$$p_t^x(1+r)-(1-\delta)p_{t+1}^x = \frac{\partial \pi_{t+1}^e}{\partial k_{t+1}}. \tag{B7}$$

The intuition is the same as the standard user cost equation, except that the marginal product of capital is now replaced with the partial derivative of expected profits with respect to the capital stock. This condition implicitly determines the capital stock, which we write, as in equation (10), as

$$k_{t+1} = k\left(p_t^x, p_{t+1}^x, z_{t+1}, P_{t+1}^Y, Y_{t+1}, p_{t+1}^v\right).$$

Appendix Proposition B1. *Consider the optimal capital stock k_{t+1}.*

1. *k_{t+1} is unique if $\alpha(\theta-1)<1$.*

2. *All else equal, k_{t+1} is increasing in p_{t+1}^x, z_{t+1}, Y_{t+1}, and P_{t+1}^Y, and decreasing in p_t^x, p_{t+1}^v, as well as interest rate r and depreciation rate δ.*

Proof. As is clear from equation (B7), the optimal capital stock is unique if $\frac{\partial \pi_{t+1}^e}{\partial k_{t+1}}$ is decreasing in capital. Differentiating equation (B6), gives

$$\frac{\partial^2 \pi_t^e}{(\partial k_t)^2} = (\alpha(\theta-1)-1)\alpha(\theta-1)\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1}k_t^{\alpha(\theta-1)-2}Y_t\left(P_t^Y\right)^\theta \int_0^{\bar{\omega}_t}\omega dG(\omega)$$
$$+\left(\alpha\left(1-\frac{1}{\theta}\right)-1\right)\alpha\left(1-\frac{1}{\theta}\right)z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)-2}(Y_t)^{\frac{1}{\theta}}P_t^Y\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)$$
$$+\alpha\frac{\theta-1}{\theta}\left[\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1}k_t^{\alpha(\theta-1)-1}Y_t\left(P_t^Y\right)^\theta\bar{\omega}_t - z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1}(Y_t)^{\frac{1}{\theta}}P_t^Y(\bar{\omega}_t)^{\frac{1}{\theta}}\right]g(\bar{\omega}_t)\frac{\partial\bar{\omega}_t}{\partial k_t}$$

Now plugging in the threshold variety $\bar{\omega}_t$ from equation (B4) again leads to cancellation of the last term and hence gives

$$\frac{\partial^2 \pi_t^e}{(\partial k_t)^2} = (\alpha(\theta-1)-1)\,\alpha(\theta-1)\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1} k_t^{\alpha(\theta-1)-2} Y_t \left(P_t^Y\right)^{\theta} \int_0^{\bar{\omega}_t} \omega dG(\omega)$$
$$+\left(\alpha\left(1-\frac{1}{\theta}\right)-1\right)\alpha\left(1-\frac{1}{\theta}\right) z_t^{1-\frac{1}{\theta}} k_t^{\alpha\left(1-\frac{1}{\theta}\right)-2} (Y_t)^{\frac{1}{\theta}} P_t^Y \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega).$$

The second term is always negative since $\alpha \in (0,1)$ and $\theta > 1$ imply that $\alpha\left(1-\frac{1}{\theta}\right)-1 < 0$. Hence, a sufficient condition for $\frac{\partial^2 \pi_t^e}{(\partial k_t)^2}$ to be negative is that $\alpha(\theta-1) < 1$. This completes the proof of part 1. Note that this parametric restriction is not necessary. In what follows, we will assume that $\frac{\partial^2 \pi_t^e}{(\partial k_t)^2} < 0$. This allows us to interpret the optimal capital stock in equation (10) as a function (rather than a correspondence).

For part 2, note first that $\frac{\partial \pi_t^e}{\partial k_t}$ is a function of $p_t^v, P_t^Y, Y_t, z_t, k_t$ as well as $\bar{\omega}_t$, which is itself a function of these variables (see equation (B4)). Using the implicit function theorem on equation (B7) implies that

$$\frac{\partial k_{t+1}}{\partial p_{t+1}^x} = -\frac{1-\delta}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial z_{t+1}} = -\frac{\frac{\partial^2 \pi_{t+1}^e}{\partial k_{t+1}\partial z_{t+1}}}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial Y_{t+1}} = -\frac{\frac{\partial^2 \pi_{t+1}^e}{\partial k_{t+1}\partial Y_{t+1}}}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial P_{t+1}^Y} = -\frac{\frac{\partial^2 \pi_{t+1}^e}{\partial k_{t+1}\partial P_{t+1}^Y}}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \tag{B8}$$

and

$$\frac{\partial k_{t+1}}{\partial p_t^x} = \frac{1+r}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial p_{t+1}^v} = -\frac{\frac{\partial^2 \pi_{t+1}^e}{\partial k_{t+1}\partial p_{t+1}^v}}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial r} = \frac{p_t^x}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}, \quad \frac{\partial k_{t+1}}{\partial \delta} = \frac{p_{t+1}^x}{\frac{\partial^2 \pi_{t+1}^e}{(\partial k_{t+1})^2}}. \tag{B9}$$

Since $\frac{\partial^2 \pi_t^e}{(\partial k_t)^2} < 0$, we immediately have that $\frac{\partial k_{t+1}}{\partial p_{t+1}^x} > 0$, $\frac{\partial k_{t+1}}{\partial p_t^x} < 0$, $\frac{\partial k_{t+1}}{\partial r} < 0$, and $\frac{\partial k_{t+1}}{\partial \delta} < 0$. To determine the signs for the remaining partial derivatives of k_{t+1}, we take the derivatives of equation (B6) with respect to z_t, Y_t, P_t^Y, and p_t^v. These are

$$\frac{\partial^2 \pi_t^e}{\partial k_t \partial z_t} = \alpha(\theta-1)^2 \frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-2} k_t^{\alpha(\theta-1)-1} Y_t \left(P_t^Y\right)^{\theta} \int_0^{\bar{\omega}_t} \omega dG(\omega)$$
$$+\alpha\left(1-\frac{1}{\theta}\right)^2 z_t^{-\frac{1}{\theta}} k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1} (Y_t)^{\frac{1}{\theta}} P_t^Y \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) > 0,$$

$$\frac{\partial^2 \pi_t^e}{\partial k_t \partial Y_t} = \alpha(\theta-1)\frac{1}{\theta}\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1} k_t^{\alpha(\theta-1)-1} \left(P_t^Y\right)^{\theta} \int_0^{\bar{\omega}_t} \omega dG(\omega)$$
$$+\alpha\frac{1}{\theta}\left(1-\frac{1}{\theta}\right) z_t^{1-\frac{1}{\theta}} k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1} (Y_t)^{\frac{1}{\theta}-1} P_t^Y \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) > 0,$$

$$\frac{\partial^2 \pi_t^e}{\partial k_t \partial P_t^Y} = \alpha(\theta-1)\left[\frac{\theta}{\theta-1}p_t^v\right]^{1-\theta} z_t^{\theta-1} k_t^{\alpha(\theta-1)-1} Y_t \left(P_t^Y\right)^{\theta-1} \int_0^{\bar{\omega}_t} \omega dG(\omega)$$

$$+\alpha\left(1-\frac{1}{\theta}\right)z_t^{1-\frac{1}{\theta}}k_t^{\alpha\left(1-\frac{1}{\theta}\right)-1}\left(Y_t\right)^{\frac{1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG\left(\omega\right)>0,$$

$$\frac{\partial^2\pi_t^e}{\partial k_t\partial p_t^v}=-\alpha\theta\left(\frac{\theta}{\theta-1}\right)^{-1-\theta}\left(p_t^v\right)^{-\theta}z_t^{\theta-1}k_t^{\alpha(\theta-1)-1}Y_t\left(P_t^Y\right)^{\theta}\int_0^{\bar{\omega}_t}\omega dG\left(\omega\right)<0.$$

The claim follows from plugging these partial derivatives into the expressions in (B8) and (B9). □

B.3 Industry capacity and utilization

We next turn to the aggregation to the industry level. For constrained varieties the level of output $y_{\ell t}$ is equal to capacity q_t. For unconstrained varieties with $y_{\ell t}<q_t$, we have

$$\frac{y_{\ell t}}{q_t}=\frac{\omega_{\ell t}Y_t\left(\frac{p_{\ell t}^y}{P_t^Y}\right)^{-\theta}}{q_t}=\frac{\omega_{\ell t}Y_t\left(\frac{\frac{\theta}{\theta-1}mc_t}{P_t^Y}\right)^{-\theta}}{q_t}=\frac{\omega_{\ell t}}{\bar{\omega}_t}. \tag{B10}$$

The first equality uses the demand function (2). The second equality uses the price setting equation (8) for unconstrained varieties. Lastly, the third equality uses the expression of the threshold variety (B4). In words, equation (B10) states that the level of output $y_{\ell t}$ is proportional to their idiosyncratic demand shock $\omega_{\ell t}$ within the cross-section of unconstrained firms in a given period. Using this property, we can write the industry's output as

$$\begin{aligned}
Y_t&=\left(\int_0^1\omega_{\ell t}^{\frac{1}{\theta}}\left(y_{\ell t}\right)^{\frac{\theta-1}{\theta}}d\ell\right)^{\frac{\theta}{\theta-1}}\\
&=\left(\int_0^{\bar{\omega}_t}\omega^{\frac{1}{\theta}}\left(y_t\left(\omega\right)\right)^{\frac{\theta-1}{\theta}}dG\left(\omega\right)+\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}\left(q_t\right)^{\frac{\theta-1}{\theta}}dG\left(\omega\right)\right)^{\frac{\theta}{\theta-1}}\\
&=\left(\int_0^{\bar{\omega}_t}\omega^{\frac{1}{\theta}}\left(\frac{\omega}{\bar{\omega}_t}q_t\right)^{\frac{\theta-1}{\theta}}dG\left(\omega\right)+\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}\left(q_t\right)^{\frac{\theta-1}{\theta}}dG\left(\omega\right)\right)^{\frac{\theta}{\theta-1}}\\
&=q_t\left(\left(\bar{\omega}_t\right)^{-\frac{\theta-1}{\theta}}\int_0^{\bar{\omega}_t}\omega dG\left(\omega\right)+\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG\left(\omega\right)\right)^{\frac{\theta}{\theta-1}}.
\end{aligned}$$

This is equation (11) in the text.

We define capacity at the industry level as

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

and the utilization rate as

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

Lemma 1. *The utilization rate as defined in (12) has the following 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. $u' < 0$

Proof. Using the definition of capacity and limit (B1), we can write

$$\begin{aligned} Q(q_t) &= \lim_{\bar{\omega}_t \to 0} Y(q_t, \bar{\omega}_t) \\ &= q_t \left(\lim_{\bar{\omega}_t \to 0} \frac{1}{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_0^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{\theta}{\theta-1}} \\ &= q_t \Theta, \end{aligned}$$

where

$$\Theta = \left(\int_0^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{\theta}{\theta-1}}.$$

Then equation (12) implies that

$$u(\bar{\omega}_t) = \frac{1}{\Theta} \left(\left(\frac{1}{\bar{\omega}_t} \right)^{\frac{\theta-1}{\theta}} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{\theta}{\theta-1}}. \tag{B11}$$

Hence, u_t is only a function of $\bar{\omega}_t$ and $u_t \geq 0$.

Regarding part 2, $\lim_{\bar{\omega}_t \to 0} u(\bar{\omega}_t) = 1$ follows directly from the definition of capacity and utilization. Further,

$$\begin{aligned} \lim_{\bar{\omega}_t \to \infty} u(\bar{\omega}_t) &= \lim_{\bar{\omega}_t \to \infty} \frac{1}{\Theta} \left(\left(\frac{1}{\bar{\omega}_t} \right)^{\frac{\theta-1}{\theta}} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{\theta}{\theta-1}} \\ &= \frac{1}{\Theta} \left(\lim_{\bar{\omega}_t \to \infty} \frac{\int_0^{\bar{\omega}_t} \omega dG(\omega)}{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}} \right)^{\frac{\theta}{\theta-1}} = 0 \end{aligned}$$

For part 3, take the derivative of equation (B11) to obtain

$$\frac{\partial u_t}{\partial \bar{\omega}_t} = -\frac{1}{\Theta (\bar{\omega}_t)^2} \left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{1}{\theta-1}} \int_0^{\bar{\omega}_t} \omega dG(\omega), \tag{B12}$$

which is strictly negative for $0 < \bar{\omega}_t < \infty$. It then follows that $u_t \leq 1$, completing the proof of part 1 of the lemma.

□

Industry capacity We can now write an industry's capacity as

$$\begin{aligned} Q_t &= \Theta q_t \\ &= \Theta z_t k_t^{\alpha} \\ &= \Theta z_t \left(k \left(p_{t-1}^x, p_t^x, z_t, P_t^Y, Y_t, p_t^v \right) \right)^{\alpha}. \end{aligned}$$

This expression makes clear that demand shocks that raise Y_t will also raise industry capacity Q_t, because k_t is increasing in Y_t (see Appendix Proposition B1). As discussed in Section 2.5, this suggests that capacity should be used as a control variable when estimating supply curves—even when using demand shift instruments.

B.4 The supply curve

Combining the price index (3) with the price setting rule (8) and equations (B4) and (B3) gives

$$\begin{aligned} P_t^Y &= \left(\int_0^1 \omega_{\ell t} \left[\frac{\theta}{\theta - 1} \left(mc_t + \lambda_{\ell t} \right) \right]^{1-\theta} d\ell \right)^{\frac{1}{1-\theta}} \\ &= \frac{\theta}{\theta - 1} mc_t \left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right)^{\frac{1}{1-\theta}} . \end{aligned}$$

Taking logs gives the supply curve (13), which is restated here for convenience,

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

where the log average markup as a function of $\bar{\omega}_t$ is given by

$$\tilde{\mathcal{M}}(\bar{\omega}_t) := \ln \frac{\theta}{\theta - 1} - \frac{1}{\theta - 1} \ln \left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \right),$$

and, using Lemma 1, the log average markup as a function of $\ln u_t$ is $\mathcal{M}(\ln u_t) = \tilde{\mathcal{M}}(\bar{\omega}(\ln u_t))$.

Proposition 1. *$\mathcal{M}$ has the following properties:*

1. $\mathcal{M}' \geq 0$
2. $\lim_{u \to 0} \mathcal{M}(\ln u) = \ln \frac{\theta}{\theta - 1}$, $\lim_{u \to 1} \mathcal{M}(\ln u) = \infty$
3. $\lim_{u \to 0} \mathcal{M}'(\ln u) = 0$, $\lim_{u \to 1} \mathcal{M}'(\ln u) = \infty$
4. *Without further restrictions on G, the sign of $\mathcal{M}''$ is generally ambiguous.*

Proof. For part 1, note that

$$\tilde{\mathcal{M}}'(\bar{\omega}_t) = -\frac{1}{\theta} \frac{(\bar{\omega}_t)^{-\frac{1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)}{\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)}. \tag{B13}$$

Further note that

$$\begin{aligned} \mathcal{M}'(\ln u_t) &= \tilde{\mathcal{M}}'(\bar{\omega}_t) \cdot \frac{\partial \bar{\omega}(u_t)}{\partial u_t} \cdot u_t \\ &= \tilde{\mathcal{M}}'(\bar{\omega}_t) \cdot \left(\frac{\partial u_t}{\partial \bar{\omega}_t} \right)^{-1} \cdot u_t \end{aligned} \tag{B14}$$

Now plugging in equations (B13), (B12), and (B11) gives, after several cancellations,

$$\mathcal{M}'(\ln u_t) = \frac{1}{\theta}\frac{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)}{\int_0^{\bar{\omega}_t}\omega dG(\omega)}, \tag{B15}$$

which is greater than or equal to zero.

For part 2 note that

$$\begin{aligned}
\lim_{u_t\to 0}\mathcal{M}(\ln u_t) &= \lim_{\bar{\omega}_t\to\infty}\tilde{\mathcal{M}}(\bar{\omega}_t) \\
&= \ln\frac{\theta}{\theta-1} - \frac{1}{\theta-1}\ln\left(\int_0^{\infty}\omega dG(\omega) + \lim_{\bar{\omega}_t\to\infty}(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)\right) \\
&= \ln\frac{\theta}{\theta-1} - \frac{1}{\theta-1}\ln\left(1 + \lim_{\bar{\omega}_t\to\infty}(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)\right) \\
&= \ln\frac{\theta}{\theta-1}
\end{aligned}$$

where we used the limit (B2). Further,

$$\lim_{u_t\to 1}\mathcal{M}(\ln u_t) = \lim_{\bar{\omega}_t\to 0}\tilde{\mathcal{M}}(\bar{\omega}_t) = \ln\frac{\theta}{\theta-1} - \frac{1}{\theta-1}\ln\left(\lim_{\bar{\omega}_t\to 0}(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)\right) = \infty.$$

For part 3, and using the limits (B1) and (B2), we obtain

$$\lim_{u_t\to 0}\mathcal{M}'(\ln u_t) = \lim_{\bar{\omega}_t\to\infty}\frac{1}{\theta}\frac{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)}{\int_0^{\bar{\omega}_t}\omega dG(\omega)} = \lim_{\bar{\omega}_t\to\infty}\frac{1}{\theta}(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega) = 0$$

and

$$\lim_{u_t\to 1}\mathcal{M}'(\ln u_t) = \lim_{\bar{\omega}_t\to 0}\frac{1}{\theta}\frac{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)}{\int_0^{\bar{\omega}_t}\omega dG(\omega)} = \lim_{\bar{\omega}_t\to 0}\frac{1}{\theta}\int_0^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)\,\frac{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}}{\int_0^{\bar{\omega}_t}\omega dG(\omega)} = \infty.$$

For part 4, define the auxiliary function

$$\varkappa(\bar{\omega}_t) = \frac{1}{\theta}\frac{(\bar{\omega}_t)^{\frac{\theta-1}{\theta}}\int_{\bar{\omega}_t}^{\infty}\omega^{\frac{1}{\theta}}dG(\omega)}{\int_0^{\bar{\omega}_t}\omega dG(\omega)} \tag{B16}$$

and note that $\mathcal{M}'(\ln u_t) = \varkappa(\bar{\omega}(u_t))$. Taking the derivative with respect to $\ln u_t$ gives

$$\begin{aligned}
\mathcal{M}''(\ln u_t) &= \varkappa'(\bar{\omega}_t)\cdot\frac{\partial\bar{\omega}_t}{\partial u_t}\cdot u_t \\
&= \varkappa'(\bar{\omega}_t)\cdot\left(\frac{\partial u_t}{\partial\bar{\omega}_t}\right)^{-1}\cdot u_t.
\end{aligned} \tag{B17}$$

Since $u_t > 0$ and $\frac{\partial u_t}{\partial \bar{\omega}_t} < 0$, the sign of $\mathcal{M}''(\ln u_t)$ is the negative of the sign of $\varkappa'(\bar{\omega}_t)$. Now

$$\varkappa'(\bar{\omega}_t) = \frac{\left[\frac{\theta-1}{\theta}(\bar{\omega}_t)^{-\frac{1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) - \bar{\omega}_t g(\bar{\omega}_t)\right] \int_0^{\bar{\omega}_t} \omega dG(\omega) - \bar{\omega}_t g(\bar{\omega}_t)(\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)}{\theta\left(\int_0^{\bar{\omega}_t} \omega dG(\omega)\right)^2}$$

$$= \frac{\frac{\theta-1}{\theta}(\bar{\omega}_t)^{-\frac{1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \int_0^{\bar{\omega}_t} \omega dG(\omega) - \bar{\omega}_t g(\bar{\omega}_t)\left[\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right]}{\theta\left(\int_0^{\bar{\omega}_t} \omega dG(\omega)\right)^2}. \tag{B18}$$

It is clear that this expression can be positive or negative, depending on the value of $g(\bar{\omega}_t)$. If $g(\bar{\omega}_t)$ is sufficiently small, the derivative on the left hand side is positive and $\mathcal{M}''$ negative. For sufficiently large $g(\bar{\omega}_t)$, the opposite is the case. Most conventional distributions result in $\mathcal{M}'' > 0$. This completes the proof.

□

Figure B1 provides three additional examples of supply curves. In panel A the distribution G of demand shocks is log-normal with unit mean and variance 0.75. In panel B the distribution of G is uniform on the interval from 0 to 2. In Panel C the distribution of G is piecewise uniform from 0 to 0.8 and from 1.2 to 2. For panels A and B the supply curve is convex everywhere. For panel C, the supply curve is locally non-convex. This non-convexity is a result of the density of demand shocks, $g(\bar{\omega}_t)$ in equation B18, being equal to zero in the relevant range. We view this example as likely not economically relevant.

B.5 Estimating equation

Letting Δ denote the first difference operator and adding industry subscripts i, linearization of the supply curve (13) around its $t-1$ values yields

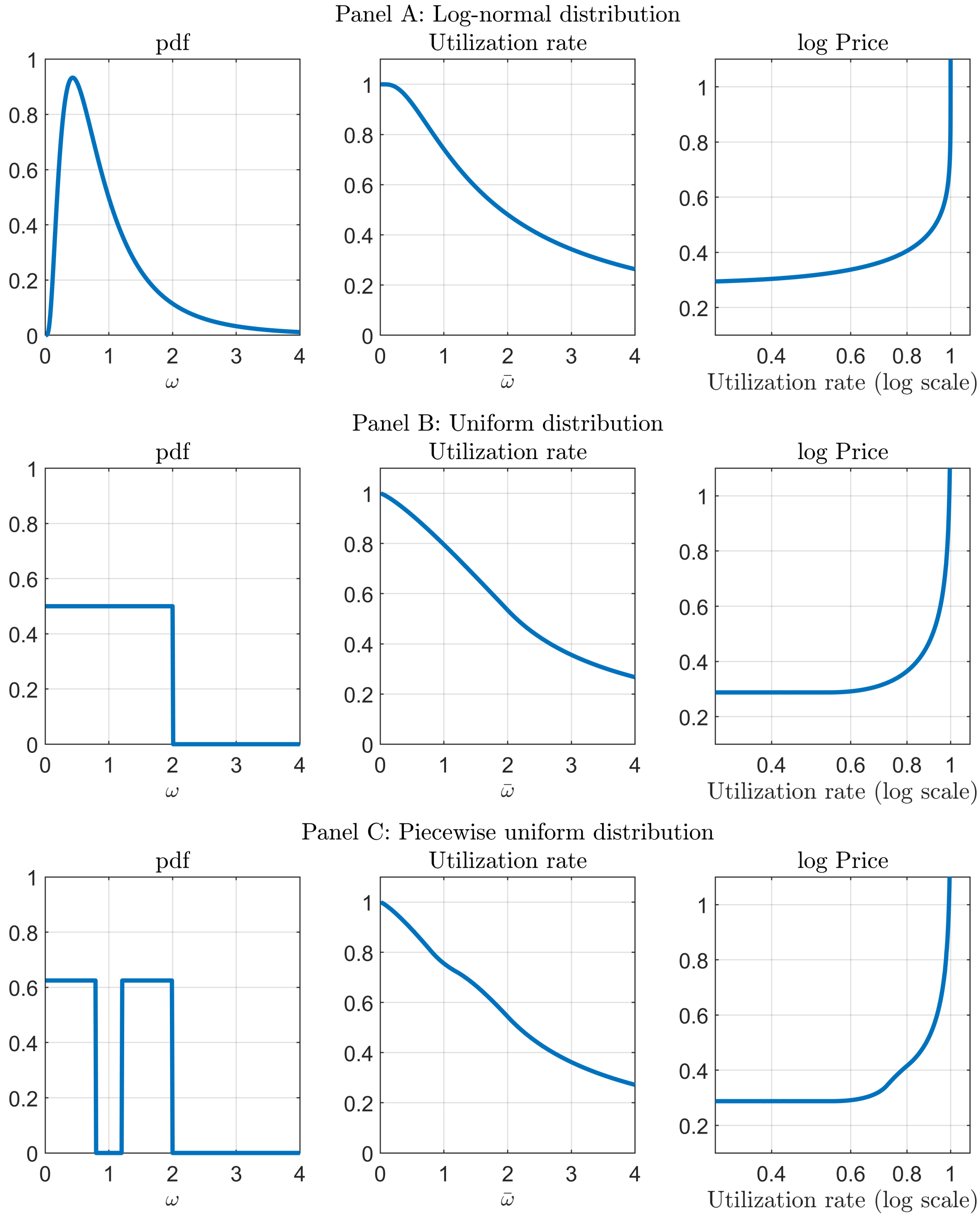
$$\begin{aligned} \Delta \ln P_{i,t}^Y &= \mathcal{M}'(\ln u_{i,t-1})(\ln u_{i,t} - \ln u_{i,t-1}) + \Delta \ln(mc_{i,t}) \\ &= \mathcal{M}'(\ln u_{i,t-1})(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t}) + \Delta \ln(mc_{i,t}). \end{aligned}$$

We next parameterize $\mathcal{M}'(\ln u_{i,t-1})$ with the linear approximation around the industry-specific mean $\ln \bar{u}_i$ so that

$$\begin{aligned} \mathcal{M}'(\ln u_{i,t-1}) &= \mathcal{M}'(\ln \bar{u}_i) + \mathcal{M}''(\ln \bar{u}_i)(\ln u_{i,t-1} - \ln \bar{u}_i) \\ &= \mathcal{M}'(\ln \bar{u}_i) + \frac{\mathcal{M}''(\ln \bar{u}_i)}{\bar{u}_i}(u_{i,t-1} - \bar{u}_i). \end{aligned}$$

Combining these two equations gives

$$\begin{aligned} \Delta \ln P_{i,t}^Y &= \mathcal{M}'(\ln \bar{u}_i)(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t}) \\ &\quad + \frac{\mathcal{M}''(\ln \bar{u}_i)}{\bar{u}_i}(u_{i,t-1} - \bar{u}_i)(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t}) \end{aligned} \tag{B19}$$



Notes: The figure provides examples of supply curve (13). The parameterizations are chosen as follows. For all figures $\theta = 4$ and marginal costs mc are set to 1. In panel A, G is log-normal with unit mean and variance 0.75. In panel B, G is uniform from 0 to 2. In panel C, G is piecewise uniform from 0 to 0.8 and 1.2 to 2.

Figure B1: Examples of supply curves

$$+ \Delta \ln (mc_{i,t}) .$$

Now, adding a constant α, an error term $\varepsilon_{i,t}$, and a main effect for the lagged utilization rate $(u_{i,t-1} - \bar{u}_i)$ gives our estimating equation (16),

$$\begin{aligned}\Delta \ln P_{i,t}^Y = \alpha + \beta_{Yu} \Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i) + \beta_Y \Delta \ln Y_{i,t} + \beta_u (u_{i,t-1} - \bar{u}_i) \\ + \beta_Q \Delta \ln Q_{i,t} + \beta_{Qu} \Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i) + \beta_{mc} \Delta \ln (mc_{i,t}) + \varepsilon_{i,t},\end{aligned}$$

where

$$\beta_{Yu} = \frac{\mathcal{M}''(\ln \bar{u}_i)}{\bar{u}_i},\ \beta_Y = \mathcal{M}'(\ln \bar{u}_i),\ \beta_Q = -\mathcal{M}'(\ln \bar{u}_i),\ \beta_{Qu} = -\frac{\mathcal{M}''(\ln \bar{u}_i)}{\bar{u}_i},\ \beta_{mc} = 1.$$

Comparison to second order approximation We next compare our estimation equation, which is based on a first order Taylor approximation around $t-1$ values, to a second order approximation around the steady state. The second order approximation of supply curve (13) is

$$\begin{aligned}\ln P_{i,t}^Y - \ln P_i^Y = \mathcal{M}'(\ln \bar{u}_i)(\ln u_{i,t} - \ln \bar{u}_i) + \frac{1}{2}\mathcal{M}''(\ln \bar{u}_i)(\ln u_{i,t} - \ln \bar{u}_i)^2 \\ + \ln (mc_{i,t}) - \ln (mc_i).\end{aligned}$$

Lagging this expression once and subtracting it from the above expression gives

$$\begin{aligned}\Delta \ln P_{i,t}^Y = \mathcal{M}'(\ln u_i)(\ln u_{i,t} - \ln u_{i,t-1}) \\ + \frac{1}{2}\mathcal{M}''(\ln u_i)\left[(\ln u_{i,t} - \ln u_i)^2 - (\ln u_{i,t-1} - \ln u_i)^2\right] \\ + \Delta \ln (mc_{i,t}).\end{aligned} \tag{B20}$$

Next note that

$$\begin{aligned}(\ln u_{i,t} - \ln u_i)^2 - (\ln u_{i,t-1} - \ln u_i)^2 &= (\ln u_{i,t} - \ln u_i)^2 - (\ln u_{i,t-1} - \ln u_{i,t} + \ln u_{i,t} - \ln u_i)^2 \\ &= (\ln u_{i,t} - \ln u_i)^2 - (\ln u_{i,t-1} - \ln u_{i,t})^2 \\ &\quad - 2(\ln u_{i,t-1} - \ln u_{i,t})(\ln u_{i,t} - \ln u_i) - (\ln u_{i,t} - \ln u_i)^2 \\ &= [\ln u_{i,t-1} - \ln u_{i,t} + 2\ln u_{i,t} - 2\ln u_i](\ln u_{i,t} - \ln u_{i,t-1}) \\ &= [\ln u_{i,t} - \ln u_i + \ln u_{i,t-1} - \ln u_i](\ln u_{i,t} - \ln u_{i,t-1}) \\ &= \left[\frac{u_{i,t} - u_i}{u_i} + \frac{u_{i,t-1} - u_i}{u_i}\right](\ln u_{i,t} - \ln u_{i,t-1}),\end{aligned}$$

where we note that the last equality holds only up to a second order.

Substituting the expression back into equation (B20) and using the definition of the utilization rate gives

$$\begin{aligned}\Delta \ln P_{i,t}^Y = \mathcal{M}'(\ln u_i)(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t}) \\ + \frac{\mathcal{M}''(\ln u_i)}{u_i}\left(\frac{u_{i,t} - u_i}{2} + \frac{u_{i,t-1} - u_i}{2}\right)(\Delta \ln Y_{i,t} - \Delta \ln Q_{i,t})\end{aligned}$$

$$+ \Delta \ln (mc_{i,t}) .$$

As noted in footnote (14), the only difference relative to equation (B19) is that the lagged utilization rate $u_{i,t-1} - u_i$ is replaced with the average $\frac{u_{i,t}-u_i}{2} + \frac{u_{i,t-1}-u_i}{2}$. Since the current utilization rate $u_{i,t}$ depends on output $Y_{i,t}$ and is simultaneously determined with price $P_{i,t}^Y$, we prefer to use the lagged utilization rate $u_{i,t}$ alone.

B.6 Measurement of marginal costs

The estimation is complicated by the fact that marginal costs are not observed. Subsuming marginal costs into the error term has two undesirable implications. First, it can lead to an omitted variable bias if the instrument is correlated with marginal costs. Second, doing so raises the variance of the estimates. It is therefore common to proxy for marginal costs with unit variable costs, which are observed. Unfortunately, this approach can also lead to biases.

In our framework industry's marginal costs differ from the industry's unit variable cost. This feature follows from the non-linear aggregation across varieties with aggregator (1). Further, the wedge between unit variable cost and marginal cost is a function of the utilization rate, that is, $\ln mc_{i,t} = \ln \mathrm{UVC}_{i,t} + \Omega (\ln u_{i,t})$, for some function Ω, where $\mathrm{UVC}_{i,t} = \left(\int_0^1 p_{it}^v v_{i\ell t} d\ell\right) / Y_{i,t}$ are unit variable costs. Substituting for marginal costs in equation (13) yields

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

This expression makes clear that if unit variable costs are held constant instead of marginal costs, exogenous variation in $\ln u_{i,t}$ does not identify $\mathcal{M}'$, but $\mathcal{M}' + \Omega'$, thus leading to a biased estimate. An analogous argument applies to $\mathcal{M}''$. The following proposition signs these biases.

Appendix Proposition B2. $\Omega' \leq 0$ *and* $\Omega'' \leq 0$.

Hence, when marginal costs are proxied for with unit variable costs, estimates of the slope and curvature both exhibit a downward bias. Our estimates should therefore be interpreted as conservative. We provide a rough assessment of the magnitude of this bias below.

Regarding the intuition of Proposition B2, note that in the baseline model the industry's marginal costs do not depend on the utilization rate and that Ω's dependence on the utilization rate arises from the dependence of unit variable costs on the utilization rate. The sum of variable costs across plants in industry i, $\int_0^1 p_{it}^v v_{i\ell t} d\ell$, depends on the industry's utilization rate, and so does the aggregation of plant-level output into industry-level output, see equation (11). The proof of Appendix Proposition B2 below provides details. Unit variable costs are defined as the *sum of plants'* variable costs per unit of industry output, consistent with the empirical analogue in Section 3. They do *not* reflect the aggregating firm's average costs, which include the markups of monopolistic competitors.

Proof of Appendix Proposition B2. Throughout this proof we drop the industry subscript i. Unit variable costs are

$$\frac{\int_0^1 p_t^v v_{\ell t} d\ell}{Y_t} = \frac{p_t^v}{q_t} \frac{\int_0^1 y_{\ell t} d\ell}{Y_t} = mc_t \frac{\int_0^1 y_{\ell t} d\ell}{Y_t},$$

where we used the production function $y_{\ell t} = q_t v_{\ell t}$ for $v_{\ell t} \leq 1$ and equation (9). Now, using equation (B4), we obtain

$$\begin{aligned}
\int_0^1 y_{\ell t} d\ell &= \int_0^{\bar{\omega}_t} \omega Y_t \left[\frac{p_t^y(\omega)}{P_t^Y}\right]^{-\theta} dG(\omega) + \int_{\bar{\omega}_t}^{\infty} q_t dG(\omega) \\
&= Y_t \left[\frac{\frac{\theta}{\theta-1} mc_t}{P_t^Y}\right]^{-\theta} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_{\bar{\omega}_t}^{\infty} q_t dG(\omega) \\
&= q_t \left(\frac{1}{\bar{\omega}_t} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_{\bar{\omega}_t}^{\infty} dG(\omega)\right).
\end{aligned}$$

Next, using equation (11), we can write

$$\frac{\int_0^1 p_t^v v_{\ell t} d\ell}{Y_t} = mc_t \frac{\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)}{\left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right)^{\frac{\theta}{\theta-1}}}. \tag{B21}$$

Defining $\Omega(\ln u_t) = \tilde{\Omega}(\bar{\omega}(u_t))$, where

$$\tilde{\Omega}(\bar{\omega}(u_t)) = -\ln\left(\frac{\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)}{\left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right)^{\frac{\theta}{\theta-1}}}\right), \tag{B22}$$

it follows that

$$\ln mc_t = \ln \frac{\int_0^1 p_t^v v_{\ell t} d\ell}{Y_t} + \tilde{\Omega}(\bar{\omega}_t)$$

and hence

$$\ln P_t^Y = \mathcal{M}(\ln u_t) + \Omega(\ln u_t) + \ln UVC_t,$$

where $UVC_t = \left(\int_0^1 p_t^v v_{\ell t} d\ell\right) / Y_t$.

We are interested in estimating $\mathcal{M}'(\ln u_t)$ and $\mathcal{M}''(\ln u_t)$, but exogenous variation in $\ln u_t$ traces out the composite term

$$\Xi(\ln u_t) = \mathcal{M}(\ln u_t) + \Omega(\ln u_t). \tag{B23}$$

We will next show that $\Omega'(\ln u_t) < 0$ and $\Omega''(\ln u_t) < 0$ in the model. This implies that we estimate a lower bound for both the slope and the curvature

$$\mathcal{M}'(\ln u_i) = \Xi'(\ln u_i) - \Omega'(\ln u_i) \geq \Xi'(\ln u_i),$$

$$\frac{\mathcal{M}''(\ln u_i)}{u_i} = \frac{\Xi''(\ln u_i)}{u_i} - \frac{\Omega''(\ln u_i)}{u_i} \geq \frac{\Xi''(\ln u_i)}{u_i}.$$

Start with $\Omega(\ln u_t) = \tilde{\Omega}(\bar{\omega}(u_t))$ and differentiate both sides with respect to $\ln u_t$. This gives

$$\Omega'(\ln u_t) = \tilde{\Omega}'(\bar{\omega}(u_t)) \cdot \frac{\partial \bar{\omega}_t}{\partial u_t} \cdot u_t$$
$$= \tilde{\Omega}'(\bar{\omega}_t) \cdot \left(\frac{\partial u_t}{\partial \bar{\omega}_t}\right)^{-1} \cdot u_t \tag{B24}$$

Now taking the derivative of equation (B22) gives

$$\tilde{\Omega}'(\bar{\omega}_t) = \frac{(\bar{\omega}_t)^{-\frac{1}{\theta}} \left[\int_{\bar{\omega}_t}^{\infty} \left(\omega^{\frac{1}{\theta}} - (\bar{\omega}_t)^{\frac{1}{\theta}}\right) dG(\omega)\right] \int_0^{\bar{\omega}_t} \omega dG(\omega)}{\left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right) \left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)\right)}, \tag{B25}$$

which is positive.

Plugging this derivative together with equation (B12) and (B11) into equation (B24) gives

$$\Omega'(\ln u_t) = -\frac{(\bar{\omega}_t)^{-\frac{1}{\theta}} \left[\int_{\bar{\omega}_t}^{\infty} \left(\omega^{\frac{1}{\theta}} - (\bar{\omega}_t)^{\frac{1}{\theta}}\right) dG(\omega)\right] \int_0^{\bar{\omega}_t} \omega dG(\omega)}{\left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^{\frac{\theta-1}{\theta}} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right) \left(\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)\right)}$$
$$\cdot \frac{\left(\left(\frac{1}{\bar{\omega}_t}\right)^{\frac{\theta-1}{\theta}} \int_0^{\bar{\omega}_t} \omega dG(\omega) + \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega)\right)}{(\bar{\omega}_t)^{\frac{1-2\theta}{\theta}} \int_0^{\bar{\omega}_t} \omega dG(\omega)}$$
$$= -\frac{(\bar{\omega}_t)^{-\frac{1}{\theta}-1} \left[\int_{\bar{\omega}_t}^{\infty} \left(\omega^{\frac{1}{\theta}} - (\bar{\omega}_t)^{\frac{1}{\theta}}\right) dG(\omega)\right]}{\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)} < 0.$$

This completes the first part of the proof.

Next define the auxiliary function

$$\vartheta(\bar{\omega}_t) = -\frac{(\bar{\omega}_t)^{-\frac{1}{\theta}-1} \left[\int_{\bar{\omega}_t}^{\infty} \left(\omega^{\frac{1}{\theta}} - (\bar{\omega}_t)^{\frac{1}{\theta}}\right) dG(\omega)\right]}{\int_0^{\bar{\omega}_t} \omega dG(\omega) + \bar{\omega}_t \int_{\bar{\omega}_t}^{\infty} dG(\omega)} \tag{B26}$$

and note that $\Omega'(\ln u_t) = \vartheta(\bar{\omega}(u_t))$. Then

$$\Omega''(\ln u_t) = \vartheta'(\bar{\omega}_t) \cdot \frac{\partial \bar{\omega}_t}{\partial u_t} \cdot u_t$$
$$= \vartheta'(\bar{\omega}_t) \cdot \left(\frac{\partial u_t}{\partial \bar{\omega}_t}\right)^{-1} \cdot u_t. \tag{B27}$$

Since $u'(\bar{\omega}_t) < 0$ and $u_t > 0$, the sign of $\Omega''(\ln u_t)$ is fully determined by the sign of $\vartheta'(\bar{\omega}_t)$. Taking the derivative of equation (B26) gives

$$\vartheta'(\bar{\omega}_t) = \frac{\frac{1}{\theta}(\bar{\omega}_t)^{-\frac{1}{\theta}-1} \int_{\bar{\omega}_t}^{\infty} \omega^{\frac{1}{\theta}} dG(\omega) \left(\bar{\omega}_t \int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^2 \int_{\bar{\omega}_t}^{\infty} dG(\omega)\right)}{\left(\bar{\omega}_t \int_0^{\bar{\omega}_t} \omega dG(\omega) + (\bar{\omega}_t)^2 \int_{\bar{\omega}_t}^{\infty} dG(\omega)\right)^2}$$

$$+\frac{\left(\int_{\bar{\omega}_t}^{\infty}\left[\omega^{\frac{1}{\theta}}-(\bar{\omega}_t)^{\frac{1}{\theta}}\right]dG(\omega)\right)\left(\int_0^{\bar{\omega}_t}\omega dG(\omega)+2(\bar{\omega}_t)\int_{\bar{\omega}_t}^{\infty}dG(\omega)\right)}{(\bar{\omega}_t)^{\frac{1}{\theta}}\left(\bar{\omega}_t\int_0^{\bar{\omega}_t}\omega dG(\omega)+(\bar{\omega}_t)^2\int_{\bar{\omega}_t}^{\infty}dG(\omega)\right)^2}, \tag{B28}$$

which is greater than zero. Hence, $\Omega''(\ln u_t) < 0$. This completes the proof.

□

Magnitude of the bias To roughly assess the magnitude of the biases of the slope and curvature estimates we proceed as follows. Recall that when we control for $\ln \mathrm{UVC}_{i,t}$ rather than $\ln mc_{i,t}$, exogenous variation in $\ln u_{i,t}$ traces out the compound term $\Xi(\ln u_{i,t})$ as defined in equation (B23) and not the object of interest $\mathcal{M}(\ln u_{i,t})$. This implies that the estimated parameters in equation (16) correspond to the slope and curvature of $\Xi(\ln u_{i,t})$, that is,

$$\beta_Y = \Xi'(\ln u) \text{ and } \beta_{Yu} = \frac{\Xi''(\ln u)}{u},$$

where we again dropped industry subscripts i. Using equation (B23), the true slope and curvature can then be constructed as

$$\mathcal{M}'(\ln u) = \frac{\Xi'(\ln u)}{1+\frac{\Omega'(\ln u)}{\mathcal{M}'(\ln u)}} = \frac{\beta_Y}{1+\frac{\Omega'(\ln u)}{\mathcal{M}'(\ln u)}}, \tag{B29}$$

$$\frac{\mathcal{M}''(\ln u)}{u} = \frac{\frac{\Xi''(\ln u)}{u}}{1+\frac{\Omega''(\ln u)}{\mathcal{M}''(\ln u)}} = \frac{\beta_{Yu}}{1+\frac{\Omega''(\ln u)}{\mathcal{M}''(\ln u)}}, \tag{B30}$$

where the two terms $\frac{\Omega'(\ln u)}{\mathcal{M}'(\ln u)}$ and $\frac{\Omega''(\ln u)}{\mathcal{M}''(\ln u)}$ are the biases relative to the true slope and curvature, respectively.

These biases can be computed as follows. First note that equations (B24), (B14), (B27), and (B17) imply that

$$\frac{\Omega'(\ln u)}{\mathcal{M}'(\ln u)} = \frac{\tilde{\Omega}'(\bar{\omega})\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u}{\tilde{\mathcal{M}}'(\bar{\omega})\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u} = \frac{\tilde{\Omega}'(\bar{\omega})}{\tilde{\mathcal{M}}'(\bar{\omega})},$$

$$\frac{\Omega''(\ln u)}{\mathcal{M}''(\ln u)} = \frac{\vartheta'(\bar{\omega})\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u}{\varkappa'(\bar{\omega})\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u} = \frac{\vartheta'(\bar{\omega})}{\varkappa'(\bar{\omega})}.$$

Expressions for $\tilde{\Omega}'(\bar{\omega})$, $\tilde{\mathcal{M}}'(\bar{\omega})$, $\vartheta'(\bar{\omega})$, and $\varkappa'(\bar{\omega})$ are then given by equations (B25), (B13), (B28), and (B18). In our baseline version of the model, these four objects depend on the parameter θ, the distribution G of idiosyncratic demand shocks ω, as well as the equilibrium threshold variety $\bar{\omega}$ that maps to the average utilization rate.

To assess the magnitude of the biases, the model therefore needs to be calibrated. We assume that ω is log-normally distributed with mean 1 and variance V. We further set the average utilization rate to $u = 0.792$ (see Appendix Table A1). We then choose the threshold variety $\bar{\omega}$, the variance V, and elasticity θ so as to minimize the sum of squared distances between the model-implied and estimated slope and curvature, that is:

$$\min_{\bar{\omega},\theta,V}\left(\Xi'\left(\ln u\left(\bar{\omega}\right)\right)-\hat{\beta}_{Y}\right)^{2}+\left(\frac{\Xi''\left(\ln u\left(\bar{\omega}\right)\right)}{u\left(\bar{\omega}\right)}-\hat{\beta}_{Yu}\right)^{2}$$

where the minimization is subject to

$$u\left(\bar{\omega}\right)=0.792.$$

We target our baseline estimates (from column (6) of Table 2) and set $\hat{\beta}_Y = 0.27$ and $\hat{\beta}_{Yu} = 1.17$. Further, we evaluate $\Xi'\left(\ln u\left(\bar{\omega}\right)\right)$ and $\frac{\Xi''(\ln u(\bar{\omega}))}{u(\bar{\omega})}$ using the relationships

$$\Xi'\left(\ln u\right)=\mathcal{M}'\left(\ln u\right)+\Omega'\left(\ln u\right)=\left(\tilde{\mathcal{M}}'\left(\bar{\omega}\right)+\tilde{\Omega}'\left(\bar{\omega}\right)\right)\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u,$$

$$\frac{\Xi''\left(\ln u\right)}{u}=\frac{\mathcal{M}''\left(\ln u\right)+\Omega''\left(\ln u\right)}{u}=\frac{\left(\varkappa'\left(\bar{\omega}\right)+\vartheta'\left(\bar{\omega}\right)\right)\cdot\left(\frac{\partial u}{\partial\bar{\omega}}\right)^{-1}\cdot u}{u},$$

which follow from equations (B24), (B14), (B27), and (B17). The solution requires that $V = 0.60$ and $\theta = 3.95$. With these parameter values the model exactly matches our slope and curvature estimates.

For this calibration, the biases are $\frac{\Omega'(\ln u)}{\mathcal{M}'(\ln u)} = -0.221$ for the slope and $\frac{\Omega''(\ln u)}{\mathcal{M}''(\ln u)} = -0.459$ for the curvature. Hence, if this model is true and correctly calibrated, these values imply that our slope estimate is 22.1 percent smaller than the true slope and our curvature estimate is 45.9 percent smaller than the true curvature.

In principle, the formulas (B29) and (B30) above can be used to calculate bias-corrected estimates and we do so in Online Appendix E. Since our model is simple and stylized, however, and not developed for quantitative statements, we do not emphasize this bias correction in the text. We instead prefer to interpret our estimates for both the slope and curvature as conservative.

C Appendix: Notes on Shea's instrument

In this appendix we provide additional notes on our version of John Shea's instrument as described in Section 3.2. In particular, we specify a condition that guarantees that criteria (1), (2), and (3) as described in the text hold. When constructing this instrument based on equation (19), note that we consider all possible downstream industries j, and not only the manufacturing industries included in our sample.

As noted in Shea (1993b), measuring direct linkages between two industries is generally not sufficient for satisfying criteria (1), (2), and (3). Nor are ultimate cost or sales shares sufficient. Following Shea, we therefore use information from both direct and ultimate cost and sales shares. We next describe our definitions of these shares.

C.1 Demand shares

Let p_i denote the price and y_i the quantity produced by industry i. Let further $x_{j,i}$ denote industry $j's$ usage of i's output. Lastly, let d_i denote the value of final demand for the good produced by industry i.

C.1.1 Direct demand share

We define the direct demand share of industry j for industry i's good as

$$dds_{j,i} = \frac{p_i x_{j,i}}{\sum_j p_i x_{j,i}}.$$

While alternative definitions are sensible, we choose the denominator such that $\sum_j dds_{j,i} = 1$.

C.1.2 Ultimate demand share

Market clearing implies that

$$p_i y_i = \sum_j p_i x_{ji} + d_i = \sum_j \mu^c_{j,i} p_j y_j + d_i,$$

where $\mu^c_{j,i} = \frac{p_i x_{j,i}}{p_j y_j}$ is the cost share of i in j's output. We can then stack the system in matrix form. Using the notation

$$py = \begin{pmatrix} p_1 y_1 \\ \vdots \\ p_I y_I \end{pmatrix}, \; d = \begin{pmatrix} d_1 \\ \vdots \\ d_I \end{pmatrix}, \; \Gamma^c = \begin{pmatrix} \mu^c_{1,1} & \cdots & \mu^c_{1,I} \\ \vdots & \ddots & \vdots \\ \mu^c_{I,1} & \cdots & \mu^c_{I,I} \end{pmatrix},$$

we can write

$$py = d + (\Gamma^c)' \, py,$$

or

$$py = \left(I - (\Gamma^c)'\right)^{-1} d.$$

Based on this relationship, we define the ultimate demand share of industry j for the output of industry i as

$$uds_{j,i} = \frac{1}{p_i y_i} \cdot \left(I - (\Gamma^c)'\right)^{-1}_{i,j} \cdot d_j,$$

where $\left(I - (\Gamma^c)'\right)^{-1}_{i,j}$ is the (i,j)th element of matrix $\left(I - (\Gamma^c)'\right)^{-1}$. By construction, $\sum_j uds_{j,i} = 1$.

C.2 Cost shares

C.2.1 Direct cost share

We define industry i's direct cost share for industry j's good as

$$dcs_{i,j} = \frac{p_j x_{i,j}}{\sum_j p_j x_{i,j}}.$$

Notice that $\sum_j dcs_{i,j} = 1$.

C.2.2 Indirect cost share

Let va_i denote industry i's value added, then

$$p_i y_i = va_i + \sum_j p_j x_{i,j} = va_i + \sum_j \mu^s_{i,j} p_j y_j,$$

where $\mu^s_{i,j} = \frac{p_j x_{i,j}}{p_j y_j}$ is industry j's sales share to industry i. Using the notation

$$py = \begin{pmatrix} p_1 y_1 \\ \vdots \\ p_I y_I \end{pmatrix}, \; va = \begin{pmatrix} va_1 \\ \vdots \\ va_I \end{pmatrix}, \; \Gamma^s = \begin{pmatrix} \mu^s_{1,1} & \cdots & \mu^s_{1,I} \\ \vdots & \ddots & \vdots \\ \mu^s_{I,1} & \cdots & \mu^s_{I,I} \end{pmatrix},$$

we can then stack the system in matrix form and write

$$py = va + \Gamma^s py,$$

or

$$py = (I - \Gamma^s)^{-1} va.$$

The ultimate cost share of industry j for industry i is then defined as

$$ucs_{i,j} = \frac{1}{p_i y_i} \cdot (I - \Gamma^s)^{-1}_{i,j} \cdot va_j,$$

where $(I - \Gamma^s)^{-1}_{i,j}$ denotes the (i,j)th element of matrix $(I - \Gamma^s)^{-1}$. Notice that $\sum_j ucs_{i,j} = 1$.

C.3 Our version of Shea's instrument

We define our version of Shea's instrument as in equation (19), where

$$\mathcal{J}^{\text{Shea}}_{i,t} = \left\{ j : \frac{\min\left\{\text{dds}_{j,i,t}, \text{uds}_{j,i,t}\right\}}{\max\left\{\text{dcs}_{j,i,t}, \text{ucs}_{j,i,t}, \text{dcs}_{i,j,t}, \text{ucs}_{i,j,t}\right\}} > 3 \right\}. \tag{C1}$$

Conditions (1), (2), and (3) as defined in Section 3.2 are satisfied because for all $j \in \mathcal{J}^{\text{Shea}}_{i,t}$ (1) j's demand share from i is large relative to j's cost share from i (2) and i's cost share from j (3).

Table C1 reports the share of qualifying partner and year observations by industry (the average of an indicator function constructed from equation (C1) and taken over all years and partners). As in Shea (1993a,b), for some industries no partner satisfies the criteria in any year. These are Food Manufacturing, Beverage and Tobacco Product Manufacturing, Chemical Manufacturing, Primary Metal Manufacturing, Fabricated Metal Product Manufacturing, and Transportation Equipment Manufacturing, a total of 6 out of 21.

Industry	NAICS	Share (percent)
Food Manufacturing	311	0.0
Beverage and Tobacco Product Manufacturing	312	0.0
Textile Mills	313	4.4
Textile Product Mills	314	4.4
Apparel Manufacturing	315	4.2
Leather and Allied Product Manufacturing	316	4.2
Wood Product Manufacturing	321	2.7
Paper Manufacturing	322	0.9
Printing and Related Support Activities	323	2.0
Petroleum and Coal Products Manufacturing	324	0.5
Chemical Manufacturing	325	0.0
Plastics and Rubber Products Manufacturing	326	2.1
Nonmetallic Mineral Product Manufacturing	327	4.6
Primary Metal Manufacturing	331	0.0
Fabricated Metal Product Manufacturing	332	0.0
Machinery Manufacturing	333	0.2
Computer and Electronic Product Manufacturing	334	0.2
Electrical Equipment, Appliance, and Component Manufacturing	335	3.7
Transportation Equipment Manufacturing	336	0.0
Furniture and Related Product Manufacturing	337	5.0
Miscellaneous Manufacturing	339	2.5

Table C1: Share of qualifying partner-year observations

D Appendix: Robustness and extensions

D.1 Estimates of the first stage

This appendix reports the estimates of the first stage of the 2SLS estimates reported in Section 3.3. Table D1 reports the first stage estimates for the 2SLS estimates reported in column (5) of Table 1. Table D2 reports the first stage estimates for the 2SLS estimates reported in columns (2)-(6) of Table 2.

The partial R-squared of all instruments indicate that the instruments explain a sizable fraction of the variation that is not explained by the other regressors in the first stage. For instance, for our baseline specification (column (6) in Table 2), the partial R-squared for the change in output is 9.3 percent and the partial R-squared for the change in output interacted with the lagged utilization rate is 33.5 percent. Both of these shares are sizable and suggest that our instruments are strong.

Table 1 column	(5)
First stage dependent variable	$\Delta \ln Y_{i,t}$
$\text{inst}_{i,t}^{\text{WID}}$	6.34
	(6.63)
$\text{inst}_{i,t}^{\text{Shea}}$	1.01
	(0.15)
$\Delta e_{i,t}$	1.51
	(1.28)
$\Delta \ln Q_{i,t}$	0.71
	(0.09)
$\Delta \ln \text{UVC}_{i,t}$	-0.13
	(0.03)
R-squared	0.742
Partial R-squared	0.058
Fixed Effects	yes
Observations	819

Notes: This table shows the estimates of the first stage of the 2SLS estimates of Table 1. Driscoll-Kraay standard errors are reported in parentheses. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j\in\mathcal{J}^F} s_{j,i,t-1}$). Partial R-squared refers to the partial R-squared of all instruments.

Table D1: First stage estimates for Table 1

Table 2 column	(2)		(3)		(3)		(5)		(6)	
First stage dependent variable	$\Delta \ln Y_{i,t}$	$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	$\Delta \ln Y_{i,t}$	$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	$\Delta \ln Y_{i,t}$	$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	$\Delta \ln Y_{i,t}$	$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	$\Delta \ln Y_{i,t}$	$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$
$\text{inst}_{i,t}^{\text{WID}}$	6.12	0.02	6.87	-0.28	5.18	0.22	5.41	0.11	7.41	-0.21
	(7.67)	(1.08)	(7.24)	(0.56)	(7.27)	(0.75)	(7.48)	(1.06)	(7.51)	(1.09)
$\text{inst}_{i,t}^{\text{Shea}}$	1.01	-0.04	0.98	-0.02	1.02	-0.04	0.99	-0.03	0.99	-0.03
	(0.16)	(0.04)	(0.13)	(0.02)	(0.18)	(0.04)	(0.13)	(0.02)	(0.13)	(0.02)
$\Delta e_{i,t}$	1.30	-0.20	1.34	-0.22	1.44	-0.26	1.29	-0.19		
	(1.33)	(0.14)	(1.36)	(0.15)	(1.25)	(0.16)	(1.27)	(0.13)		
$\text{inst}_{i,t}^{\text{WID}} \cdot (u_{i,t-1} - \bar{u}_i)$	-79.60	30.93					-58.28	25.59	-75.56	28.82
	(17.50)	(6.20)					(21.78)	(5.33)	(19.09)	(6.01)
$\text{inst}_{i,t}^{\text{Shea}} \cdot (u_{i,t-1} - \bar{u}_i)$			-3.71	1.68			-2.35	1.16	-2.39	1.17
			(2.41)	(0.49)			(2.29)	(0.44)	(2.36)	(0.45)
$\Delta e_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$					-24.95	7.13	-15.39	2.89		
					(6.59)	(4.08)	(7.70)	(1.69)		
$u_{i,t-1} - \bar{u}_i$	-0.33	0.01	-0.32	0.00	-0.33	0.01	-0.34	0.01	-0.34	0.01
	(0.05)	(0.01)	(0.06)	(0.01)	(0.06)	(0.02)	(0.05)	(0.01)	(0.05)	(0.01)
$\Delta \ln Q_{i,t}$	0.95	0.01	0.94	0.01	0.93	0.02	0.95	0.01	0.96	0.01
	(0.11)	(0.01)	(0.13)	(0.01)	(0.12)	(0.01)	(0.11)	(0.01)	(0.11)	(0.01)
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.39	0.38	1.21	0.45	0.65	0.63	1.11	0.42	1.40	0.36
	(0.78)	(0.15)	(0.83)	(0.18)	(0.65)	(0.14)	(0.78)	(0.16)	(0.79)	(0.16)
$\Delta \ln \text{UVC}_{i,t}$	-0.07	0.01	-0.06	0.00	-0.06	0.00	-0.07	0.00	-0.07	0.01
	(0.04)	(0.00)	(0.04)	(0.00)	(0.04)	(0.00)	(0.04)	(0.00)	(0.04)	(0.00)
R-squared	0.775	0.576	0.770	0.456	0.773	0.470	0.777	0.609	0.775	0.599
Partial R-squared	0.092	0.297	0.071	0.099	0.084	0.122	0.100	0.352	0.093	0.335
Fixed Effects	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Observations	819	819	819	819	819	819	819	819	819	819

Notes: This table shows the estimates of the first stage of the 2SLS estimates of Table 2. Driscoll-Kraay standard errors are reported in parentheses. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). Partial R-squared refers to the partial R-squared of all instruments.

Table D2: First stage estimates for Table 2

D.2 Robustness

D.2.1 Sensitivity to adding and dropping controls and alternative measures

The unit cost control As discussed in Online Appendix B.6, proxying marginal costs with unit variable costs may lead to downward-biased estimates of the slope and curvature in our model. Consistent with this prediction and as shown in Table D3 column (1), the estimates of both increase, when we instead subsume marginal cost changes into the error term. While these estimates likely exhibit less bias, the error bands also increase substantially. We therefore prefer to include unit variable costs as a control and to interpret our estimates as conservative.

The capacity control and anticipation effects In columns (2) and (3) of Table D3 we examine the implications of dropping the change in capacity and its interaction with the utilization rate from the regression. Consistent with the model's prediction that changes in capacity shift the supply curve, the estimates of the slope and curvature fall (relative to column (6) of Table 2). Hence, the change in capacity is a useful control variable—even when the supply curve is estimated with instrumental variables.

If the model is correctly specified anticipation effects do not pose a problem for identification, because the observed change in capacity captures all relevant information about future shocks. To the extent that the model is incorrectly specified, anticipation effects could still pose a problem for identification. We address this concern below by estimating the effect of exchange rate changes on output. Since the size of this effect decreases with the initial utilization rate (equation (S3.7)), and changes in the exchange rate are not predictable, anticipation effects do not appear to drive the estimated curvature of the supply curve.

Sticky prices Column (4) of Table D3 adds the percent change of the industry's price from t to $t+1$. Extensions of the model to include sticky prices suggest that this variable should capture the firm's expectations about changes in future marginal costs (see Supplementary Appendix S1.5). Adding this control has virtually no effect on the estimates of slope and curvature. Further, the coefficient on future price changes is close to zero and tightly estimated, suggesting that producer prices are flexible over a year-long horizon.[1]

[1] A second diagnostic that suggests that producer prices are quite flexible when differenced over one year is the high pass-through of unit variable costs changes into price changes. In models with sticky prices, this pass-through is substantially less than one. Our estimates suggest that it is close to 0.9.

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

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.83	1.06	0.87	1.17	1.05	1.19	1.56	1.41	0.87
	(0.88)	(0.29)	(0.26)	(0.30)	(0.27)	(0.29)	(0.38)	(0.33)	(0.25)
$\Delta \ln Y_{i,t}$	0.76	0.27	0.23	0.27	0.27	0.28	0.31	0.33	0.18
	(0.25)	(0.08)	(0.06)	(0.07)	(0.07)	(0.08)	(0.08)	(0.08)	(0.04)
$u_{i,t-1} - \bar{u}_i$	0.43	0.04	-0.01	0.02	0.00	0.03	0.06	0.03	-0.02
	(0.13)	(0.04)	(0.02)	(0.04)	(0.02)	(0.04)	(0.04)	(0.02)	(0.02)
$\Delta \ln Q_{i,t}$	-0.84	-0.22		-0.22	-0.19	-0.20	-0.27	-0.21	-0.09
	(0.29)	(0.10)		(0.09)	(0.07)	(0.09)	(0.09)	(0.07)	(0.05)
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-1.93			-1.10	-1.01	-1.12	-2.50	-2.30	-0.84
	(1.17)			(0.42)	(0.39)	(0.42)	(0.56)	(0.50)	(0.42)
$\Delta \ln \mathrm{UVC}_{i,t}$		0.89	0.89	0.89	0.87	0.89	0.90	0.88	0.84
		(0.03)	(0.03)	(0.03)	(0.02)	(0.03)	(0.03)	(0.02)	(0.05)
$\Delta \ln P^{Y}_{i,t+1}$				0.00				0.01	
				(0.02)				(0.03)	
$\Delta \ln \mathrm{UNPW}_{i,t}$					0.08			0.10	
					(0.07)			(0.07)	
$\Delta \ln N^{\text{plants}}_{i,t}$						-0.12		-0.13	
						(0.06)		(0.06)	
$(u_{i,t-1} - \bar{u}_i)^2$							1.09	1.00	
							(0.26)	(0.21)	
R-squared	0.443	0.900	0.900	0.900	0.903	0.900	0.899	0.903	0.876
First stage and instrument diagnostics									
F Main effect	24.05	24.64	23.39	24.39	33.37	30.08	26.23	34.90	25.55
F Interaction	41.93	45.63	50.29	44.37	44.16	43.09	19.23	19.75	24.51
Cragg-Donald Wald F	9.04	9.29	10.21	9.16	13.44	9.14	8.31	11.57	8.70
SW F Main effect	43.28	45.60	27.06	42.37	38.37	56.55	35.48	35.27	25.24
SW F Interaction	49.07	60.76	36.16	49.53	45.82	58.94	39.71	39.02	16.79
Hansen J (p-value)	0.733	0.799	0.584	0.748	0.697	0.755	0.243	0.290	0.895

Notes: The 2SLS estimates are based on equation (16) using the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$. $\Delta \ln \mathrm{UNPW}_{i,t}$ denotes the percent change in nonproduction worker salaries and wages per unit of output. $\Delta \ln N^{\text{plants}}_{i,t}$ is the percent change in the number of plants within industry i. Driscoll-Kraay standard errors are reported in parentheses. All specifications include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.

Table D3: Robustness of the non-linear model

Nonproduction worker salaries and wages Column (5) adds to the baseline specification the percent change in nonproduction worker salaries and wages per unit of output ($\Delta \ln \mathrm{UNPW}_{i,t}$) as an additional control. Nonproduction worker salaries and wages are not included in our preferred measure of unit variable costs, which sum production worker wages, costs of materials, and expenditures on energy and then divide by real gross output. To the extent that nonproduction workers have a positive marginal product this omission may be a concern. As the estimates in column (5) of Table D3 show, however, the slope and curvature estimates change little (relative to column (6) of Table 2).

The number of plants The baseline model in Section 2 assumes a fixed number of firms for tractability. In Supplementary Appendix S1.3 we present a version of the model with firm entry. In this model extension, the estimating equation has an additional supply shifter on the right-hand side because the number of varieties offered by firms affects the industries' price through a love-of-variety mechanism. Further, as we discuss in the appendix, the number of varieties could be correlated with the instruments, and hence bias the estimation.

In column (6) we therefore add the percent change in the number of plants in an industry as a control. This control has a significant coefficient, but the slope and curvature estimates barely change. In unreported results, we have also added the percent change in the number of firms as a control, but again the slope and curvature estimates hardly change.

Data on the number of plants and firms for this robustness check are from the Business Dynamics Statistics (see US Census Bureau, 1978-2019). Since these data are only available from 1978 onwards, we replaced changes in the number of plants and firms with their respective unconditional mean prior to 1978 for these robustness checks.

Higher order terms Our estimating equation (14) is a first order approximation around $t-1$ values. Relative to an approximation around the steady state, the approximation around $t-1$ values allows us to estimate the curvature of the supply curve with an interaction term (see discussion in Section 2.5 and Figure 3). It is natural to ask whether our results are robust to the inclusion of other higher order terms as controls.

Column (7) includes the square of the lagged utilization rate as a control and therefore better controls for industries' "initial position" on their supply curve. Doing so raises both the slope and the curvature estimates. In additional specifications not reported here, we have added an interaction term of the change in unit variable costs with the utilization rate, the square of the change in capacity, and the square of the change in unit variable costs. Neither of these controls has a meaningful impact on the slope and curvature estimates.

All controls Column (8) includes all controls simultaneously. In this specification the main effect on output is 0.33 and the coefficient on the interaction term is 1.41.

Alternative price and quantity measures One potential concern with the estimates is that there is a purely mechanical correlation between the price change on the left hand side and the change in unit variable costs on the right hand side. In all specifications this far, the price index has been constructed as an implicit deflator by dividing the market value of production by the index of industrial production, and the unit variable cost measure on the right hand side was constructed by dividing variable costs by the index of industrial production. The common division by industrial production could therefore induce a purely mechanical correlation. As column (1) in Table D3 showed, the slope and curvature estimates are not driven by this correlation and increase when unit variable costs are dropped from the regression. As an additional check, we use the price index from the NBER-CES manufacturing industry database instead of our preferred implicit price measure on the left hand side. We also replace our preferred quantity measure industrial production with the production measure from the NBER-CES database. The estimates, reported in column (9) of Table D3, both fall relative to the baseline estimates in column (6) of Table 2, but they remain highly significant because their standard errors fall as well.

D.2.2 Nonparametric estimates

To ensure that our estimates are not driven by the assumption that the inverse supply elasticity is linear in the utilization rate (see equation (15)), we next report nonparametric estimates. For these nonparametric estimates, we group observations into four bins, defined by $U_1 = (-\infty, p^u_{15})$, $U_2 = [p^u_{15}, p^u_{50})$, $U_3 = [p^u_{50}, p^u_{85})$, and $U_4 = [p^u_{85}, \infty)$, where p^u_{15}, p^u_{50}, and p^u_{85} denote the 15th, the 50th, and the 85th percentile of $u_{i,t-1} - \bar{u}_i$, respectively, and their values are $p^u_{15} = -0.065$, $p^u_{50} = 0.009$, and $p^u_{85} = 0.061$. We then estimate the specification

$$\begin{aligned}\Delta \ln P^Y_{i,t} = &\sum_{b=1}^{4} 1\left\{u_{i,t-1} - \bar{u}_i \in U_b\right\}\left(\beta_{Y,b}\Delta \ln Y_{i,t} + \beta_{Q,b}\Delta \ln Q_{i,t} + \beta_{u,b}\right) \\ &+ \beta_{\text{UVC}}\Delta \ln \text{UVC}_{i,t} + \text{fixed effects} + \varepsilon_{i,t}. \end{aligned} \tag{D1}$$

The coefficients of main interest are $\beta_{Y,b}$ for $b = 1, 2, 3, 4$. These coefficients measure the respective local inverse supply elasticity, that is, the elasticity of price $P^Y_{i,t}$ with respect to output $Y_{i,t}$ of observations in bin b. The indicator function $1\left\{u_{i,t-1} - \bar{u}_i \in U_b\right\}$ is equal to one if an observation $u_{i,t-1} - \bar{u}_i$ belongs to bin b and zero otherwise.

Table D4 shows the results. The inverse supply elasticity is 0.57 and highly significant in the fourth utilization bin U_4 and 0.12 and statistically insignificant in the lowest bin U_1. Hence, for a demand-induced increase in the quantity by one percent industry-year observations above the 85th percentile raise prices by approximately five times as much as observations below the 15th percentile (0.573/0.116 = 4.95). Two other results in this table are noteworthy. First, the inverse supply elasticity is monotonically increasing over the utilization bins, implying that the linearity assumption we maintain for most of the paper is a reasonably good approximation. Second, and consistent with the model, the estimated coefficients $\beta_{Q,b}$ are decreasing in the initial utilization rate and broadly align with the estimated inverse supply elasticities in absolute value.

D.2.3 Inventories

Inventory holdings could pose two types of concerns for our empirical analysis. First, by holding sufficient inventories, firms may decouple production from sales and thereby reduce the degree to which capacity constraints affect pricing decisions. To the extent that this is the case, our esti-

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

Bin	U_1 $u_{i,t-1}-\bar{u}_i<p^u_{15}$	U_2 $p^u_{15}\leq u_{i,t-1}-\bar{u}_i<p^u_{50}$	U_3 $p^u_{50}\leq u_{i,t-1}-\bar{u}_i<p^u_{85}$	U_4 $p^u_{85}\leq u_{i,t-1}-\bar{u}_i$
$\beta_{Y,b}$	0.12	0.28	0.31	0.57
	(0.08)	(0.10)	(0.09)	(0.14)
$\beta_{Q,b}$	-0.05	-0.20	-0.38	-0.56
	(0.10)	(0.10)	(0.10)	(0.17)
$\beta_{u,b}$	(omitted)	0.00	0.00	0.01
		(0.00)	(0.00)	(0.01)
β_{UVC}	0.89			
	(0.03)			
R-squared	0.897			

Notes: The 2SLS estimates are based on equation (D1) using the interactions of the WID and Shea's instrument with indicators of the utilization bins as instruments. The specification includes industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j\in\mathcal{J}^F} s_{j,i,t-1}$). p^u_{15}, p^u_{50}, and p^u_{85} denote the 15th, the 50th, and the 85th percentile of $u_{i,t-1}-\bar{u}_i$, respectively, and $p^u_{15}=-0.065$, $p^u_{50}=0.009$, and $p^u_{85}=0.061$. Driscoll-Kraay standard errors are reported in parentheses.

Table D4: Nonparametric estimates

mates this far indicate that capacity constraints generate convex supply curves *despite* the possible presence of inventories. Second, and as discussed in Section 3.2, it is possible that industries' inventory holdings are correlated with their capacity utilization. This could imply that our curvature estimates are instead driven by inventory holdings and that we would incorrectly attribute the estimated curvature to capacity utilization. We next explore the role of inventories in greater detail.

Figure D1 shows a histogram of industry's inventory holdings relative to annual production. The histogram is based on the same sample as the estimation. For most industry-year observations, inventories cover between one and two months worth of production. They rarely exceed three months worth of production. Under the assumption that the goods held in stock match those in higher demand, the figure suggests that industries may temporarily satisfy higher demand by running down their inventories.

Table D5 shows correlations of the level and changes of inventory holdings with the utilization rate. With a correlation coefficient of 0.01 the utilization rate and the level of inventory holdings are essentially uncorrelated. This low correlation implies that our curvature estimates cannot be driven by inventory holdings. The correlation of the utilization rate at time t with the change in inventories from $t-1$ to t is 0.43. Further, the correlation with the change in inventories from t to $t+1$ is 0.12. These positive correlations indicate that industries tend to *increase* their inventories—rather than running them down—when the utilization rate is high.[2] It is therefore not clear whether firms in practice use inventories to escape capacity constraints.

[2]That inventory investment is procyclical is well documented. Bils and Kahn (2000) offer an explanation based on the assumption that inventories facilitate sales.

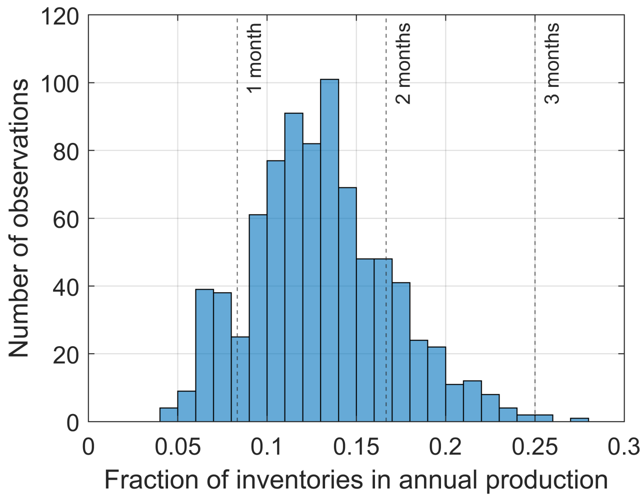


Figure D1: Inventory holdings

	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			
$\frac{Y^{\text{inv}}_{i,t}}{Y_{i,t}}$	0.01	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.

Table D5: Utilization rates and inventories

We next turn to a number of robustness checks of our regression analysis. The starting point for these checks is column (6) of Table 2, which estimates the slope and curvature of the supply curve using the WID instrument, Shea's instrument, and their interactions with the utilization rate. In column (1) of Table D6, we include the industry-demeaned lag of inventory holdings $(Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i})$ as a control. In column (2) we additionally include an interaction term with the change in output. When doing so, we add interactions of the WID instrument and Shea's instrument with $Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$ to the set of instruments. The objective of both specifications is to trace out the slope and curvature of the supply curve, holding the initial level of inventories constant. In both cases the estimates remain essentially unchanged. In column (3) we further include the contemporaneous and lagged change in inventories as controls. Again, the estimates are barely effected.

In column (4) of Table D6 we drop from the sample observations for which the initial level of inventories exceeds two months worth of production. In this "low-inventory" sample, the slope and curvature estimates are higher than in the full sample (column (6) of Table 2). While this finding is qualitatively consistent with the view that inventories allow firms to reduce the frequency of hitting their capacity constraints, the effect on the estimates is quantitatively small. Further, when we instead drop observations with less than one month worth of inventories in column (5), the slope and curvature also rise relative to the baseline (though less than in the low-inventory sample).[3]

[3] When we split the sample in the middle, the instruments are weak in both subsamples.

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

	(1)	(2)	(3)	(4)	(5)
Sample	full	full	full	$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1}$ $\leq 2/12$	$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1}$ $\geq 1/12$
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.15	1.18	1.21	1.45	1.28
	(0.29)	(0.28)	(0.27)	(0.37)	(0.28)
$\Delta \ln Y_{i,t}$	0.27	0.28	0.29	0.28	0.32
	(0.07)	(0.06)	(0.06)	(0.08)	(0.07)
$u_{i,t-1} - \bar{u}_i$	0.02	0.02	0.05	0.00	0.05
	(0.04)	(0.04)	(0.04)	(0.05)	(0.05)
$\Delta \ln Q_{i,t}$	-0.22	-0.23	-0.22	-0.22	-0.30
	(0.09)	(0.07)	(0.07)	(0.10)	(0.09)
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-1.08	-1.08	-1.15	-1.09	-1.15
	(0.42)	(0.50)	(0.48)	(0.61)	(0.46)
$\Delta \ln \text{UVC}_{i,t}$	0.89	0.89	0.90	0.90	0.83
	(0.03)	(0.03)	(0.03)	(0.03)	(0.05)
$Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$	-0.03	-0.03	0.03		
	(0.08)	(0.08)	(0.08)		
$\Delta \ln Y_{i,t} \cdot \left(Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}\right)$		-0.28	-0.36		
		(1.15)	(1.17)		
$\Delta Y^{\text{inv}}_{i,t}/Y_{i,t-1}$			0.14		
			(0.14)		
$\Delta Y^{\text{inv}}_{i,t-1}/Y_{i,t-2}$			-0.43		
			(0.16)		
R-squared	0.900	0.899	0.902	0.903	0.870
Fixed Effects	yes	yes	yes	yes	yes
Observations	819	819	819	673	719
First stage and instrument diagnostics					
F Main effect	24.52	21.16	21.35	13.87	24.69
F Interaction w/ $u_{i,t-1} - \bar{u}_i$	43.25	27.71	24.88	26.01	38.19
F Interaction w/ $Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$		27.10	28.83		
Cragg-Donald Wald F	9.29	6.61	7.59	8.53	7.72
SW F Main effect	43.60	37.40	27.85	21.56	53.42
SW F Interaction w/ $u_{i,t-1} - \bar{u}_i$	49.93	33.99	50.36	48.18	55.28
SW F Interaction w/ $Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$		62.52	60.97		
Hansen J (p-value)	0.768	0.812	0.924	0.544	0.839

Notes: The estimates are based on equation (16) using 2SLS with the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$. The set of instruments for columns (2) and (3) further includes interactions of the WID and Shea's instrument with $Y^{\text{inv}}_{i,t-1}/Y_{i,t-1} - \overline{Y^{\text{inv}}_i/Y_i}$. Driscoll-Kraay standard errors are reported in parentheses. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.

Table D6: The role of inventories

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

	(1)
$\Delta \ln Y^{\text{ship}}_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.12
	(0.26)
$\Delta \ln Y^{\text{ship}}_{i,t}$	0.27
	(0.07)
$u_{i,t-1} - \bar{u}_i$	0.01
	(0.04)
$\Delta \ln Q_{i,t}$	-0.21
	(0.07)
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-1.04
	(0.44)
$\Delta \ln \text{UVC}_{i,t}$	0.78
	(0.04)
R-squared	0.904
Fixed Effects	yes
Observations	819
First stage and instrument diagnostics	
F Main effect	9.19
F Interaction	30.56
Cragg-Donald Wald F	4.53
SW F Main effect	8.41
SW F Interaction	7.74
Hansen J (p-value)	0.705

Notes: The estimates are based on equation (16) with $\Delta \ln Y^{\text{ship}}_{i,t}$ in place of $\Delta \ln Y_{i,t}$, using 2SLS with the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$. Driscoll-Kraay standard errors are reported in parentheses. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.

Table D7: Shipments in place of production

Lastly, Table D7 reports estimates after replacing the change in production on the right-hand side ($\Delta \ln Y_{i,t}$) with the change in shipments, denoted by $\Delta \ln Y^{\text{ship}}_{i,t}$. Since the difference between shipments and production is the change in inventories, that is, $Y_{i,t} + Y^{\text{inv}}_{i,t-1} = Y^{\text{ship}}_{i,t} + Y^{\text{inv}}_{i,t}$, one might expect the curvature estimates to be smaller in this case. While the curvature estimate indeed drops, the decline relative to the baseline in column (6) of Table 2 is very small. In summary, neither of these checks indicates that the presence of inventories affects our results or their interpretation to a substantial degree.

D.2.4 The share of constrained capacity

We construct as an alternative utilization measure industry i's capacity-weighted share of constrained plants,

$$u^{sc}_{i,t} = \sum_{j \in J_{i,t}} \omega^q_{i,jt} \cdot 1\{u_{jt} \geq 0.95\}, \tag{D2}$$

where j indexes plants, $J_{i,t}$ is the set of plants in industry i, u_{jt} is the plant-level capacity utilization rate, and $\omega^q_{i,jt}$ is the sampling weight ω^s_{jt} multiplied by plant i's capacity, q_{jt}, divided by total capacity in industry i, that is,

$$\omega^q_{i,jt} = \frac{\omega^s_{jt} q_{jt}}{\sum_{j \in J_{i,t}} \omega^s_{jt} q_{jt}}.$$

For simplicity we also refer to $u^{sc}_{i,t}$ as the industry's share of constrained capacity.

All data come from the SPC or QSPC (see US Census Bureau, 1974-2006, 2007-2018). The indicator function counts plants as capacity constrained if their capacity utilization exceeds 95 percent. This threshold is chosen below one for the following reasons. First, it aims to make the utilization measure robust to measurement error in the plant-level utilization rate. Second, it accommodates the possibility that firms begin raising their markup when approaching capacity and not only when hitting the constraint. Third, this lower threshold increases the fraction of capacity constrained plants, which, in turn, raises the precision of the estimates and helps with complying with the disclosure rules of the US Census.

While this measure may better capture the model mechanism that the share of constrained capacity in an industry drives the convexity of the supply curve, we note several limitations and caveats with this measure. Because of these caveats we prefer to use the publicly available measures of capacity and utilization for our baseline analysis.

First, data are missing or miscoded for some years (1972, 1973, 1974, 1975, 1998). Our census project has no data for 1972 and 1973. While data for years the 1974 and 1975 is principally available, it is not used, because the Longitudinal Business Database (LBD)—needed to match and clean the data (see below)—is only available from 1976 onwards. The data for year 1998 appears to be miscoded and is therefore not used (see also Gorodnichenko and Shapiro, 2011). Therefore, while our baseline sample uses data from 1972 to 2011, our sample for this alternative utilization measure ranges from 1976 to 2011 with the exception of year 1998. For some analyses below we impute the missing values for $u^{sc}_{i,t} - \bar{u}^{sc}_i$ from $u_{i,t} - \bar{u}_i$ using the regression equation

$$\left(u^{sc}_{i,t} - \bar{u}^{sc}_i\right) = \alpha + \beta \left(u_{i,t} - \bar{u}_i\right) + \varepsilon_{i,t}. \tag{D3}$$

Second, in some cases the data from the QSPC and the SPC, that we have access to, appear to be miscoded, for instance, because a variable might not be reported in thousands but in millions of US dollars. To identify observations that are miscoded, we merge the utilization data with the LBD (see US Census Bureau, 1976-2016), the Annual Survey of Manufacturers (ASM) (see US Census Bureau, 1973-2016), and the Census of Manufacturers (CM) (see US Census Bureau, 1972-2012). We then compare the data on the market value of actual and full capacity production from the QSPC and the SPC with the market value of production from the ASM and the CM and to payroll from the LBD. We make adjustments if the reported data in the QSPC and SPC are implausible. Since we cannot identify all cases of miscoding, plant capacity q_{jt} is winsorized at the 10th and 90th percentile when constructing the weights $\omega^q_{i,jt}$. The upper bound prevents individual observations from exerting too much influence on the industry-level estimate and thus contains the role of measurement error. The lower bound ensures that information from small plants and plants with capacity that is incorrectly reported too low is also used to a significant extent.

Third, the SPC, which is the source for constructing $u_{i,t}^{sc}$ up to and including 2006, surveys plants only in the fourth quarter of each year. Hence, we only use information from the fourth quarter to measure the share of constrained capacity within an industry prior to year 2006. Data from the QSPC is available in all quarters.

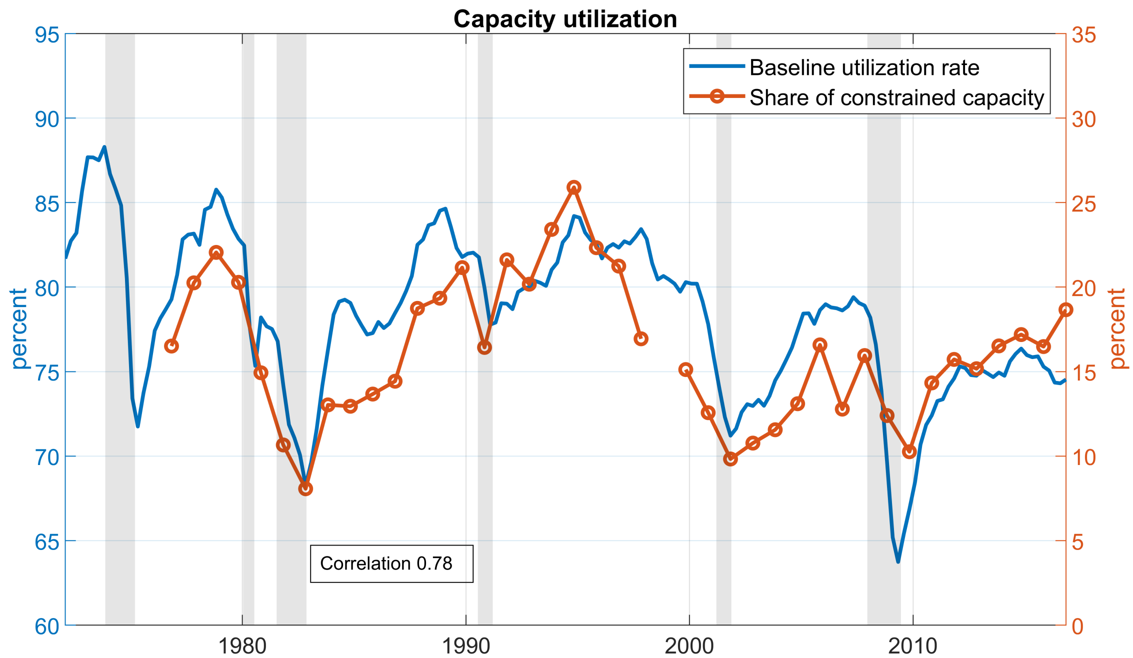
Fourth, both the SPC and QSPC are relatively small surveys. Recent vintages of the QSPC sample approximately 7500 establishments, not all of which are in manufacturing industries. In part due to non-response, sample sizes for estimating $u_{i,t}^{sc}$ at the 3-digit NAICS level can therefore be relatively small. (We use the longitudinally consistent NAICS codes from Fort and Klimek (2018) to assign establishments to industries.)

Note that all of these points are less problematic for the publicly available data, because the utilization rates are based on additional data sources. For instance, the utilization rates from the FRB are based on industrial production data and to a lesser extent rely on the reported market value of actual production from the SPC. Further, capacity is projected on a measure of the capital stock, which removes measurement error, before constructing the utilization rates (for details, see e.g., Gilbert et al. (2000) and `https://www.federalreserve.gov/releases/g17/About.htm`).[4] Lastly, we note that when using the share of constrained capacity (equation (D2)) instead of our baseline utilization measure, the relationship between the utilization rate, output, and capacity (equation (12)) no longer holds.

With these caveats in mind, Figure D2 shows the time series of the share of constrained capacity for all of manufacturing together with the publicly available utilization rate from the FRB (also the manufacturing-wide aggregate, see Federal Reserve Board (1972-2020)). The share of constrained capacity averages approximately 16 percent. The series is highly volatile, dropping below 10 percent during the Volcker disinflation and exceeding 25 percent in the mid-90s. With a correlation coefficient of 0.78 it correlates highly with our baseline utilization series from the FRB. When we instead correlate the utilization rates from the FRB with the share of constrained capacity at the 3-digit NAICS level, the correlation coefficient is 0.56. We interpret this reduced correlation as reflecting at least in part the increase in measurement error at the 3-digit industry level—due to the smaller sample sizes.

Table D8 shows the estimates of the supply curve when we use the share of constrained capacity instead of our baseline utilization measures from the FRB. We re-scale the share of constrained capacity in these regressions so that this alternative utilization series has the same standard deviation as our baseline utilization measure from the FRB and the reported coefficient estimates on the interaction term of interest are comparable in magnitude. Column (1) shows the estimates for our baseline set of controls on the sample from 1977-2011, excluding year 1998. Relative to our baseline estimate from column (6) in Table 2, the coefficient on the interaction term increases to 1.75. The coefficient estimate remains similar at 1.67 when we additionally include the controls from column (8) of Table D3. In columns (3) and (4) of Table D8 we repeat the estimation on the

[4]As discussed in Morin and Stevens (2004), the uncorrected survey data exhibit a “cyclical bias”.



Notes: The figure plots the baseline utilization rate for all manufacturing industries (seasonally adjusted) from the Federal Reserve Board together with our series of constrained capacity as constructed in equation (D2), but for the entire manufacturing sector. The share of constrained capacity is reported only for the fourth quarter (see text for details). Shaded areas represent NBER recessions.

Figure D2: Comparison of utilization measures

full sample, imputing the missing data on the share of constrained capacity using equation (D3). The estimates of interest rise slightly to 1.83 and 1.71. Taken together, these estimates based on the share of constrained capacity are greater than the estimates obtained using the baseline utilization measure. This may indicate that the curvature of industries' supply curve is driven by the share of constrained capacity rather than variation in the utilization rates of unconstrained plants—consistent with our model in Section 2.

D.3 Ad-hoc estimation of the supply curve

In this appendix, we show the results from an *ad-hoc* estimation of the supply curve, which does not use the guidance of the model in Section 2. To do so, we estimate the specification

$$\Delta \ln P_{i,t}^{Y} = \beta_0 + \beta_1 \Delta \ln Y_{i,t} + \beta_2 \left(\Delta \ln Y_{i,t}\right)^2 + \text{controls} + \varepsilon_{i,t}, \tag{D4}$$

using the WID and Shea's instrument as well as their squares to address simultaneity.

The results are shown in Table D9. The key problem with using this *ad-hoc* specification is that the first stage for the squared term is uniformly weak across all three specifications ($F < 2$). With our instruments, it is therefore not possible to estimate the curvature of the supply curve reliably without the structure of the model.

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

Sample	1977-2011 except 1998		Full sample (1973-2011)†	
	(1)	(2)	(3)	(4)
$\Delta \ln Y_{i,t} \cdot \left(u^{sc}_{i,t-1} - \bar{u}^{sc}_i\right)$	1.75	1.67	1.83	1.71
	(0.58)	(0.54)	(0.54)	(0.49)
$\Delta \ln Y_{i,t}$	0.24	0.24	0.27	0.28
	(0.07)	(0.08)	(0.07)	(0.08)
$u^{sc}_{i,t-1} - \bar{u}^{sc}_i$	0.01	0.02	0.02	0.02
	(0.02)	(0.02)	(0.02)	(0.02)
$\Delta \ln Q_{i,t}$	-0.15	-0.13	-0.18	-0.15
	(0.07)	(0.06)	(0.07)	(0.06)
$\Delta \ln Q_{i,t} \cdot \left(u^{sc}_{i,t-1} - \bar{u}^{sc}_i\right)$	-1.77	-1.65	-1.74	-1.58
	(0.85)	(0.80)	(0.82)	(0.78)
$\Delta \ln \mathrm{UVC}_{i,t}$	0.87	0.86	0.89	0.87
	(0.03)	(0.03)	(0.03)	(0.02)
$\Delta \ln P^Y_{i,t+1}$		0.01		0.00
		(0.03)		(0.03)
$\Delta \ln \mathrm{UNPW}_{i,t}$		0.04		0.09
		(0.07)		(0.07)
$\Delta \ln N^{\text{plants}}_{i,t}$		-0.09		-0.10
		(0.06)		(0.06)
$\left(u_{i,t-1} - \bar{u}_i\right)^2$		-0.10		-0.05
		(0.20)		(0.21)
R-squared	0.885	0.887	0.895	0.899
Observations (rounded)	700	700	800	800
First stage and instrument diagnostics				
F Main effect	19.24	15.67	24.90	23.05
F Interaction	8.29	9.14	9.19	9.49
Cragg-Donald Wald F	8.44	10.91	9.66	13.41
SW F Main effect	23.22	25.52	32.69	36.27
SW F Interaction	8.87	10.90	11.34	12.46
Hansen J (p-value)	0.377	0.422	0.697	0.623

Notes: The 2SLS estimates are based on equation (16) using the WID and Shea's instrument as well as interactions of both with $u^{sc}_{i,t-1} - \bar{u}^{sc}_i$. $\Delta \ln \mathrm{UNPW}_{i,t}$ denotes the percent change in nonproduction worker salaries and wages per unit of output. $\Delta \ln N^{\text{plants}}_{i,t}$ is the percent change in the number of plants within industry i. To ensure that the estimates in this table are comparable in magnitude to our baseline estimates, we re-scale the share of constrained capacity so as to have the same standard deviation as the demeaned utilization measure from the FRB. Driscoll-Kraay standard errors are reported in parentheses. The number of observations is rounded to the closest one hundred to comply with the disclosure rules of the US Census. All specifications include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.
†: Missing utilization rates $u^{sc}_{i,t-1} - \bar{u}^{sc}$ are imputed based on equation (D3).

Table D8: Robustness with alternative utilization measure

D.4 Testing the model's coefficient restrictions

Our derived estimating equation (14) implies a number of coefficient restrictions, which we test in this appendix. The tests are based on the specification reported at the top of Table D10, estimated

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

Estimator	2SLS	2SLS	2SLS
Instrument(s):			
Main effect		WID, Shea	
Squared term		WID, Shea	
	(1)	(2)	(3)
$\Delta \ln Y_{i,t}$	0.63	0.18	0.21
	(0.34)	(0.09)	(0.09)
$(\Delta \ln Y_{i,t})^2$	0.12	-0.14	-0.12
	(1.83)	(0.69)	(0.73)
$\Delta \ln Q_{i,t}$			-0.14
			(0.07)
$\Delta \ln \mathrm{UVC}_{i,t}$		0.89	0.89
		(0.03)	(0.03)
R-squared	0.419	0.908	0.909
Fixed Effects	yes	yes	yes
First stage and instrument diagnostics			
F Main effect	10.54	13.73	13.18
F Squared term	1.58	1.55	1.62
Cragg-Donald Wald F	2.53	2.53	2.49
SW F Main effect	2.56	2.49	2.31
SW F Squared term	1.52	1.52	1.55
Hansen J (p-value)	0.751	0.425	0.503

Notes: The 2SLS estimates are based on equation (D4) using the WID and Shea's instrument as well as their squares as instruments. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). Driscoll-Kraay standard errors are reported in parentheses. F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.

Table D9: Ad-hoc estimation

with 2SLS using the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$ as instruments. The specification also includes industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share. The associated point estimates are reported in column (6) of Table 2.

The model's restrictions are listed and tested individually in Panel A of Table D10. The model predicts that the coefficients on output and capacity sum to zero—both for the main effect and for the interaction with utilization. We cannot reject either null hypothesis. The model further predicts that the coefficient on the utilization rate is zero. Again, we cannot reject the null hypothesis. Lastly, the model predicts that the coefficient on the unit variable cost control is unity. This null hypothesis is strongly rejected. When we test these restrictions jointly in Panel B, the null hypothesis is also rejected (joint test 1). We next drop the restriction that the coefficient on unit variable costs is unity. In this case we cannot reject the null hypothesis (joint test 2).

The overall conclusion from these tests is that the model does well, except that the coefficient on the unit variable cost control is too low. However, we do not view this as a major failing of the model. A likely reason for this low coefficient is that we use unit variable cost as a proxy for marginal cost. If doing so introduces classical measurement error, the coefficient is biased towards zero.

Specification

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

Panel A: Individual tests

H_0 :	p-value
$\beta_Y + \beta_Q = 0$	0.196
$\beta_{Yu} + \beta_{Qu} = 0$	0.858
$\beta_u = 0$	0.628
$\beta_{\mathrm{UVC}} = 1$	0.000

Panel B: Joint tests

H_0 :	p-value
Joint test 1	0.000
$\beta_Y + \beta_Q = 0$	
$\beta_{Yu} + \beta_{Qu} = 0$	
$\beta_u = 0$	
$\beta_{\mathrm{UVC}} = 1$	
Joint test 2	0.272
$\beta_Y + \beta_Q = 0$	
$\beta_{Yu} + \beta_{Qu} = 0$	
$\beta_u = 0$	

Note: As in column (6) of Table 2 the estimates are obtained via 2SLS with the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$ as instruments, and include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). The reported tests are Wald tests and based on Driscoll-Kraay standard errors.

Table D10: Testing the model's coefficient restrictions

D.5 Heterogeneity

In this appendix we explore cross-industry heterogeneity in the slope and curvature of the supply curve. We do so by assigning each industry to one of two groups and then estimate equation (16) while allowing the two groups of industries to have different coefficients for all right-hand-side variables except the fixed effects. The instruments are the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$. The coefficients on each instrument differ by industry group in the first stage.

Column (1) in Table D11 shows a split by durability, where durability is defined as in the North American Industry Classification System (NAICS), see Table A1. The differences in curvature between durable and nondurable goods producing industries are small and not statistically significant ($p = 0.525$). In column (2) we split industries by average utilization rate. Again, there are no significant differences in curvature between these two groups ($p = 0.617$). Supply curves slope up and are convex in all groupings.

E Supply curve estimates as calibration targets

Using the notation from estimating equation (16), our baseline estimates are $\hat{\beta}_Y = 0.27$ and $\hat{\beta}_{Yu} = 1.17$ (from column (6) of Table 2). Further, the average utilization rate in our sample is $\bar{u}_i = 0.792$. Equation (16) then implies that

$$\widehat{\mathcal{M}' (\ln \bar{u}_i)} = \hat{\beta}_Y = 0.27, \tag{E1}$$

$$\widehat{\mathcal{M}'' (\ln \bar{u}_i)} = \hat{\beta}_{Yu} \cdot \bar{u}_i = 1.17 \cdot 0.792 = 0.93. \tag{E2}$$

Table E1 summarizes these and other selected estimates, including the baseline estimates with bias correction (see Online Appendix B.6). The estimates in this table can be used as calibration targets.

Our model In our model, these estimates can be plugged into the second order approximation of supply curve (13) around the industry-specific steady state,

$$\begin{aligned} \ln P^Y_{i,t} - \ln P^Y_i = {} & \mathcal{M}' (\ln \bar{u}_i) (\ln u_{i,t} - \ln \bar{u}_i) + \frac{1}{2} \mathcal{M}'' (\ln \bar{u}_i) (\ln u_{i,t} - \ln \bar{u}_i)^2 \\ & + \ln (mc_{i,t}) - \ln (mc_i) . \end{aligned} \tag{E3}$$

The inverse supply elasticity is

$$\begin{aligned} \frac{\partial \ln P^Y_{i,t}}{\partial \ln Y_{i,t}} & = \mathcal{M}' (\ln \bar{u}_i) + \mathcal{M}'' (\ln \bar{u}_i) (\ln u_{i,t} - \ln \bar{u}_i) \\ & \approx \mathcal{M}' (\ln \bar{u}_i) + \frac{\mathcal{M}'' (\ln \bar{u}_i)}{\bar{u}_i} (u_{i,t} - \bar{u}_i) . \end{aligned}$$

Models without capacity In models without capacity, our estimates can still be used to inform the slope and curvature of supply curves. Using the definition of the utilization rate (12), equation

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

	(1) By durability		(2) By average utilization rate	
	nondurable	durable	low	high
$\Delta \ln Y_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	1.10	0.78	1.16	0.87
	(0.32)	(0.40)	(0.35)	(0.46)
$\Delta \ln Y_{i,t}$	0.15	0.21	0.26	0.22
	(0.07)	(0.06)	(0.09)	(0.11)
$u_{i,t-1} - \bar{u}_i$	0.05	-0.04	0.07	-0.01
	(0.03)	(0.04)	(0.03)	(0.06)
$\Delta \ln Q_{i,t}$	-0.10	-0.13	-0.31	-0.11
	(0.08)	(0.08)	(0.10)	(0.15)
$\Delta \ln Q_{i,t} \cdot (u_{i,t-1} - \bar{u}_i)$	-0.15	-1.15	-1.38	0.25
	(0.76)	(0.46)	(0.53)	(0.54)
$\Delta \ln \mathrm{UVC}_{i,t}$	0.86	0.94	0.80	0.92
	(0.03)	(0.03)	(0.05)	(0.02)
R-squared	0.907		0.906	
Fixed Effects	yes		yes	
First stage and instrument diagnostics				
F Main effect	24.26	119.47	43.19	30.77
F Interaction	46.23	21.57	97.71	16.99
Cragg-Donald Wald F	7.61		4.57	
SW F Main effect	58.38	80.80	57.22	20.90
SW F Interaction	113.50	25.15	67.82	20.73
Hansen J (p-value)	0.429		0.312	

Notes: The 2SLS estimates are based on equation (16), but allow the two groups of industries to have different coefficients for all right-hand-side variables except the fixed effects. The instruments are the WID and Shea's instrument as well as interactions of both with $u_{i,t-1} - \bar{u}_i$ and an indicator for the category (nondurable/durable, low/high average utilization). Durability is defined at the 3-digit NAICS level. Industries in the low/high utilization groups are separated at the mean. Driscoll-Kraay standard errors are reported in parentheses. Fixed effects include industry fixed effects, time fixed effects, and time fixed effects interacted with industries' lagged foreign sales share ($\sum_{j \in \mathcal{J}^F} s_{j,i,t-1}$). F is the standard F-statistic. For details on the Cragg-Donald statistic, see Cragg and Donald (1993) and Stock and Yogo (2005). SW F is the Sanderson and Windmeijer (2016) conditional F-statistic.

Table D11: Heterogeneity

(E3) can be rewritten as

$$\begin{aligned}
\ln P^Y_{i,t} - \ln P^Y_i &= \mathcal{M}'(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i) + \frac{1}{2}\mathcal{M}''(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i)^2 \\
&\quad - \mathcal{M}''(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i)(\ln Q_{i,t} - \ln Q_i) \\
&\quad - \mathcal{M}'(\ln \bar{u}_i)(\ln Q_{i,t} - \ln Q_i) + \frac{1}{2}\mathcal{M}''(\ln \bar{u}_i)(\ln Q_{i,t} - \ln Q_i)^2
\end{aligned}$$

Estimate	$\widehat{\mathcal{M}'(\ln \bar{u}_i)}$	$\widehat{\mathcal{M}''(\ln \bar{u}_i)}$
Baseline (from column (6) of Table 2)	0.27	0.93
With additional controls (from column (8) of Table D3)	0.33	1.12
Baseline with bias correction (using equations (B29) and (B30))	0.35	1.71

Table E1: Calibration targets

$$+ \ln(mc_{i,t}) - \ln(mc_i).$$

In the short run, a reasonable assumption is to hold industries' capacity fixed at the steady state level so that $\ln Q_{i,t} = \ln Q_i$. Then the above expression simplifies to

$$\ln P_{i,t}^Y - \ln P_i^Y = \mathcal{M}'(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i) + \frac{1}{2}\mathcal{M}''(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i)^2 \tag{E4}$$
$$+ \ln(mc_{i,t}) - \ln(mc_i).$$

Alternatively, it may be convenient to directly target the inverse supply elasticity as a function of output,

$$\frac{\partial \ln P_{i,t}^Y}{\partial \ln Y_{i,t}} = \mathcal{M}'(\ln \bar{u}_i) + \mathcal{M}''(\ln \bar{u}_i)(\ln Y_{i,t} - \ln Y_i). \tag{E5}$$

The analogues of equations (E4) and (E5) in models without capacity depend on whether the model in question features capital accumulation. In models without endogenous capital accumulation, these two equations are simply the supply curve and the inverse supply elasticity. In models with capital accumulation, the assumption of holding capacity fixed corresponds to an assumption of holding capital fixed. Hence, in models with capital accumulation equation (E4) corresponds the short-run supply curve for a fixed capital stock. Further, equation (E5) corresponds to the inverse supply elasticity, holding the capital stock fixed.

Our baseline estimates (E1) and (E2) then imply that the inverse supply elasticity is 0.27 when output is at its steady state level. Further, a one percent increase in output raises the inverse supply elasticity by approximately 0.0093. These numbers imply that the inverse supply elasticity is approximately 0.177 when output is 10 percent below its steady state and approximately 0.363 when output is 10 percent above its steady state. For the other two estimates in Table E1 the inverse supply elasticity varies more with the level of output. Figure E1 depicts the inverse supply elasticity and the second order approximation of the supply curve as functions of output.

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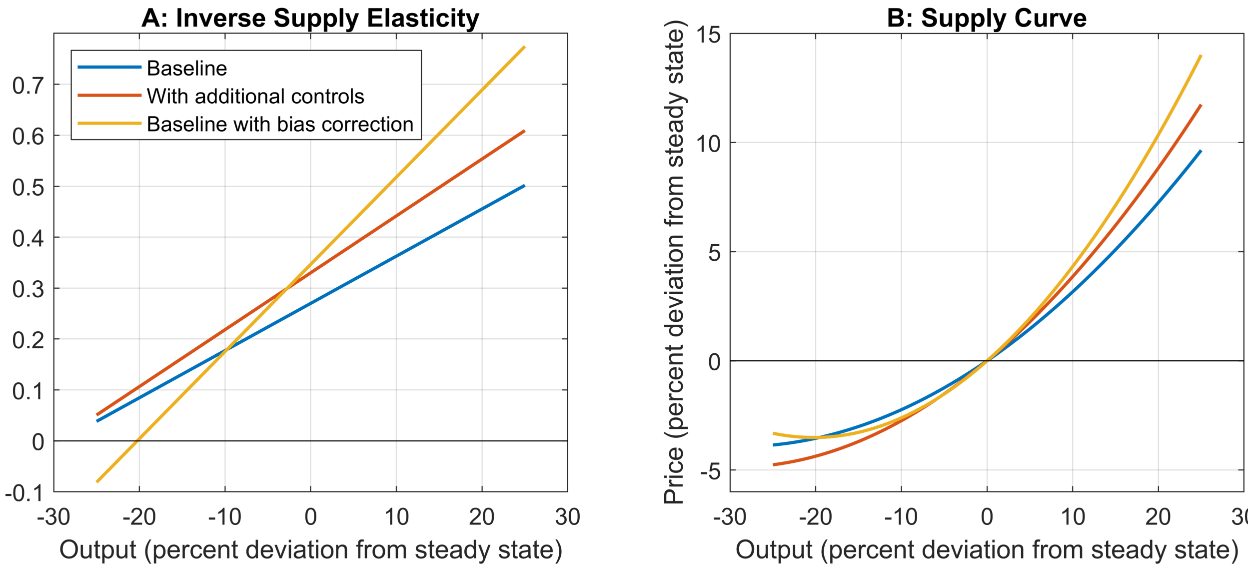

Notes: Panel A shows the inverse supply elasticity and Panel B the supply curve both as functions of output. Baseline refers to the estimates from column (6) of Table 2. With additional controls refers to the estimates from column (8) of Table D3. Baseline with bias correction uses the baseline estimates and additionally applies the bias correction using equations (B29) and (B30).

Figure E1: The supply curve as a calibration target

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