# Are responses to demand shocks state dependent?*

Christoph E. Boehm[1] Aaron Flaaen[2] Nitya Pandalai-Nayar[1]

[1]Princeton University and UT Austin
[2]Federal Reserve Board of Governors

April 2017

PRELIMINARY AND INCOMPLETE (PLEASE DO NOT CIRCULATE)

**Abstract**

This paper studies whether responses to demand shocks are state-dependent. To guide our empirical analysis we develop a putty-clay model in which short-run capacity constraints can lead to rationing. At the industry level the framework generates a convex supply curve, which leads to state-dependent responses to shocks. Using a sufficient statistics approach, we estimate the model and find strong support for state-dependent production responses to exchange rate shocks. Industries with low capacity utilization rates expand much more after dollar depreciations than industries with high utilization rates. Additional reduced form evidence based on confidential U.S. micro-data supports the interpretation that capacity constraints limit the responses to increased demand in the short run.

JEL Codes: F14, F16, F23

Keywords: State-Dependence, Fiscal Policy, Monetary Policy, Exchange Rate Passthrough, Slack, Capacity Utilization, Plant Capacity

---

*`cboehm@princeton.edu`, `aflaaen@frb.gov` and `npnayar@princeton.edu`. We would like to thank Javier Cravino, Oleg Itskhoki, Andrei Levchenko and Jaume Ventura as well as seminar participants at Princeton for valuable comments and suggestions. Pandalai-Nayar thanks the ECB for the Baron Alexandre Lamfalussy Fellowship which supported this research. Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau, the Board of Governors, or its research staff.

# 1 Introduction

A recent literature in macroeconomics has suggested that the effectiveness of fiscal and monetary policy depends on whether the economy is in recession or expansion at the time of the shock. For instance, Auerbach and Gorodnichenko (2012a) argue that the fiscal multiplier may be as high as 2.5 during recessions, while the expansionary multiplier is around zero or even negative. Since then a number of studies have put forward similar evidence, whereas others have challenged their results.[1] As of now, no consensus has emerged as to whether such state dependence exists and is quantitatively important.

In light of its relevance for policymaking this paper revisits this question. Unlike earlier work, we study one prominent mechanism that can generate state dependent responses to shocks: the convexity of supply curves. At low levels of factor utilization supply curves are flat. As a result greater demand predominantly raises output and has small effects on prices. Stabilization policies that shift out demand are effective in such environments. Conversely, if factors of production are highly utilized, additional demand mostly generates inflation with little effect on output. Figure 1 illustrates this mechanism.

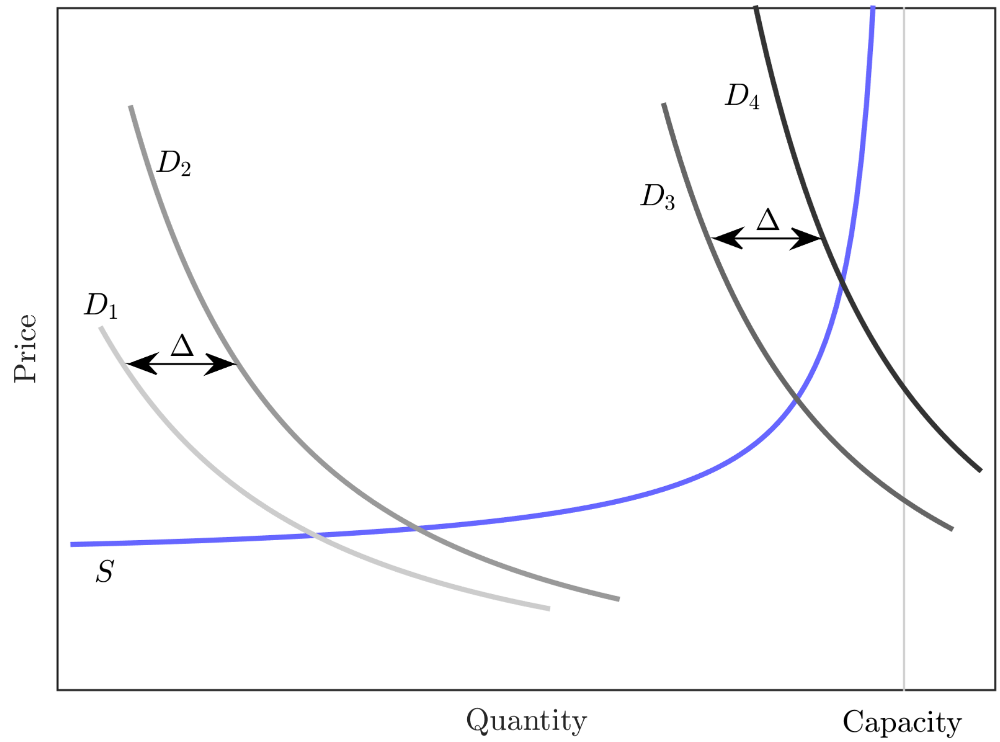
We find strong evidence for convex supply curves. Our preferred estimates suggest that the output of industries with low factor utilization rates responds by almost 2.5 times as much to demand shocks as industries with high utilization rates. Further, industries with high utilization rates experience price increases when subjected to positive demand shocks while industries with low utilization rates do not. These results are highly statistically significant and robust to a large number of alternative specifications.

We begin our analysis with developing a putty-clay-type model in the spirit of Fagnart, Licandro, and Portier (1999). The main assumption is that firms invest into a set of factors that are fixed in the short run and determine their maximum productive capacity. When demand for these firms is sufficiently high, they become capacity constrained — and their production unresponsive to shocks. Once aggregated to the industry level, the framework generates a convex supply curve.

Imposing this additional structure has a number of advantages. First, it allows us to be precise about the relevant state of the economy that determines the responses to shocks. In our framework the capacity utilization rate—the level of actual production divided by full capacity production—is

[1] See also Auerbach and Gorodnichenko (2012b), Owyang, Ramey, and Zubairy (2013)...add literature

Figure 1: State dependent responses to shocks




a sufficient statistic for this state. Since the Federal Reserve estimates and publishes utilization rates we do not need to rely on ad-hoc measures that may or may not affect responses to shocks. Second, whether supply curves are convex can be tested at various aggregation levels. We conduct our analysis at the industry-level data which provides substantial variation and allows us to obtain precise estimates. Finally, the structural approach implies that our findings are relevant for all types of demand shocks. While we use exchange rate variation for our estimation, the convexity of supply curves implies that responses to fiscal and monetary shocks will also exhibit state dependence.

Our framework suggests that one critical mechanism behind the convexity of the supply curve is an increase in firms' markups. Firms whose output is limited by their capacity will raise prices above the unconstrained optimal level because doing so does not reduce their production. ...to be completed.

While our main structural specification can be estimated on publicly available data, we test whether the demand elasticity depends on the industry's utilization rate using confidential Census

Bureau micro-data. The transactions-level trade data from the Longitudinal Foreign Trade Transactions Database (LFTTD), contains daily frequency information on unit values, values, HS-10 product and partner countries by firm. This enables us to construct prices, quantities and values of trade at the NAICS-3 level that are less subject to the well-known measurement issues in publicly available data. With this improved sample, we are able to construct separate interactions of industry slack and exchange rate change in appreciations and depreciations, while still including the rich set of industry-time and destination country-time fixed effects.

We first verify that our estimate of a variable demand elasticity holds on the full sample. Indeed, with the rich micro-data we obtain impulse responses of prices, quantities and output to the demand shocks that we estimate using local projections as in Jordà (2005). This approach avoids the shape restrictions imposed by VARs. We then show that the coefficient on the interaction is strongly significant and positive when the exchange rate depreciates. That is, industries in slack respond to a positive demand shock by raising quantities more and prices less. When interpreted through the lens of our model, this evidence is consistent with the rationing mechanism. Overall, our empirical evidence suggests the presence of important convexities in the supply curve.... to be completed.

This paper is related to several active strands of the literature. First, a recent literature lead by Auerbach and Gorodnichenko (2012a),Auerbach and Gorodnichenko (2012b) and Owyang, Ramey, and Zubairy (2013) has debated whether responses to fiscal stimulus is state-dependent using aggregate data and a variety of identification techniques. In contrast to these papers, we use a structural sufficient statistics approach and industry-level data to answer this question for a broad set of demand shocks. We complement our analysis with reduced-form findings from confidential microdata. Nakamura and Steinsson (2014) pioneered the use of disaggregate data to obtain enough variation to understand the implications of macroeconomic policy (see also Boehm (2016) for a closely related application).

The sufficient statistic in our model that captures the aggregate state is capacity utilization. A separate branch of the literature has studied (add Shapiro (1989), Shapiro (1993), Ottonello (2017), scar Jord, Schularick, and Taylor (2017)).

Section 2 describes our model of convex supply curves. Section 3 discusses our sufficient statistics approach to estimation and discusses the results of the structural estimation. Section 4 introduces our microdata and presents results related to the rationing hypothesis. We also present reduced form evidence related to our narrative in this section. Section ?? extends our model to general equilibrium, quantifies our findings and provides a discussion of the implications for fiscal and monetary policy effectiveness. Section 6 concludes.

# 2 Model

The main objective of this theoretical analysis is to develop a theory that (1) can generate a convex supply curve and (2) will guide our empirical analysis. In particular, the model will feature an observable notion of slack (or utilization) which, in special cases, is sufficient to determine the subsequent response to a demand shock.

The framework we present next features a competitive aggregating firm and monopolistically competitive intermediate goods firms. In order to generate a notion of capacity and utilization we assume a putty-clay-type production function (as in Fagnart, Licandro, and Portier, 1999) which requires firms to choose their maximum scale prior to making the actual production decision. If demand materializes sufficiently high, production will be limited by capacity.

## 2.1 Aggregating firm

In the baseline model a competitive aggregating firm uses a constant elasticity of substitution (CES) aggregator with elasticity $\theta$ to produce the industry's composite good,

$$X_t = \left( \int_0^1 v_t(j)^{\frac{1}{\theta}} x_t(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}. \tag{1}$$

The weights $v$ in the aggregator are firm-specific and time-varying, and present themselves as demand shocks to the intermediate goods firms.

The final goods firm solves

$$\max P_t X_t - \int_0^1 p_t(j) x_t(j) dj$$

subject to the production function (1). This problem yields the demand curves

$$x_t(j) = v_t(j) X_t \left( \frac{p_t(j)}{P_t} \right)^{-\theta}$$

and the industry's price index

$$P_t = \left( \int_0^1 v_t(j)\, p_t(j)^{1-\theta}\, dj \right)^{\frac{1}{1-\theta}}.$$

## 2.2 Intermediate goods producers

### 2.2.1 Production Function

To introduce the notion of capacity constraints our framework departs from standard theory by assuming that a bundle of factors $k_t$ is fixed in the short run. $k_t$ could be structures, equipment, or even specialized workers. Further, the firm has to decide ex-ante the maximum of variable factors, $b_t$, that it can employ (or process) in the short run. Since variable factors include primarily production workers and intermediate inputs, $b_t$ has the natural interpretation of workstations or processing capacity of intermediates.[2]

We assume that the *production capacity* of a firm is given by

$$q_t = z_t F(k_t, b_t) \tag{2}$$

where $z_t$ is productivity and $F$ is constant returns to scale. The firm's actual production $x_t$ is

$$x_t = q_t \frac{l_t}{b_t} = z_t F(\kappa_t, 1)\, l_t \tag{3}$$

where $\kappa_t = \frac{k_t}{b_t}$ and $l_t$ represents the firm's choice of a bundle of factors that are variable in the short run. Production $x_t$ is limited in the short run because the variable factors $l_t$ cannot exceed $b_t$, that is $l_t \leq b_t$. Note that the marginal product of the variable factors, $z_t F(\kappa_t, 1)$, is constant in the short run and determined by $z_t$ and $\kappa_t$. Letting $w_t$ denote the price of input bundle $l_t$, short run marginal costs are

$$mc_t = \frac{w_t}{z_t F(\kappa_t, 1)}. \tag{4}$$

[2] This paper emphasizes a technological interpretation of capacity constraint. An alternative is that firms do not find it optimal to produce above the level of capacity.

### 2.2.2 The producer's problem

Firms own their capital stock $k$ and maximize the present value of profits. To keep the notation clean, we drop the index $j$ in this section. Investment is subject to (possibly nonconvex) adjustment costs $\phi(i,k)$. The firm's Bellman equation is then

$$V(k,b,z,v) = \max_{x,i,l,b} \left\{ p_x x - wl - p_i i - \phi(i,k) + \frac{1}{1+r} \mathbb{E}\left[ V\left(k', b', z', v'\right)\right] \right\}$$

where the maximization is subject to

$$x = zF(k,b)\frac{l}{b} = zF(\kappa,1)\, l \text{ where } \kappa = \frac{k}{b}$$

$$l \leq b$$

$$k' = (1-\delta)k + i$$

$$vX\left[\frac{p}{P}\right]^{-\theta} = x$$

The productivity shock $z$ may have an aggregate, an industry-specific, as well as an idiosyncratic component. While this setup is fairly general up to here, an important case which is not nested in this setup is that of price stickiness. We will discuss this case below.

While we stick with the literature in assuming a one period time-to-build, this is not essential for what follows. The key point is that firms' decisions on capacity (capital, etc.) are motivated by long-run objectives, while other decisions, such as hiring of production workers, purchases of intermediates, and production itself are made in the short run without dynamic implications (an important exception is dynamic price setting, again, we return to this issue below). This observation is important for the empirical approach we take.

Optimal price setting requires that

$$p = \frac{\theta}{\theta - 1}(mc + \psi)$$

where $mc$ is given by equation (ref) and $\psi$ is the multiplier on the capacity constraint $x \leq q$. $q = zF(k,b)$

For illustrative purposes, we next move to a special case, although the results are more general, as we will discuss below.

**Capacity utilization** We define the industry's utilization rate as the ratio of actual production to the hypothetical level of output that would be attainable if every intermediate firm produced at full capacity, that is

$$u_t := \frac{X(q_t, \bar{v}_t)}{\lim_{\bar{v}_t \to 0} X(q_t, \bar{v}_t)}. \tag{5}$$

This definition has several attractive properties. First, it is constructed very similar to its empirical counterpart. For example, it is possible to express $u_t$ as an (appropriately constructed) average of firms' idiosyncratic utilization rates $u_t(j) := \frac{x(j)}{q_t} = \frac{p_t x_t(j)}{p_t q_t}$. The surveys of plant capacity that we will use below construct utilization measures by asking respondents to state the market value of their actual production $p_t x_t(j)$ and the market value of their full capacity production $p_t q_t$. Further, since $\lim_{\bar{v}_t \to 0} X(q_t, \bar{v}_t) \propto q_t$ it follows that $u_t \propto \frac{X_t}{q_t}$, that is, utilization is proportional to actual production divided by capacity. This corresponds closely to the utilization series that the Federal Reserve constructs by dividing an industrial production index by an index of production capacity.

**Lemma 1.** *The utilization rate as defined in (A12) has the following properties:*

1. $u_t \in [0,1]$ *is only a function of* $\bar{v}_t$*:* $u_t = u(\bar{v}_t)$
2. $\lim_{\bar{v} \to 0} u(\bar{v}) = 1$, $\lim_{\bar{v} \to \infty} u(\bar{v}) = 0$
3. $u' < 0$
4. *The sign of* $u''$ *is ambiguous*

The lemma highlights that the aggregate utilization rate is only a function of the threshold value $\bar{v}_t$ above which intermediate input suppliers produce at maximum capacity. The utilization rate approaches zero if no intermediate input supplier is producing at full capacity. It tends to one if all intermediate input suppliers become capacity constrained. Further, $u$ is decreasing everywhere, and this implies that $u$ is invertible and we can write $\bar{v}(u_t)$. We will make extensive use of this feature, both for the remainder of the theoretical analysis and when taking the model to the data. One immediate application is that we can write the rationing wedge as a function of utilization: $\Omega_t = \Omega(u_t)$. Figure A.3 illustrates a numerical example of the variation of $u$ with $\bar{v}$.

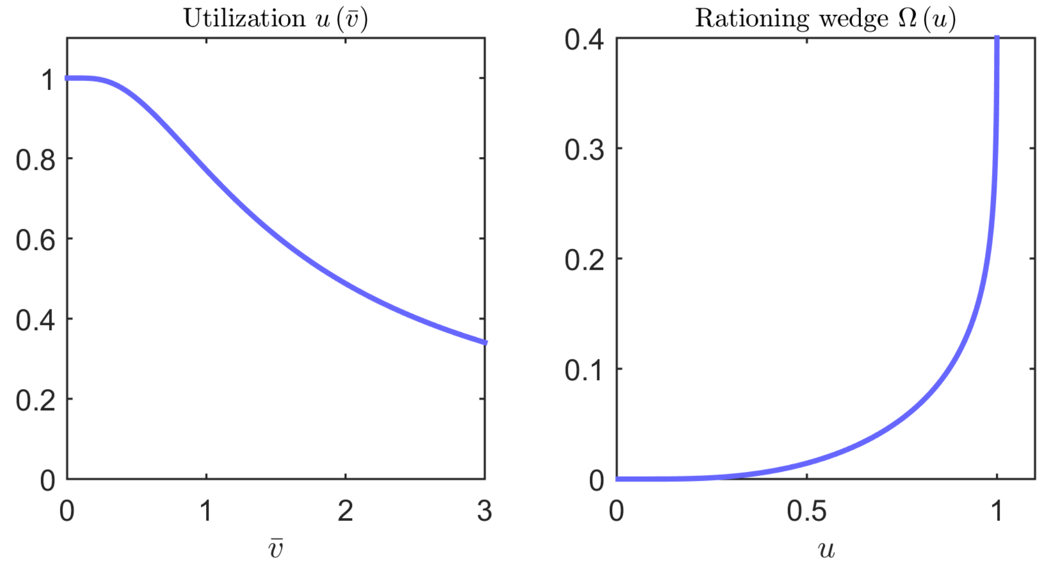



Figure 2: Utilization and the Rationing Wedge

**The rationing wedge** With Lemma 3 in hand we can now summarize the properties of $\Omega(u_t)$.

**Proposition 1.** *Under minor assumptions on $G$*

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

The rationing wedge is increasing in utilization everywhere. As an increasing number of suppliers become constrained, the input allocation becomes worse and the wedge widens. When the utilization rate approaches one, all suppliers become constrained and the wedge and its derivative tend to infinity. Conversely, when the utilization rate tends to zero, intermediate input suppliers are no longer capacity constrained. As a result both the rationing wedge and its derivative tend to zero. While $\Omega(u)$ is convex everywhere for many choices of $G$, it is possible to construct examples in which the wedge is locally concave. We conclude that the rationing wedge is a potential source of convexity of the supply curve, but whether this is so in the relevant range of utilization remains an empirical question. The right panel of Figure A.3 illustrates a numerical example of the rationing wedge.

## 2.3 Intermediate Goods Firms

Before turning to the intermediate goods producers, we describe the timing assumptions we make. As noted before the objective of these assumptions is to preserve simple aggregation properties of the model. Over the course of a period, firms

1. choose their fixed factor bundle $k_t$ and the maximum processing capacity $b_t$
2. learn the aggregate productivity draw $z_t$
3. choose their price $p_t$
4. learn their idiosyncratic demand shock $v_t$
5. choose the variable factor bundle $l_t$ and produce.

Since the choices of $k_t$ and $b_t$ are secondary for our empirical analysis, we relegate them to Appendix A. For the remainder of the paper it is sufficient to know that $k_t$ and $b_t$ have been chosen optimally and are fixed until the end of the period.

Having learned the aggregate productivity draw $z_t$, firms choose their price $p_t$. They maximize expected profits

$$E_v\left[\left(p_t - mc_t\right)x_t\right] \tag{6}$$

subject to the demand curve (A7). To understand the firms' incentives, it is useful to first consider the expected quantity sold,

$$E_v\left[x_t\right] = X_t\left[\frac{p_t}{P_t}\right]^{-\theta}\int_0^{\bar{v}_t} v dG\left(v\right) + q_t\int_{\bar{v}_t}^{\infty} dG\left(v\right).$$

When setting their price, firms take into account that they become capacity constrained when demand materializes sufficiently high. Conditional on becoming constrained, there are no costs of choosing higher prices because doing so does not reduce the quantity sold. As a result, the relevant notion of the demand elasticity for the firm is

$$-\frac{\partial \ln E_v\left[x_t\right]}{\partial \ln p_t}=\theta \frac{\int_0^{\bar{v}(u_t)} v dG\left(v\right)}{\int_0^{\bar{v}(u_t)} v dG\left(v\right)+\bar{v}\left(u_t\right) \int_{\bar{v}(u_t)}^{\infty} dG\left(v\right)}=: \tilde{\theta}\left(u_t\right) \tag{7}$$

We call this elasticity the effective demand elasticity. Clearly, $\tilde{\theta}\left(u_t\right) \in [0, \theta]$. Further, since the industry-wide utilization measure $u$ is a sufficient statistic for the firm to predict whether it will be capacity constrained, $\tilde{\theta}$ is a function of $u_t$ (and only of $u_t$). It is also easy to verify that under minor regularity conditions on $G$, $\lim_{u \to 0} \tilde{\theta}\left(u_t\right) = \theta$: As the industry's utilization rate approaches zero and the probability of being capacity constrained tends to zero and $\tilde{\theta}$ approaches the true demand elasticity. Similarly, $\lim_{u \to 1} \tilde{\theta}\left(u_t\right) = 0$.

It is not generally true that $\tilde{\theta}$ is decreasing everywhere since two competing effects govern the sign of the derivative of $\tilde{\theta}$ and either one can dominate. First, as utilization increases, the probability of becoming capacity constrained rises. This *rationing effect* reduces $\tilde{\theta}$ because for constrained suppliers the quantity does not fall when they raise the price by one marginal unit.

Second, there is a *composition effect*. To see this, suppose that capacity $q_t$ is fixed and recall that $u_t \propto \frac{X_t}{q_t}$. Since a higher utilization rate requires higher output of the industry, the assembling firm must increase demand from suppliers that are not rationed. In expectation, this raises the quantity of output for which the demand curve is downward sloping. As a result $\tilde{\theta}$ rises.

For many choices of $G$, the rationing effect dominates the composition effect and $\tilde{\theta}'$ is negative everywhere. In Appendix $B$ we present an example where this is not the case. The left panel of A2 shows a numerical example of $\tilde{\theta}$ and Lemma 4 summarizes its properties

**Lemma 2.** *Under minor regularity conditions on $G$, $\tilde{\theta}\left(u_t\right) \in [0, \theta]$ satisfies the following properties*

1. $\lim_{u \to 0} \tilde{\theta}\left(u_t\right) = \theta$, $\lim_{u \to 1} \tilde{\theta}\left(u_t\right) = 0$
2. $\lim_{u \to 0} \tilde{\theta}'\left(u_t\right) = 0$
3. *The sign of $\tilde{\theta}'$ is generally ambiguous.*

The optimal price choice implies that

$$p_t = \mathcal{M}\left(u_t\right) mc_t, \tag{8}$$

where $\mathcal{M}(u_t) = \frac{\tilde{\theta}(u_t)}{\tilde{\theta}(u_t)-1}$ and $\tilde{\theta}(u_t)$ is given by (A14). Clearly, the effective demand elasticity cannot fall below one because the markup would not be defined. The properties of $\mathcal{M}(u_t)$ follow immediately from Lemma 4.

**Proposition 2.** *Let* $\bar{u} = \sup\left\{u : \tilde{\theta}(u) = 1\right\}$. *Then*

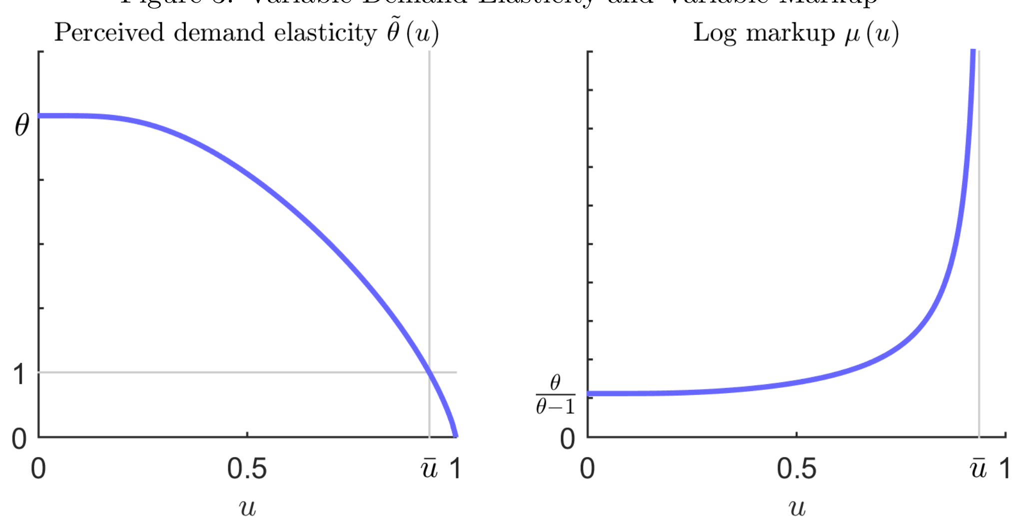
1. $\lim_{u\to 0} \mathcal{M}(u) = \frac{\theta}{\theta-1}$, $\lim_{u\uparrow\bar{u}} \mathcal{M}(u) = \infty$

2. $\lim_{u\to 0} \mathcal{M}'(u) = 0$ *and* $\lim_{u\uparrow\bar{u}} \mathcal{M}'(u) = \infty$

3. *The markup may not be increasing in* $u$ *everywhere*

As the utilization rate approaches zero, the markup tends to $\frac{\theta}{\theta-1}$–the value that would prevail in the absence of capacity constraints. Further, as the utilization rate tends to $\bar{u}$, the markup as well as its slope go to infinity. Note further, that if the effective demand elasticity $\tilde{\theta}$ is not monotonic, the markup inherits this property. The intuition is the following. If utilization rises, more firms are constrained. This raises the markup. However, this effect can locally be dominated by the fact that the aggregating firm purchases more from firms that are not rationed. Since in these states of the world the optimal markups are lower this composition effect reduces $\mathcal{M}(u)$. Appendix *B* discusses this possibility further. The right panel of Figure A2 illustrates a numerical example of the log markup $\mu(u) = \ln \mathcal{M}(u)$.

Figure 3: Variable Demand Elasticity and Variable Markup



### 2.4 Equilibrium

We can now put the individual pieces together and write the supply curve of the industry as a function of the markups, the rationing wedge and marginal costs

$$\ln P_t = \mu(u_t) + \Omega(u_t) + \ln mc_t. \tag{9}$$

Both the (log) markup and the rationing wedge are mechanisms that potentially lead to a convex supply curve.

We now close the model, assuming that the assembling firm of industry $i$ sells its output to $N$ countries which have CES demand functions

$$X_{i,n,t} = \omega_{i,n,t} X_{n,t} \left[\frac{P^*_{i,n,t}}{\mathcal{P}^*_{n,t}}\right]^{-\sigma}. \tag{10}$$

Here, $P^*_{i,n,t}$ is the price of the good in local currency, $X_{n,t}$ is the country's GDP, and $\mathcal{P}^*_{n,t}$ the associated price index. Each country has a possible industry-specific demand shock $\omega_{i,n,t}$. Let $\mathcal{E}_{n,t}$ be the exchange rate in US dollars per unit of foreign currency. Then the dollar-denominated price is

$$P_{i,n,t} = \mathcal{E}_{n,t} P^*_{i,n,t}. \tag{11}$$

Finally, market clearing requires that

$$X_{i,t} = \sum_n X_{i,n,t}. \tag{12}$$

### 2.5 Empirical specifications

**Proposition 3.** *The reduced form of the industry's quantity, linearized around its equilibrium in* $t-1$ *is*

$$\Delta \ln X_{i,t} = \beta_e(u_{t-1}) e_{i,t} + \beta_\pi(u_{t-1}) \pi_{i,t} + \beta_\xi(u_{t-1}) \xi_{i,t} + \beta_q(u_{t-1}) \Delta \ln q_{i,t} + \beta_{mc}(u_{t-1}) \Delta \ln mc_{i,t} + \omega^X_{i,t}$$

*where*

$$\beta_e > 0, \beta_\pi > 0, \beta_\xi > 0, \beta_q > 0, \beta_{mc} < 0.$$

*Further*

$$e_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln \mathcal{E}_{n,t}, \quad \pi_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln \mathcal{P}^*_{n,t}, \quad \xi_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln X_{n,t}$$

*and $s_{i,n,t-1}$ are sales shares to the respective counties in $t-1$, and*

$$\omega^X_{i,t} = \Gamma (u_{t-1}) \sum_n s_{i,n,t-1} \Delta \ln \omega_{i,n,t}$$

$\Gamma (u_{t-1})$ *is only a function of $u_{t-1}$. Further, if the supply curve is convex, then*

$$\beta'_e < 0,\ \beta'_\pi < 0,\ \beta'_\xi < 0,\ \beta'_q > 0,\ \beta'_{mc} > 0$$

And now the price

**Proposition 4.** *The reduced form of the price, linearized around its equilibrium in $t-1$ is given by*

$$\Delta \ln P_{i,t} = \gamma_e (u_{t-1})\, e_{i,t} + \gamma_\pi (u_{t-1})\, \pi_{i,t} + \gamma_\xi (u_{t-1})\, \xi_{i,t} + \gamma_q (u_{t-1})\, \Delta \ln q_{i,t} + \gamma_{mc} (u_{t-1})\, \Delta \ln mc_{i,t} + \omega^P_{i,t}$$

*where*

$$\gamma_e > 0,\ \gamma_\pi > 0,\ \gamma_\xi > 0,\ \gamma_q < 0,\ \gamma_{mc} > 0,$$

*$e_{i,t}$, $\pi_{i,t}$, $\xi_{i,t}$, and $s_{i,n,t-1}$ are defined as in the earlier proposition. Further,*

$$\omega^P_{i,t} = \Xi (u_{t-1}) \sum_n s_{i,n,t-1} \Delta \ln \omega_{i,n,t}$$

*and $\Xi (u_{t-1})$ is only a function of $u_{t-1}$. If the supply curve is convex, then*

$$\gamma'_e > 0,\ \gamma'_\pi > 0,\ \gamma_\xi > 0,\ \gamma'_q < 0,\ \gamma'_{mc} < 0$$

Discussion... (to be completed)

Threats to identification

1. $\omega_{i,t}$ may be correlated with $q_{i,t}$

2. Average costs may not equal marginal costs

3. Measurement error

4. Everything that is not in the model

### 2.6 Taking the model to the data

There are two ways to take the model to the data. First, we estimate the reduced form. Second, we test whether the effective demand elasticity is a function of $u$, as the model predicts:

$$\Delta \ln X_{i,n,t} = \beta u_{i,t-1} \Delta \ln \mathcal{E}_{n,t} + \gamma_{i,t} + \delta_{n,t} + \varepsilon_{i,n,t} \tag{13}$$

## 3 State Dependence in the Data

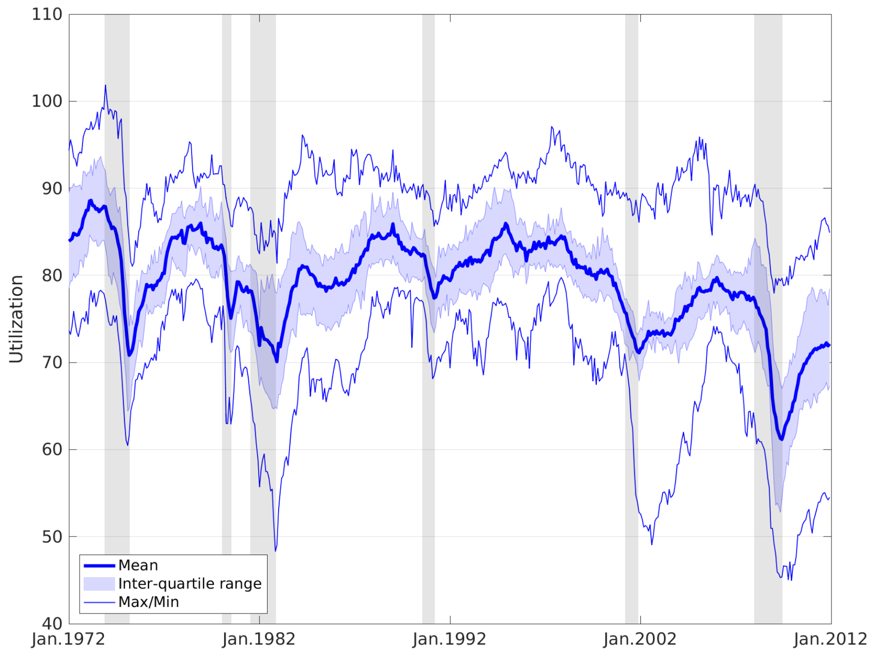
### 3.1 What is state-dependence?

### 3.2 Data

#### 3.2.1 Measuring Slack

Our preferred measure of slack is based on an alternative approach, which relies on direct measures of industry capacity utilization and is published by the Board of Governors of the Federal Reserve System (FRB). Rather than relying on the own trend movements of industrial production to back-out slack, the FRB separately measures industry capacity, defined as the "maximum level of production that could reasonably expect to attain under normal and realistic operating conditions, fully utilizing the machinery and equipment in place." Further details on the data sources and methodology underlying the capacity utilization series are provided below and in Appendix C.. Figure 4 presents details on the cross-sectional and time-series variation in this slack measure across industries. Table 1 provides a detailed breakdown of the properties of the utilization series we use by industry.

Figure 4: Measuring Capacity Utilization




Source: FRB.

This figure reports plots of the mean, maximum, minimum and interquartile range of the capacity utilization series constructed using the FRB capacity utilization data and industrial production. Shaded areas represent NBER recessions.

Table 1: Summary Statistics on Utilization Rates by 3-digit NAICS Industries

| Name | NAICS | 10th Pctile | Median | 90th Pctile | Mean | S.D. | Skewness | Kurtosis | Durable |
|---|---|---|---|---|---|---|---|---|---|
| Food Manufacturing | 311 | 79.6 | 82.3 | 85.2 | 82.4 | 2.4 | 0.3 | 2.5 | 0 |
| Beverage and Tobacco Product Manufacturing | 312 | 68.3 | 79.2 | 83.0 | 77.3 | 5.3 | -0.5 | 2.1 | 0 |
| Textile Mills | 313 | 68.3 | 82.0 | 89.5 | 79.8 | 8.6 | -0.8 | 3.2 | 0 |
| Textile Product Mills | 314 | 69.8 | 82.3 | 90.4 | 80.9 | 8.3 | -0.8 | 3.2 | 0 |
| Apparel Manufacturing | 315 | 71.0 | 80.2 | 84.2 | 79.0 | 4.9 | -0.9 | 3.4 | 0 |
| Leather and Allied Product Manufacturing | 316 | 59.3 | 74.9 | 82.1 | 72.8 | 8.8 | -1.2 | 3.7 | 0 |
| Wood Product Manufacturing | 321 | 63.8 | 79.2 | 85.2 | 77.1 | 8.4 | -1.2 | 4.6 | 1 |
| Paper Manufacturing | 322 | 81.4 | 87.6 | 91.4 | 86.9 | 4.2 | -0.2 | 2.4 | 0 |
| Printing and Related Support Activities | 323 | 72.2 | 82.7 | 89.3 | 81.3 | 7.6 | -1.0 | 3.8 | 0 |
| Petroleum and Coal Products Manufacturing | 324 | 77.3 | 87.1 | 92.6 | 85.7 | 5.8 | -0.7 | 2.8 | 0 |
| Chemical Manufacturing | 325 | 72.1 | 77.8 | 83.1 | 77.7 | 4.3 | -0.4 | 2.3 | 0 |
| Plastics and Rubber Products Manufacturing | 326 | 71.4 | 83.7 | 89.6 | 82.4 | 7.2 | -0.9 | 3.3 | 0 |
| Nonmetallic Mineral Product Manufacturing | 327 | 62.3 | 77.2 | 84.0 | 75.3 | 9.2 | -1.6 | 5.3 | 1 |
| Primary Metal Manufacturing | 331 | 68.2 | 79.6 | 89.5 | 79.3 | 9.3 | -0.7 | 3.4 | 1 |
| Fabricated Metal Product Manufacturing | 332 | 71.7 | 77.7 | 84.4 | 77.4 | 5.7 | -0.2 | 3.1 | 1 |
| Machinery Manufacturing | 333 | 67.6 | 78.9 | 87.0 | 77.8 | 7.8 | -0.2 | 2.5 | 1 |
| Computer and Electronic Product Manufacturing | 334 | 70.1 | 79.0 | 84.2 | 78.2 | 5.7 | -1.0 | 4.0 | 1 |
| Electrical Equipment, Appliance, and Component Manufacturing | 335 | 73.2 | 82.8 | 90.6 | 82.6 | 6.7 | -0.2 | 2.6 | 1 |
| Transportation Equipment Manufacturing | 336 | 66.4 | 75.6 | 81.5 | 74.4 | 6.1 | -1.0 | 4.1 | 1 |
| Furniture and Related Product Manufacturing | 337 | 68.0 | 77.8 | 84.1 | 76.8 | 7.4 | -0.2 | 3.9 | 1 |
| Miscellaneous Manufacturing | 339 | 72.8 | 76.9 | 79.7 | 76.3 | 3.1 | -0.5 | 3.1 | 1 |
| All | | 70.0 | 79.8 | 88.6 | 79.1 | 7.6 | -0.8 | 4.4 | |

Source: FRB

## 3.3 Publicly Available Data

We use industry-level measures of industrial production and capacity utilization as published by the Federal Reserve. Industrial production data are seasonally adjusted indexes of real output at the industry-level, and are based on a combination of 1) physical units of output, and 2) inferred output from input data such as hours worked by production workers. An extensive discussion of the coverage and methodology of the industrial production data can be found in XXXX.

Capacity utilization is based on measures of output and capacity. The annual FRB measure of capacity is based on a variety of data sources, including establishment-level estimates of utilization rates in the Survey of Plant Capacity, measures of capital input from the Annual Survey of Manufacturers, and alternative estimates of capacity for select industries. The monthly capacity series that are used to construct utilization are linearly interpolated from these annual estimates. The data are available for roughly 90 detailed industries going back to 1972. We use the end-of-period values of utilization unless noted otherwise.

Aggregate data on country GDP, CPI and PPI is obtained from the Penn World Tables (annual), or from the OECD and IFS (quarterly). Nominal exchange rate data is obtained from the IFS where possible, and augmented with information from the OECD. Exchange rates are computed as alternatively the period average or the end of period values. For countries such as Taiwan where exchange rates or CPI information is not available from these sources, we turn to national statistical agencies.

## 3.4 Baseline Specifications

Our baseline reduced form of the model was illustrated in Proposition 6 and Proposition **??**. For convenience, we rewrite our estimating equation here:

$$\Delta \ln X_{i,t} = \beta_e (u_{t-1}) e_{i,t} + \beta_\pi (u_{t-1}) \pi_{i,t} + \beta_\xi (u_{t-1}) \xi_{i,t} + \beta_q (u_{t-1}) \Delta \ln q_{i,t} + \beta_{mc} (u_{t-1}) \Delta \ln mc_{i,t} + \omega_{i,t}^X \tag{14}$$

Here, $u_{t-1}$ is the lagged utilization rate of the industry, $e_{i,t}$ is the sales weighted exchange rate shock to the industry (sales weighted average of all bilateral shocks faced by the industry), $\pi_{i,t}$ is the sales weighted average growth rate of partner price indices and $\xi_{i,t}$ is the sales weighted average partner output growth. $\ln mc_{i,t}$ is the log of industry marginal costs. Proposition 6 outlines the model implied predictions for all of the coefficients on the estimating equation, which form our test of the reduced form implied by the model.

A similar expression for prices is outlined in Proposition **??**, with predictions for coefficient signs implied by the model also clearly described.

We estimate the reduced form of the model for both prices and quantities using the publicly available data outlined in Section 3.3.

#### 3.4.1 Results

The results from our estimation are presented in Tables 2 (quantities) and 3 (prices). The first five columns of the table present a baseline estimation of equation 14 where we do not include interactions with industry utilization. This helps understand how the baseline model with no utilization fits the data. Column 1 includes no additional fixed effects, but columns 2-5 include various combinations of industry and time fixed effects, as well as higher order terms for controls.

We find that the model does extremely well at explaining changes in industrial production. The coefficients all have the predicted sign, are almost all significant, and the R-squared is very high across specifications.

We next augment the regressions to include interactions with lagged industry capacity utilization, as suggested by the reduced form of the model. Columns 6-10 illustrate the results. Again, the columns vary based on the combination of industry/time fixed effects, and higher order terms for controls.

The results suggest that our mechanism of convex supply curves due to variation in the perceived demand elasticity is operative in the data. Again, the non-interacted terms all have the predicted sign and are generally significant. Further, the coefficients on the interactions all have the signs predicted by Proposition 6. In most cases they are significant at at least the 5% level. Importantly, the coefficient on the interaction of the demand shock (the exchange rate change) and lagged capacity utilization is strongly significant and very negative. This suggests the presence of significant convexities in the supply curve – increasing utilization results in a much smaller quantity response to a positive demand shock (a depreciation).

We next estimate the reduced form for prices discussed in Proposition **??**. The results are in Table 3. Again, the first five columns illustrate the fit of the baseline model with no utilization interactions, and columns 6-10 include interactions with capacity utilization. We include various combinations of fixed effects and additional controls in the specifications as a robustness exercise.

The baseline regressions on price changes are less successful in that not all coefficient estimates are significant, though the point estimates generally have the right sign. We do find strong significant positive effects for increase unit costs on price growth. Interestingly, while not all coefficient estimates are significant, the R-squared of even the baseline specification in column 1, with no fixed effects, is an extremely high 0.9. This suggests that our model might not be bad for prices, despite the noise in the data preventing finding significant results.

A clearer picture emerges upon interacting the variables in the price regression with utilization. Again, the non-interacted coefficients are largely insignificant, but the interactions are often significant and of the right sign. In particular, the interaction between utilization and the demand shock is significant in most specifications at at least the 5% level. The point estimates also support our mechanism of a convex supply curve. As utilization increases, the industry responds to a positive supply shock by increasing prices.

Table 2: IP Table

| VARIABLES | (1)<br>Dlog_ip | (2)<br>Dlog_ip | (3)<br>Dlog_ip | (4)<br>Dlog_ip | (5)<br>Dlog_ip | (6)<br>Dlog_ip | (7)<br>Dlog_ip | (8)<br>Dlog_ip | (9)<br>Dlog_ip | (10)<br>Dlog_ip |
|---|---|---|---|---|---|---|---|---|---|---|
| L.util | | | | | | -0.17** | -0.24* | -0.17* | -0.25* | -0.26** |
| | | | | | | (0.08) | (0.12) | (0.09) | (0.13) | (0.12) |
| Dlog_agg_er | 3.20*** | 2.25** | 3.01*** | 2.01* | 2.04* | 2.22*** | 0.86 | 2.21*** | 0.85 | 0.56 |
| | (0.56) | (0.95) | (0.64) | (0.98) | (1.03) | (0.51) | (0.66) | (0.56) | (0.68) | (0.47) |
| Dlog_agg_er_util | | | | | | -16.32*** | -17.69*** | -16.56** | -16.62** | -18.57*** |
| | | | | | | (5.18) | (4.87) | (5.96) | (6.01) | (4.55) |
| Dlog_agg_output | 1.57*** | 0.40 | 1.61*** | -1.06 | -1.01 | 1.48*** | 1.30 | 1.49*** | 0.32 | 0.06 |
| | (0.17) | (2.27) | (0.17) | (2.31) | (2.47) | (0.15) | (2.10) | (0.16) | (2.25) | (2.26) |
| Dlog_agg_output_util | | | | | | -2.95** | -2.43* | -2.90** | -2.08 | -2.04 |
| | | | | | | (1.19) | (1.36) | (1.23) | (1.43) | (1.56) |
| Dlog_agg_price | 0.07 | -0.38 | 0.10 | -3.66** | -3.67** | 0.21** | -3.39*** | 0.22** | -5.27*** | -5.20*** |
| | (0.07) | (0.90) | (0.07) | (1.39) | (1.31) | (0.08) | (0.84) | (0.09) | (1.38) | (1.38) |
| Dlog_agg_price_util | | | | | | -0.10 | -0.07 | 0.06 | 0.11 | 0.13 |
| | | | | | | (1.49) | (2.13) | (1.75) | (2.32) | (2.14) |
| Dlog_cap | 0.86*** | 0.92*** | 0.71*** | 0.81*** | 0.81*** | 0.98*** | 0.99*** | 0.97*** | 0.96*** | 0.97*** |
| | (0.06) | (0.04) | (0.07) | (0.06) | (0.05) | (0.03) | (0.04) | (0.06) | (0.07) | (0.08) |
| Dlog_cap_util | | | | | | -0.54 | -0.79 | -0.46 | -0.57 | -0.60 |
| | | | | | | (0.84) | (0.71) | (0.92) | (0.79) | (1.10) |
| Dlog_unit_cost | -0.06** | -0.10** | -0.05 | -0.10** | -0.10** | -0.03 | -0.06 | -0.03 | -0.06 | -0.06 |
| | (0.03) | (0.04) | (0.03) | (0.04) | (0.04) | (0.03) | (0.03) | (0.04) | (0.04) | (0.04) |
| Dlog_unit_cost_util | | | | | | -0.55 | -0.29 | -0.60 | -0.36 | -0.35 |
| | | | | | | (0.57) | (0.59) | (0.58) | (0.61) | (0.65) |
| Constant | -0.05*** | 0.00 | -0.05*** | 0.30* | 0.29* | -0.05*** | 0.09 | -0.05*** | 0.34** | 0.35** |
| | (0.00) | (0.07) | (0.00) | (0.15) | (0.15) | (0.01) | (0.08) | (0.01) | (0.16) | (0.16) |
| Observations | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 |
| R-squared | 0.566 | 0.663 | 0.578 | 0.671 | 0.671 | 0.619 | 0.696 | 0.621 | 0.699 | 0.700 |
| Time FE | no | yes | no | yes | yes | no | yes | no | yes | yes |
| Industry FE | no | no | yes | yes | yes | no | no | yes | yes | yes |
| Other controls[1] | no | no | no | no | yes | no | no | no | no | yes |

[1] Other controls include higher order terms

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source:

Table 3: P Table

| VARIABLES | (1) Dlog_p | (2) Dlog_p | (3) Dlog_p | (4) Dlog_p | (5) Dlog_p | (6) Dlog_p | (7) Dlog_p | (8) Dlog_p | (9) Dlog_p | (10) Dlog_p |
|---|---|---|---|---|---|---|---|---|---|---|
| L.util | | | | | | -0.06* | -0.05 | -0.07* | -0.05 | -0.02 |
| | | | | | | (0.03) | (0.04) | (0.03) | (0.05) | (0.04) |
| Dlog_agg_er | -0.15 | -0.23 | -0.11 | -0.17 | -0.13 | -0.08 | -0.18 | -0.09 | -0.13 | -0.05 |
| | (0.19) | (0.54) | (0.21) | (0.53) | (0.57) | (0.13) | (0.32) | (0.14) | (0.32) | (0.35) |
| Dlog_agg_er_util | | | | | | 4.18** | 5.16** | 3.62 | 4.78** | 5.95*** |
| | | | | | | (1.93) | (1.83) | (2.21) | (2.01) | (1.85) |
| Dlog_agg_output | -0.02 | 0.18 | -0.02 | 0.70 | 0.77 | 0.02 | 0.29 | 0.02 | 0.70 | 0.95 |
| | (0.04) | (0.89) | (0.05) | (1.00) | (0.93) | (0.04) | (0.77) | (0.05) | (0.79) | (0.73) |
| Dlog_agg_output_util | | | | | | 1.02** | 0.75 | 1.03* | 0.78 | 0.93 |
| | | | | | | (0.47) | (0.58) | (0.50) | (0.63) | (0.69) |
| Dlog_agg_price | 0.14* | -0.83 | 0.15* | 0.15 | 0.13 | 0.10* | -0.50 | 0.10 | 0.29 | 0.24 |
| | (0.07) | (0.83) | (0.08) | (0.80) | (0.81) | (0.05) | (0.72) | (0.06) | (0.76) | (0.77) |
| Dlog_agg_price_util | | | | | | 0.73 | 0.69 | 0.92 | 0.79 | 0.37 |
| | | | | | | (0.65) | (0.77) | (0.70) | (0.81) | (0.83) |
| Dlog_cap | -0.03 | -0.02 | 0.00 | 0.00 | -0.00 | -0.02 | -0.01 | 0.00 | 0.00 | -0.01 |
| | (0.04) | (0.03) | (0.04) | (0.04) | (0.04) | (0.04) | (0.02) | (0.05) | (0.04) | (0.04) |
| Dlog_cap_util | | | | | | -0.58* | -0.65** | -0.50 | -0.57* | -0.86*** |
| | | | | | | (0.30) | (0.26) | (0.37) | (0.32) | (0.28) |
| Dlog_unit_cost | 0.82*** | 0.86*** | 0.81*** | 0.85*** | 0.85*** | 0.82*** | 0.86*** | 0.81*** | 0.85*** | 0.85*** |
| | (0.05) | (0.05) | (0.06) | (0.05) | (0.05) | (0.06) | (0.05) | (0.06) | (0.05) | (0.05) |
| Dlog_unit_cost_util | | | | | | 0.53 | 0.56 | 0.51 | 0.57 | 0.47 |
| | | | | | | (0.44) | (0.43) | (0.47) | (0.46) | (0.45) |
| Constant | 0.00*** | 0.03 | 0.00*** | -0.03 | -0.03 | 0.00*** | 0.02 | 0.00*** | -0.04 | -0.05 |
| | (0.00) | (0.03) | (0.00) | (0.06) | (0.05) | (0.00) | (0.03) | (0.00) | (0.05) | (0.05) |
| Observations | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 | 819 |
| R-squared | 0.900 | 0.915 | 0.903 | 0.916 | 0.916 | 0.905 | 0.918 | 0.907 | 0.920 | 0.920 |
| Time FE | no | yes | no | yes | yes | no | yes | no | yes | yes |
| Industry FE | no | no | yes | yes | yes | no | no | yes | yes | yes |
| Other controls[1] | no | no | no | no | yes | no | no | no | no | yes |

[1] Other controls include higher order terms

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source:

# 4 Evidence from micro-data

## 4.1 Confidential Census Data

We utilize several restricted-access micro datasets from the U.S. Census Bureau. Export information comes from the Linked Foreign Trade Transactions Database (LFTTD), which matches individual trade transactions data from U.S. Customs to the Business Register (BR) in the U.S. Census. The trade data span 1993-2014, and include information on value, quantity, destination country, narrow product categories, and whether a particular transaction was undertaken at arms-length or between related parties. [3] We eliminate transactions that report missing, imputed, or zero quantities, as well as those associated with extreme changes in unit values at a monthly frequency. For the industry sample, we use the HS-NAICS concordance from Pierce and Schott (2012) and aggregate to the 3-digit NAICS level using Tornqvist indexes.

We link the export data to the universe of U.S. establishments in the Longitudinal Business Database, which provides industry information, establishment counts, and employment/payroll. Additional information on the manufacturing establishments owned by exporting firms comes from the quinquennial Census of Manufacturers (1992, 1997, 2002, 2007, 2012) and the Annual Survey of Manufacturers (all other years between 1993 and 2014). These datasets contain information on the shipments of manufacturing plants as well as other variables related to their costs of production.

Finally, we utilize establishment-level measures of slack based on the micro-data associated with the Survey of Plant Capacity (SPC). These surveys are available annually prior to 2007, and quarterly thereafter (Quarterly Surveys of Plant Capacity, QSPC).

## 4.2 Empirical specifications

The goals of the micro-data analysis are to (1) validate and complement the structural results in Section 3 and (2) provide additional evidence supportive of the rationing wedge as reason for convexity of the supply curve.

However, as we perform various cleaning procedures on the underlying transactions-level data prior to aggregating to the industry-level, we first estimate several standard pass-through regressions along the lines of Neiman (2010) and **?**. The goal here is to illustrate that our data delivers similar

[3] Other studies using this data include Bernard, Jensen, and Schott (2009), Bernard et al. (2009), etc

results to those previously established in the literature in varied contexts, when we do not introduce measures of slack. Our first set of estimating equations on the microdata (aggregated to NAICS-3 level) are

$$\Delta x_{i,j,t,s} = \beta_e \Delta ER_{j,s} + \beta_y \Delta GDP_{j,s} + \beta_p \Delta CPI_{j,s} + \gamma_{i,s} + \texttt{other controls} + u_{i,j,t,s} \tag{15}$$

Here, $\Delta x_{i,j,t,s}$ is the growth rate of outcome variable $x$ in industry $i$ for country $j$ from periods $s$ to $t$. $x$ can be prices, quantities or values of trade to $j$, or alternatively the number of firm-product combinations being exported to $j$ or the number of products being exported to $j$. The last two measures allow us to assess the role of demand shocks on the extensive margin of the industry. $\beta_e$, the coefficient of interest in passthrough regressions is the coefficient on $\Delta ER_{j,s}$, the current bilateral exchange rate shock (quarter-on-quarter growth rate of the exchange rate). The other controls in the equation include partner country real GDP growth, the growth of the price index in the partner country and industry-time fixed effects, which absorb all relevant U.S. variation. We control for three lags of all right-hand-side variables in every equation, and standard errors are clustered at the NAICS-2 digit level. Our main specifications are weighted by the value of trade to $j$ for industry $i$, to avoid allowing outlier large exchange rate shocks to small trading partners to be very influential for the results. Weighting allows us to estimate aggregate passthrough, and is the best analog to existing results in the literature.

We estimate specification 15 as a direct projection with $t = s+1$ to $t = s+8$, a horizon of two years. This allows us to plot impulse responses to an exchange rate shock, which are presented in Figure **??**[4].

We next return to the focus of the section, and estimate the following specification for the same set of variables as a direct projection for two years, augmented with industry slack

$$\Delta x_{i,j,t,s} = \beta_{eu} S_{i,t} x \Delta ER_{j,s} + \delta_{d,s} + \gamma_{i,s} + u_{i,j,t,s} \tag{16}$$

Here, $\beta_{eu}$ identifies our coefficient of interest, which is the analog of the structural estimation result in Section 3. This permits us to validate our conclusions that the time-varying perceived

[4] Pending disclosure review

demand elasticity is an important driver the differential responses of industries in slack. We plot impulse responses of the key variables to an exchange rate shock when the industry is at capacity and in complete slack ($S_{i,t} = 1$ or $S_{i,t} = 0$).

Finally, we estimate a specification that permits an indirect test of whether our rationing hypothesis has any support in the data.

$$\Delta x_{i,j,t,s} = \beta_{eu,dep} S_{i,t} x \mathbb{1}\left\{\Delta ER_{j,s} > 0\right\} + \beta_{eu,app} S_{i,t} x \mathbb{1}\left\{\Delta ER_{j,s} \leq 0\right\} \delta_{d,s} + \gamma_{i,s} + u_{i,j,t,s} \tag{17}$$

This specification separates the interaction coefficient into a coefficient identified from the interaction of industry slack with U.S. dollar depreciations, $\beta_{eu,dep}$ and one identified from appreciations $\beta_{eu,app}$. A stronger response in depreciations of quantities and a weaker response of prices for industries in slack would provide evidence supporting the rationing hypothesis, as depreciations are positive demand shocks for the industry.

### 4.3 Results

Our results from specifications 16 and 17 are presented in Tables XX-XX. They complement the analysis in the structural model estimation, and provide further evidence that the convexity of the supply curve is an empirically relevant reason for state-dependent responses.

.. To be completed in detail once Census releases our results after disclosure review.

## 5 Quantification and Discussion

Add general equilibrium model here..

## 6 Conclusion

This paper studies whether responses to demand shocks are state-dependent. To guide our empirical analysis we develop a putty-clay model in which short-run capacity constraints can lead to rationing. At the industry-level the framework can generate a convex supply curve, which leads to state-dependent responses to shocks. Using a sufficient statistics approach, we estimate the model using publicly available data and find strong support for state-dependent production responses to exchange rate shocks. Additional reduced form evidence using confidential U.S. micro-data supports the interpretation that capacity constraints limit the responses to increased demand in the short run. We show that industries in slack respond more strongly to a U.S. dollar depreciation, as is implied by the rationing mechanism in the model. Our results imply that fiscal and monetary policy is more effective in times of slack, that is, in recessions.

## References


Auerbach, Alan J. and Yuriy Gorodnichenko. 2012a. "Fiscal Multipliers in Recession and Expansion." In *Fiscal Policy after the Financial Crisis*, NBER Chapters. National Bureau of Economic Research, Inc, 63–98.

———. 2012b. "Measuring the Output Responses to Fiscal Policy." *American Economic Journal: Economic Policy* 4 (2):1–27.

Bernard, Andrew, Bradford Jensen, and Peter Schott. 2009. "Importers, Exporters, and Multinationals: A Portrait of Firms in the U.S. that Trade Goods." In *Producer Dynamics: New Evidence from Micro Data*, edited by Timothy Dunne, J. Bradford Jensen, and Mark J. Roberts. Chicago: University of Chicago Press, 513–552.

Bernard, Andrew B., J. Bradford Jensen, Stephen J. Redding, and Peter K. Schott. 2009. "The Margins of US Trade." *American Economic Review* 99 (2):487–93.

Boehm, Christoph E. 2016. "Government Spending and Durable Goods." Tech. rep.

Fagnart, Jean-Franois, Omar Licandro, and Franck Portier. 1999. "Firm Heterogeneity, Capacity Utilization and the Business Cycle." *Review of Economic Dynamics* 2 (2):433–455.

Jordà, Òscar. 2005. "Estimation and Inference of Impulse Responses by Local Projections." *American Economic Review* 95 (1):161–182.

Nakamura, Emi and Jn Steinsson. 2014. "Fiscal Stimulus in a Monetary Union: Evidence from US Regions." *American Economic Review* 104 (3):753–92. URL `http://www.aeaweb.org/articles?id=10.1257/aer.104.3.753`.

Neiman, Brent. 2010. "Stickiness, synchronization, and passthrough in intrafirm trade prices." *Journal of Monetary Economics* 57 (3):295–308.

Ottonello, Pablo. 2017. "Capital Unemployment." Tech. rep.

Owyang, Michael T., Valerie A. Ramey, and Sarah Zubairy. 2013. "Are Government Spending Multipliers Greater during Periods of Slack? Evidence from Twentieth-Century Historical Data." *American Economic Review* 103 (3):129–34. URL `http://www.aeaweb.org/articles?id=10.1257/aer.103.3.129`.

Pierce, Justin and Peter Schott. 2012. "A Concordance Between U.S. Harmonized System Codes and SIC/NAICS Product Classes and Industries." *Journal of Economic and Social Measurement* 37 (1-2):61–96.

scar Jord, Moritz Schularick, and Alan M. Taylor. 2017. "Large and State-Dependent Effects of Quasi-Random Monetary Experiments." Nber working papers, National Bureau of Economic Research, Inc.

Shapiro, Matthew D. 1989. "Assessing the Federal Reserve's Measures of Capacity Utilization." *Brookings Paper on Economic Activity* (1):181–241.

———. 1993. “Cyclical Productivity and the Workweek of Capital.” *American Economic Review* 83 (2):229–233.

# A Appendix: Model Extensions

## A.1 Fagnart et al.

## A.2 Intermediate goods producers

### A.2.1 Production Function

To introduce the notion of capacity constraints our framework departs from standard theory by assuming that a bundle of factors $k_t$ is fixed in the short run. $k_t$ could be structures, equipment, or even specialized workers. Further, the firm has to decide ex-ante the maximum of variable factors, $b_t$, that it can employ (or process) in the short run. Since variable factors include primarily production workers and intermediate inputs, $b_t$ has the natural interpretation of workstations or processing capacity of intermediates.[5]

We assume that the *production capacity* of a firm is given by

$$q_t = z_t F\left(k_t, b_t\right) \tag{A1}$$

where $z_t$ is productivity and $F$ is constant returns to scale. The firm's actual production $x_t$ is

$$x_t = q_t \frac{l_t}{b_t} = z_t F\left(\kappa_t, 1\right) l_t \tag{A2}$$

where $\kappa_t = \frac{k_t}{b_t}$ and $l_t$ represents the firm's choice of a bundle of factors that are variable in the short run. Production $x_t$ is limited in the short run because the variable factors $l_t$ cannot exceed $b_t$, that is $l_t \leq b_t$. Note that the marginal product of the variable factors, $z_t F\left(\kappa_t, 1\right)$, is constant in the short run and determined by $z_t$ and $\kappa_t$. Letting $w_t$ denote the price of input bundle $l_t$, short run marginal costs are

$$mc_t = \frac{w_t}{z_t F\left(\kappa_t, 1\right)}. \tag{A3}$$

## A.3 Aggregating firm

The perfectly competitive aggregating firm uses a constant returns to scale (CES) production function with elasticity of substitution $\theta$. Unlike the standard model, however, the aggregating firm's suppliers are subject to capacity constraints. Whenever a supplier's production is limited by its capacity the aggregating firm is constrained in the factor market.

The aggregating firm maximizes

$$\max P_t X_t - \int_0^1 p_t\left(j\right) x_t\left(j\right) dj \tag{A4}$$

subject to the capacity constraints of the intermediate suppliers

$$x_t\left(j\right) \leq q_t\left(j\right) \;\; \forall j \tag{A5}$$

[5] This paper emphasizes a technological interpretation of capacity constraint. An alternative is that firms do not find it optimal to produce above the level of capacity.

and its production technology

$$X_t = \left( \int_0^1 v_t(j)^{\frac{1}{\theta}} x_t(j)^{\frac{\theta-1}{\theta}} dj \right)^{\frac{\theta}{\theta-1}}. \tag{A6}$$

Here, $P_t$ is the price index, $X_t$ is output, and $p_t(j)$ and $x_t(j)$ are the price and quantity of variety $j$. The production function of the aggregate bundle features variety specific shocks $\nu_t(j)$ which represent the importance of the associated intermediate input. For simplicity, we assume that $v_t(j)$ are i.i.d. shocks with cumulative distribution function $G(v)$ and unit mean.

To maintain tractable aggregation, we also make a set of timing assumptions that will guarantee that $p_t(j) = p_t$ and $q_t(j) = q_t$ $\forall j$. We will discuss these assumptions below. Imposing this symmetry implies that the factor demand functions are

$$x_t = \begin{cases} v_t X_t \left[\frac{p_t}{P_t}\right]^{-\theta} & \text{if} \quad v_t < \bar{v}_t \\ q_t & \phantom{\text{if}} \quad v_t \geq \bar{v}_t \end{cases} \tag{A7}$$

for all $j$, where the threshold variety $\bar{v}_t$ above which the supply of intermediates is rationed satisfies

$$\bar{v}_t = \frac{q_t}{X_t \left[\frac{p_t}{P_t}\right]^{-\theta}}. \tag{A8}$$

The price index of the aggregating firm is (in logs)

$$\ln(P_t) = \ln(p_t) + \Omega_t. \tag{A9}$$

where

$$\Omega_t = \frac{1}{1-\theta} \ln \left( \int_0^1 v(j) \left[ 1 + \frac{\lambda_t(j)}{p_t} \right]^{1-\theta} dj \right).$$

In this equation $\lambda_t(j)$ are the multipliers on the capacity constraints. Note that if all suppliers are unconstrained, $\lambda_t(j) = 0$ for all $j$, and the price index $P_t$ equals the (common) price of intermediates $p_t$. However, when the supplier's capacity falls short of the quantity demanded, the aggregating firm cannot equate the marginal product of the intermediate to its price. Instead, the marginal product exceeds its price and the firm begins to earn profits.

In order to raise production the aggregating firm must now purchase input varieties from suppliers that are not constrained and these varieties have lower marginal products. As a result marginal costs rise. We call this increment of the price index above the price of intermediates the *rationing wedge* $\Omega_t$. Whenever some input varieties are rationed, this wedge will be positive. It is easy to show that $\Omega_t$ is only a function of the threshold variety $\bar{v}_t$,

$$\Omega_t = \frac{1}{1-\theta} \ln \left( \int_0^{\bar{v}_t} v dG(v) + \bar{v}_t^{\frac{\theta-1}{\theta}} \int_{\bar{v}_t}^{\infty} v^{\frac{1}{\theta}} dG(v) \right). \tag{A10}$$

Similarly, production $X_t$ of the industry can be written as a function of capacity $q_t$ and $\bar{v}_t$,

$$X\left(q_t, \bar{v}_t\right) := q_t \left( \left(\frac{1}{\bar{v}_t}\right)^{\frac{\theta-1}{\theta}} \int_0^{\bar{v}_t} v dG\left(v\right) + \int_{\bar{v}_t}^{\infty} v^{\frac{1}{\theta}} dG\left(v\right) \right)^{\frac{\theta}{\theta-1}}. \tag{A11}$$

**Capacity utilization** We define the industry's utilization rate as the ratio of actual production to the hypothetical level of output that would be attainable if every intermediate firm produced at full capacity, that is

$$u_t := \frac{X\left(q_t, \bar{v}_t\right)}{\lim_{\bar{v}_t \to 0} X\left(q_t, \bar{v}_t\right)}. \tag{A12}$$

This definition has several attractive properties. First, it is constructed very similar to its empirical counterpart. For example, it is possible to express $u_t$ as an (appropriately constructed) average of firms' idiosyncratic utilization rates $u_t\left(j\right) := \frac{x(j)}{q_t} = \frac{p_t x_t(j)}{p_t q_t}$. The surveys of plant capacity that we will use below construct utilization measures by asking respondents to state the market value of their actual production $p_t x_t\left(j\right)$ and the market value of their full capacity production $p_t q_t$. Further, since $\lim_{\bar{v}_t \to 0} X\left(q_t, \bar{v}_t\right) \propto q_t$ it follows that $u_t \propto \frac{X_t}{q_t}$, that is, utilization is proportional to actual production divided by capacity. This corresponds closely to the utilization series that the Federal Reserve constructs by dividing an industrial production index by an index of production capacity.

**Lemma 3.** *The utilization rate as defined in (A12) has the following properties:*

1. $u_t \in [0,1]$ *is only a function of* $\bar{v}_t$*:* $u_t = u\left(\bar{v}_t\right)$
2. $\lim_{\bar{v} \to 0} u\left(\bar{v}\right) = 1$*,* $\lim_{\bar{v} \to \infty} u\left(\bar{v}\right) = 0$
3. $u' < 0$
4. *The sign of* $u''$ *is ambiguous*

The lemma highlights that the aggregate utilization rate is only a function of the threshold value $\bar{v}_t$ above which intermediate input suppliers produce at maximum capacity. The utilization rate approaches zero if no intermediate input supplier is producing at full capacity. It tends to one if all intermediate input suppliers become capacity constrained. Further, $u$ is decreasing everywhere, and this implies that $u$ is invertible and we can write $\bar{v}\left(u_t\right)$. We will make extensive use of this feature, both for the remainder of the theoretical analysis and when taking the model to the data. One immediate application is that we can write the rationing wedge as a function of utilization: $\Omega_t = \Omega\left(u_t\right)$. Figure A.3 illustrates a numerical example of the variation of $u$ with $\bar{v}$.

**The rationing wedge** With Lemma 3 in hand we can now summarize the properties of $\Omega\left(u_t\right)$.

**Proposition 5.** *Under minor assumptions on* $G$

1. $\Omega'\left(u\right) \geq 0$
2. $\lim_{u \to 0} \Omega\left(u\right) = 0$*,* $\lim_{u \to 1} \Omega\left(u\right) = \infty$
3. $\lim_{u \to 0} \Omega'\left(u\right) = 0$*,* $\lim_{u \to 1} \Omega'\left(u\right) = \infty$

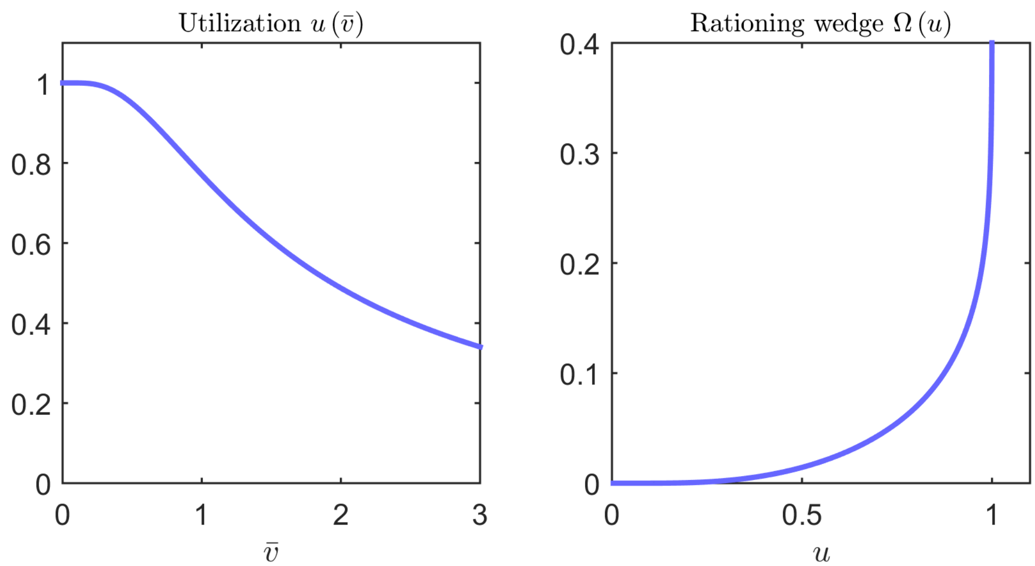



Figure A1: Utilization and the Rationing Wedge

4. *Without further restrictions on $G$, the sign of $\Omega''(u)$ is generally ambiguous.*

The rationing wedge is increasing in utilization everywhere. As an increasing number of suppliers become constrained, the input allocation becomes worse and the wedge widens. When the utilization rate approaches one, all suppliers become constrained and the wedge and its derivative tend to infinity. Conversely, when the utilization rate tends to zero, intermediate input suppliers are no longer capacity constrained. As a result both the rationing wedge and its derivative tend to zero. While $\Omega(u)$ is convex everywhere for many choices of $G$, it is possible to construct examples in which the wedge is locally concave. We conclude that the rationing wedge is a potential source of convexity of the supply curve, but whether this is so in the relevant range of utilization remains an empirical question. The right panel of Figure A.3 illustrates a numerical example of the rationing wedge.

## A.4 Intermediate Goods Firms

Before turning to the intermediate goods producers, we describe the timing assumptions we make. As noted before the objective of these assumptions is to preserve simple aggregation properties of the model. Over the course of a period, firms

1. choose their fixed factor bundle $k_t$ and the maximum processing capacity $b_t$
2. learn the aggregate productivity draw $z_t$
3. choose their price $p_t$
4. learn their idiosyncratic demand shock $v_t$
5. choose the variable factor bundle $l_t$ and produce.

Since the choices of $k_t$ and $b_t$ are secondary for our empirical analysis, we relegate them to Appendix A. For the remainder of the paper it is sufficient to know that $k_t$ and $b_t$ have been chosen optimally and are fixed until the end of the period.

Having learned the aggregate productivity draw $z_t$, firms choose their price $p_t$. They maximize expected profits

$$E_v\left[\left(p_t - mc_t\right) x_t\right] \tag{A13}$$

subject to the demand curve (A7). To understand the firms' incentives, it is useful to first consider the expected quantity sold,

$$E_v\left[x_t\right] = X_t \left[\frac{p_t}{P_t}\right]^{-\theta} \int_0^{\bar{v}_t} v dG\left(v\right) + q_t \int_{\bar{v}_t}^{\infty} dG\left(v\right).$$

When setting their price, firms take into account that they become capacity constrained when demand materializes sufficiently high. Conditional on becoming constrained, there are no costs of choosing higher prices because doing so does not reduce the quantity sold. As a result, the relevant notion of the demand elasticity for the firm is

$$-\frac{\partial \ln E_v\left[x_t\right]}{\partial \ln p_t} = \theta \frac{\int_0^{\bar{v}(u_t)} v dG\left(v\right)}{\int_0^{\bar{v}(u_t)} v dG\left(v\right) + \bar{v}\left(u_t\right) \int_{\bar{v}(u_t)}^{\infty} dG\left(v\right)} =: \tilde{\theta}\left(u_t\right) \tag{A14}$$

We call this elasticity the effective demand elasticity. Clearly, $\tilde{\theta}\left(u_t\right) \in [0, \theta]$. Further, since the industry-wide utilization measure $u$ is a sufficient statistic for the firm to predict whether it will be capacity constrained, $\tilde{\theta}$ is a function of $u_t$ (and only of $u_t$). It is also easy to verify that under minor regularity conditions on $G$, $\lim_{u \to 0} \tilde{\theta}\left(u_t\right) = \theta$: As the industry's utilization rate approaches zero and the probability of being capacity constrained tends to zero and $\tilde{\theta}$ approaches the true demand elasticity. Similarly, $\lim_{u \to 1} \tilde{\theta}\left(u_t\right) = 0$.

It is not generally true that $\tilde{\theta}$ is decreasing everywhere since two competing effects govern the sign of the derivative of $\tilde{\theta}$ and either one can dominate. First, as utilization increases, the probability of becoming capacity constrained rises. This *rationing effect* reduces $\tilde{\theta}$ because for constrained suppliers the quantity does not fall when they raise the price by one marginal unit.

Second, there is a *composition effect*. To see this, suppose that capacity $q_t$ is fixed and recall that $u_t \propto \frac{X_t}{q_t}$. Since a higher utilization rate requires higher output of the industry, the assembling firm must increase demand from suppliers that are not rationed. In expectation, this raises the quantity of output for which the demand curve is downward sloping. As a result $\tilde{\theta}$ rises.

For many choices of $G$, the rationing effect dominates the composition effect and $\tilde{\theta}'$ is negative everywhere. In Appendix $B$ we present an example where this is not the case. The left panel of A2 shows a numerical example of $\tilde{\theta}$ and Lemma 4 summarizes its properties

**Lemma 4.** *Under minor regularity conditions on $G$, $\tilde{\theta}\left(u_t\right) \in [0, \theta]$ satisfies the following properties*

1. $\lim_{u \to 0} \tilde{\theta}\left(u_t\right) = \theta$, $\lim_{u \to 1} \tilde{\theta}\left(u_t\right) = 0$
2. $\lim_{u \to 0} \tilde{\theta}'\left(u_t\right) = 0$
3. *The sign of $\tilde{\theta}'$ is generally ambiguous.*

The optimal price choice implies that

$$p_t = \mathcal{M}(u_t)\, mc_t, \tag{A15}$$

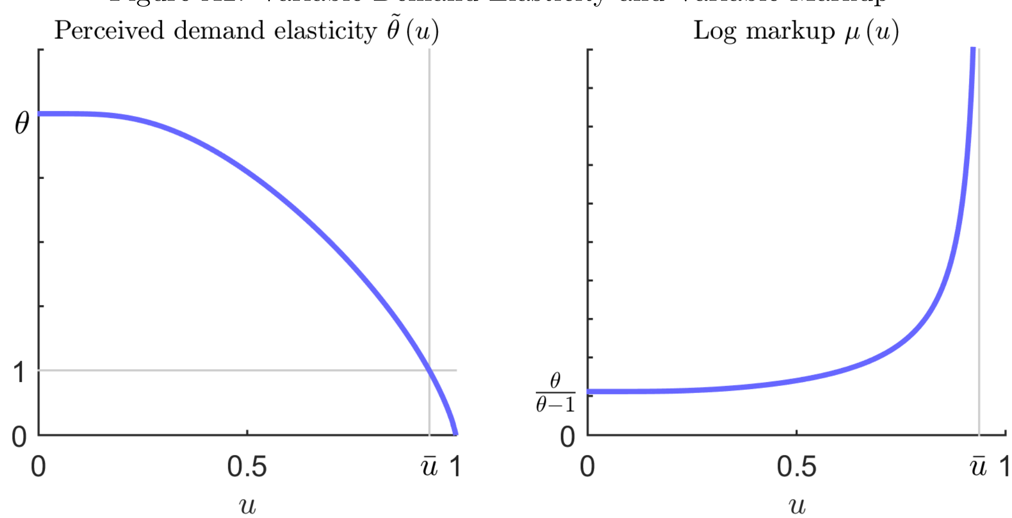
where $\mathcal{M}(u_t) = \frac{\tilde{\theta}(u_t)}{\tilde{\theta}(u_t)-1}$ and $\tilde{\theta}(u_t)$ is given by (A14). Clearly, the effective demand elasticity cannot fall below one because the markup would not be defined. The properties of $\mathcal{M}(u_t)$ follow immediately from Lemma 4.

**Proposition 6.** *Let* $\bar{u} = \sup\left\{u : \tilde{\theta}(u) = 1\right\}$. *Then*

1. $\lim_{u\to 0} \mathcal{M}(u) = \frac{\theta}{\theta-1}$, $\lim_{u\uparrow\bar{u}} \mathcal{M}(u) = \infty$
2. $\lim_{u\to 0} \mathcal{M}'(u) = 0$ *and* $\lim_{u\uparrow\bar{u}} \mathcal{M}'(u) = \infty$
3. *The markup may not be increasing in* $u$ *everywhere*

As the utilization rate approaches zero, the markup tends to $\frac{\theta}{\theta-1}$–the value that would prevail in the absence of capacity constraints. Further, as the utilization rate tends to $\bar{u}$, the markup as well as its slope go to infinity. Note further, that if the effective demand elasticity $\tilde{\theta}$ is not monotonic, the markup inherits this property. The intuition is the following. If utilization rises, more firms are constrained. This raises the markup. However, this effect can locally be dominated by the fact that the aggregating firm purchases more from firms that are not rationed. Since in these states of the world the optimal markups are lower this composition effect reduces $\mathcal{M}(u)$. Appendix *B* discusses this possibility further. The right panel of Figure A2 illustrates a numerical example of the log markup $\mu(u) = \ln \mathcal{M}(u)$.

Figure A2: Variable Demand Elasticity and Variable Markup



## A.5 Equilibrium

We can now put the individual pieces together and write the supply curve of the industry as a function of the markups, the rationing wedge and marginal costs

$$\ln P_t = \mu(u_t) + \Omega(u_t) + \ln mc_t. \tag{A16}$$

Both the (log) markup and the rationing wedge are mechanisms that potentially lead to a convex supply curve.

We now close the model, assuming that the assembling firm of industry $i$ sells its output to $N$ countries which have CES demand functions

$$X_{i,n,t} = \omega_{i,n,t} X_{n,t} \left[\frac{P^*_{i,n,t}}{\mathcal{P}^*_{n,t}}\right]^{-\sigma}. \tag{A17}$$

Here, $P^*_{i,n,t}$ is the price of the good in local currency, $X_{n,t}$ is the country's GDP, and $\mathcal{P}^*_{n,t}$ the associated price index. Each country has a possible industry-specific demand shock $\omega_{i,n,t}$. Let $\mathcal{E}_{n,t}$ be the exchange rate in US dollars per unit of foreign currency. Then the dollar-denominated price is

$$P_{i,n,t} = \mathcal{E}_{n,t} P^*_{i,n,t}. \tag{A18}$$

Finally, market clearing requires that

$$X_{i,t} = \sum_n X_{i,n,t}. \tag{A19}$$

## A.6 Empirical specifications

**Proposition 7.** *The reduced form of the industry's quantity, linearized around its equilibrium in $t-1$ is*

$$\Delta \ln X_{i,t} = \beta_e(u_{t-1}) e_{i,t} + \beta_\pi(u_{t-1}) \pi_{i,t} + \beta_\xi(u_{t-1}) \xi_{i,t} + \beta_q(u_{t-1}) \Delta \ln q_{i,t} + \beta_{mc}(u_{t-1}) \Delta \ln mc_{i,t} + \omega^X_{i,t}$$

*where*

$$\beta_e > 0, \beta_\pi > 0, \beta_\xi > 0, \beta_q > 0, \beta_{mc} < 0.$$

*Further*

$$e_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln \mathcal{E}_{n,t}, \quad \pi_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln \mathcal{P}^*_{n,t}, \quad \xi_{i,t} = \sum_n s_{i,n,t-1} \Delta \ln X_{n,t}$$

*and $s_{i,n,t-1}$ are sales shares to the respective counties in $t-1$, and*

$$\omega^X_{i,t} = \Gamma(u_{t-1}) \sum_n s_{i,n,t-1} \Delta \ln \omega_{i,n,t}$$

$\Gamma(u_{t-1})$ *is only a function of $u_{t-1}$. Further, if the supply curve is convex, then*

$$\beta'_e < 0,\ \beta'_\pi < 0,\ \beta'_\xi < 0,\ \beta'_q > 0,\ \beta'_{mc} > 0$$

And now the price

**Proposition 8.** *The reduced form of the price, linearized around its equilibrium in $t-1$ is given by*

$$\Delta \ln P_{i,t} = \gamma_e(u_{t-1}) e_{i,t} + \gamma_\pi(u_{t-1}) \pi_{i,t} + \gamma_\xi(u_{t-1}) \xi_{i,t} + \gamma_q(u_{t-1}) \Delta \ln q_{i,t} + \gamma_{mc}(u_{t-1}) \Delta \ln mc_{i,t} + \omega_{i,t}^P$$

*where*

$$\gamma_e > 0,\ \gamma_\pi > 0,\ \gamma_\xi > 0,\ \gamma_q < 0,\ \gamma_{mc} > 0,$$

$e_{i,t}$*,* $\pi_{i,t}$*,* $\xi_{i,t}$*, and* $s_{i,n,t-1}$ *are defined as in the earlier proposition. Further,*

$$\omega_{i,t}^P = \Xi(u_{t-1}) \sum_n s_{i,n,t-1} \Delta \ln \omega_{i,n,t}$$

*and* $\Xi(u_{t-1})$ *is only a function of* $u_{t-1}$*. If the supply curve is convex, then*

$$\gamma_e' > 0,\ \gamma_\pi' > 0,\ \gamma_\xi > 0,\ \gamma_q' < 0,\ \gamma_{mc}' < 0$$

Discussion... (to be completed)
Threats to identification

1. $\omega_{i,t}$ may be correlated with $q_{i,t}$
2. Average costs may not equal marginal costs
3. Measurement error
4. Everything that is not in the model

### A.7 Taking the model to the data

There are two ways to take the model to the data. First, we estimate the reduced form. Second, we test whether the effective demand elasticity is a function of $u$, as the model predicts:

$$\Delta \ln X_{i,n,t} = \beta u_{i,t-1} \Delta \ln \mathcal{E}_{n,t} + \gamma_{i,t} + \delta_{n,t} + \varepsilon_{i,n,t} \tag{A20}$$

## B Appendix: Theory

Proofs of proposition and additional theory including the choice of $k_t$ and $b_t$.

$$\gamma_e(u_{t-1}) = \frac{\sigma\Phi(u_{i,t-1})}{1+\sigma\Phi(u_{i,t-1})},\ \gamma_\pi(u_{t-1}) = \frac{\sigma\Phi(u_{i,t-1})}{1+\sigma\Phi(u_{i,t-1})},\ \gamma_\xi(u_{t-1}) = \frac{\Phi(u_{i,t-1})}{1+\sigma\Phi(u_{i,t-1})}$$

$$\gamma_q(u_{t-1}) = -\frac{\Phi(u_{i,t-1})}{1+\sigma\Phi(u_{i,t-1})},\ \gamma_{mc}(u_{t-1}) = \frac{1}{1+\sigma\Phi(u_{i,t-1})}$$

$$\beta_e\left(u_{t-1}\right)=\frac{\sigma}{1+\sigma\Phi\left(u_{i,t-1}\right)},\ \beta_\pi\left(u_{t-1}\right)=\frac{\sigma}{1+\sigma\Phi\left(u_{i,t-1}\right)},\ \beta_\xi\left(u_{t-1}\right)=\frac{1}{1+\sigma\Phi\left(u_{i,t-1}\right)}$$

$$\beta_q\left(u_{t-1}\right)=\frac{\sigma\Phi\left(u_{i,t-1}\right)}{1+\sigma\Phi\left(u_{i,t-1}\right)},\ \beta_{mc}\left(u_{t-1}\right)=-\frac{\sigma}{1+\sigma\Phi\left(u_{i,t-1}\right)}$$

$$e_{i,t}=\sum_n s_{i,n,t-1}\Delta\ln\mathcal{E}_{n,t}$$

$$\pi_{i,t}=\sum_n s_{i,n,t-1}\Delta\ln\mathcal{P}^*_{n,t}$$

$$\xi_{i,t}=\sum_n s_{i,n,t-1}\Delta\ln X_{n,t}$$

$$\omega^X_{i,t}=\frac{1}{1+\sigma\Phi\left(u_{i,t-1}\right)}\sum_n s_{i,n,t-1}\Delta\ln\omega_{i,n,t}$$

$$\omega^P_{i,t}=\frac{\Phi\left(u_{i,t-1}\right)}{1+\sigma\Phi\left(u_{i,t-1}\right)}\sum_n s_{i,n,t-1}\Delta\ln\omega_{i,n,t}$$

# C Data Appendix

## C.1 Measures of Capacity at the Industry-Level

## C.2 Establishment-Level Allocation of Trade

The LFTTD export data matches an individual trade transaction to a firm identified as the U.S. principal party in interest (USPPI); it does not match an export transaction to an individual establishment or location within that firm. We use two sources of information to allocate a firm's trade to individual establishments. First, the quinquennial Census of Manufacturer's Products Trailer file indicates the individual goods produced by an establishment in a particular Census year. We use this information to construct the industries that are the primary producers of a given product. Together with information on the industry of an establishment, this can be used to narrow the list of potential establishments that are likely producers of a given exported product. Second, each export transaction contains location information zipcode and state – that indicates the origin of movement: where the shipment began its journey to the port of export. Unfortunately, this origin of movement need not be the same as the origin of production, for a variety of reasons, which we discuss in detail below. Nevertheless, the existence of establishment(s) of an exporting firm in the zipcode listed on an export transaction of the firm should help to allocate the product exported by the firm to the establishment(s) that produced it.

We proceed to describe in detail the process for how we use each of these sources of information, independently, to identify potential establishments where a firm's export transaction originated. We then discuss how we combine both sources of information in the final allocation of exports to the establishment-level.

### C.2.1 Industry-Based Matching

As part of the quinquennial Census of Manufacturers (CM), the Census Bureau surveys establishments on their total shipments broken down into a set of NAICS-based (6 digit) product categories. Each establishment is given a form—specific to its industry—with a list of pre-specified products. There is also additional space to record other product shipments not on the pre-specified list. Using the information in the resultant products-trailer file to the CM, we can construct the set of industries that are the primary producers of a particular product.

There are several data issues that must be addressed before using the CM-Products file as a source of information on the product-level shipments of an establishment or it's parent firm. First, the trailer file contains product-codes that are used to "balance" the aggregated product-level value of shipments with the total value of shipments reported on the base CM survey form. We drop these product codes from the dataset. Second, there are often codes that do not correspond to any official 7-digit product code identified by Census. (These are typically products that are self-identified by the establishment but do not match any of the pre-specified products identified for that industry, or other industries, by Census.) Rather than ignoring the value of shipments corresponding to these codes, we attempt to match at a more aggregated level. We iteratively attempt to find a product code match at the 6, 5, and 4 digit product code level, and use the existing set of 7-digit matches for the establishment as weights to allocate the product value among the 7-digit product codes encompassed by the more aggregated level.

We then construct the set of primary industry producers associated with a given product. Let $x_{pij}$ denote the value of shipments of product $p$ by establishment $i$ in industry $j$ during a census year. Then the total output of product $p$ in industry $j$ can be written as:

$$X_{pj} = \sum_{i=1}^{I_j} x_{pij},$$

where $I_{jp}$ is the number of establishments producing $p$ in industry $j$. Total output of product $p$ is then:

$$X_p = \sum_{j=1}^{I_{jp}} X_{pj}.$$

The share of product output accounted for by a given industry $j$ is therefore:

$$S_{pj} = \frac{X_{pj}}{X_p}.$$

Because of reporting errors and aggregation of products, we designate an industry as a primary producer of product $p$ provided that its share $S_{pj}$ passes a certain threshold – which we set at 5 percent. We define the set of industries for product $p$ for which $S_{pj} > 0.05$ as $J_p$. We have experimented with varying this threshold, as well as combining this threshold with an alternative threshold based on the share of value of a product in a particular industry, and find this makes little difference to our results. Table XX shows the mean fraction of product-value produced by the top three industries in our data.

We proceed by flagging, for the exports of firm $f$ of product $p$ to a destination country $c$ in month $m$ in year $t$, any establishment whose industry is in the set $J_p$.

### C.2.2 Location-Based Matching

Using the state or zipcode information on the raw LFTTD is problematic for identifying the location of production for at least the three reasons outlined below:

- Consolidation: if a shipment combines with similar commodities from the same USPPI then only the location of consolidation is recorded for that shipment.
- Wholesale/Retail: if the exporter is a wholesale/retailer, then the location of origin of the wholesaler/retailer is recorded, and not the location of production.
- Warehousing: a shipment could be sent to a storage or warehouse facility and then subsequently exported. In this case, the origin of movement is the warehouse facility, and not the location of production.

To mitigate these problems in our allocation process, we look for a match for a particular transaction via a narrow location criteria – the 5-digit zipcode – from the set of establishments of the firm. In addition, we pay particular attention to whether the zipcode match captures a manufacturing or non-manufacturing establishment. A zipcode match capturing a manufacturing establishment is less likely to suffer from the second and third problems listed above.

### C.2.3 Allocation Rules

We combine both sources of information for allocating a firm's exports across its establishments. We allocate trade at a very disaggregate level: the firm-product-country-month level. We use the following rules for the allocation:

- If multiple zipcodes are identified for a particular firm-product-country-month but only one is matched to an establishment of the firm, then the full trade of that firm-product-country-month is allocated to that establishment.
- If multiple differing zipcodes are matched to separate establishments within a firm-product-country-month, but where the matches do not sum to the total exports, then the share of matched trade is used to gross up the matched trade to equal the total.
- For establishments with the same zipcode matching to a transaction, employment shares are used to allocate the exports across establishments.

# D Appendix: Additional Results

This appendix gathers additional results on the impact of exchange rate shocks to the margins of trade, as well as some robustness exercises