ARE SUPPLY SHOCKS CONTRACTIONARY AT THE ZLB? EVIDENCE FROM UTILIZATION-ADJUSTED TFP DATA

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Abstract—The basic New Keynesian model predicts that positive supply shocks are less expansionary at the zero lower bound (ZLB) compared to periods of active monetary policy. We test this prediction empirically using Fernald’s (2014) utilization-adjusted total factor productivity series, which we take as a measure of exogenous productivity. In contrast to the predictions of the model, positive productivity shocks are estimated to be more expansionary at the ZLB compared to normal times. We find that there is no significant difference in the response of expected inflation to a productivity shock at the ZLB compared to normal times.

I. Introduction

Are positive supply shocks contractionary in periods where monetary policy is constrained by the zero lower bound (ZLB)? The textbook New Keynesian (NK) model suggests that this is a possibility. The potential for this paradoxical result is driven by general equilibrium effects. Suppose that the supply shock is an increase in neutral productivity. Higher productivity lowers the natural rate of interest (i.e., the real interest rate consistent with a hypothetical equilibrium where prices are flexible). An inflation-targeting central bank can optimally respond by lowering nominal interest rates, which allows output to expand. If the central bank is constrained by the ZLB, however, nominal interest rates cannot fall. This results in a decrease in current and expected future inflation, which drives the equilibrium real interest rate up. The increase in the real interest rate chokes off demand, resulting in a smaller output increase than if policy were active. If the expected duration of the ZLB is long enough, the rise in the real interest rate can be sufficiently large that output declines.

In this paper, we empirically test this prediction of the NK model using aggregate U.S. data. Until very recently, this has been a virtual impossibility, given the paucity of aggregate time series observations where the ZLB was binding. But there are now seven years of data (from the end of 2008 through the end of 2015) in which the effective Federal Funds Rate was at 0. We use Fernald’s (2014) quarterly utilization-adjusted total factor productivity (TFP) series, which we take to be a good measure of exogenous productivity. We then estimate impulse responses of output to changes in productivity, both inside and outside the ZLB, using a smoothed version of Jordá’s (2005) local projections method, which has recently been proposed by Barnichon and Brownlees (2016). The local projections method is a simple and robust way to estimate impulse responses and can easily accommodate the kind of nonlinearity induced by a binding ZLB.

In contrast to the predictions of the textbook NK model, we find that output responds more on impact and for several quarters thereafter to an increase in productivity when the ZLB binds in comparison to periods where it does not. The differences in output responses at and away from the ZLB are both economically and statistically significant. In particular, we find that output increases by more than three times as much to a positive productivity shock on impact when the ZLB binds than when it does not. We can easily reject the hypothesis of pointwise equality of impulse responses to the productivity shock across monetary regimes for several forecast horizons and can reject pathwise equality of responses at all horizons. We also find similar results when focusing on labor market indicators such as total hours worked or the unemployment rate; a positive productivity shock is estimated to be significantly more expansionary when the ZLB binds than when it does not. This basic result is also robust to several different variations on our baseline empirical specification.

Since a decline in expected inflation is the mechanism by which the textbook NK model generates a smaller output response to a productivity shock at the ZLB, we also empirically examine the effects of productivity shocks on expected inflation, both inside and outside the ZLB. We consider several different measures of expected inflation, including the Michigan Survey of Consumers, the Survey of Professional Forecasters, and the Federal Reserve Bank of Cleveland’s inflation expectations model. Outside of the ZLB, we find that a positive productivity shock results in a mild decline in expected inflation. Over most forecast horizons, we find no significant difference in the estimated responses of expected inflation to a productivity shock when the ZLB binds versus when it does not. This is true regardless of which inflation expectations series we use.

Taken together, our empirical results are puzzling from the perspective of the basic NK model. Intertemporal substitution is the key economic mechanism in the model. When the nominal interest rate is fixed because of a binding ZLB, the real interest rate moves one-for-one in the opposite direction of expected inflation, and the behavior of current and expected real interest rates determines output. If positive productivity shocks were to raise expected inflation at the ZLB,
it would be conceivable that output could rise more when the ZLB binds compared to when it does not. But this is not consistent with what we find: expected inflation falls after a positive productivity shock both when the ZLB binds and when it does not. Furthermore, while not typically statistically significant, in most specifications, we find that expected inflation falls more when the ZLB binds compared to when it does not. Our empirical results therefore suggest some failing of the textbook NK model and its more complicated but closely related medium-scale dynamic stochastic general equilibrium (DSGE) variant. Caution is of course in order when interpreting our results, as they are based on an admittedly small sample (twenty-nine observations where the ZLB binds). But viewed in conjunction with other empirical evidence (some of it discussed below), we feel that there is a compelling empirical case that some important ingredient is missing from the textbook NK model.

While we focus on the effects of supply shocks at the ZLB, our work has implications for demand-side policies as well. Christiano, Eichenbaum, and Rebelo (2011) and others have argued that the government spending multiplier is significantly larger at the ZLB in comparison to normal times. A number of authors, most notably Del-Negro and Gian- noni (2015), have noted that extended periods of anticipated monetary accommodation can be wildly expansionary. The mechanism by which demand shocks can have large effects at the ZLB is, in a sense, the mirror image of why supply shocks might have small effects. Demand shocks raise expected inflation, which pushes down real interest rates when nominal rates are constrained by the ZLB. Our empirical findings suggest that this “expected inflation channel” (Dupor & Li 2015) does not seem to be operative at the ZLB in the way predicted by the theory, at least conditional on productivity shocks. Our results therefore imply that caution ought to be in order when applying the basic intuition from the NK model to draw inferences about the likely effects of demand shocks.

Our work contributes to a burgeoning literature investigating the effects of supply shocks at the zero lower bound. Eggertsson (2012) and Eggertsson and Krugman (2012) both argue that New Deal policies, which reduced the natural rate of output, were in fact expansionary due to the zero lower bound. Wieland (forthcoming) uses the Great Japan Earthquake and global oil supply disruptions as exogenous supply shocks and finds that negative shocks are contractionary at the zero lower bound.1 In a similar vein, Cohen-Setton, Hausman, and Wieland (2017) show that cartelization efforts exacerbated France’s Great Depression. These papers focus on shocks to aggregate supply, which are different from neutral productivity shocks. We are unaware of any other paper that studies the consequences of exogenous productivity shocks at the zero lower bound.

Our work also fits more broadly into a growing literature that empirically tests other predictions of the textbook NK model when the ZLB binds. Bachmann, Berg, and Sims (2015) find no evidence that consumer willingness to spend on durable goods is affected by inflation expectations, either at or away from the ZLB. Burke and Ozdagli (2013) reach similar conclusions. In contrast, D’Acunto, Hoang, and Weber (2016) argue that a VAT increase in Germany that raised household inflation expectations was quite expansionary. Similar, Ichiu and Nishiguchi (2015) find that higher inflation expectations positively correlate with consumption spending for households in Japan. Dupor and Li (2015) find no evidence to support an important “expected inflation channel” for large fiscal multipliers at the ZLB. Ramey and Zubairy (2018) estimate state-dependent regression models similar to ours to study the magnitude of the fiscal multiplier, both across states of the business cycle as well as in periods where the ZLB binds. They find no evidence of a significantly larger multiplier during periods in which the ZLB binds.

II. Theory

Consider the textbook NK model. The two principal equations of the model are the linearized IS equation and a Phillips curve:

\[ x_t = \beta x_{t+1} - \frac{1}{\sigma}(\beta - \bar{E}_t \pi_{t+1} - r'_t), \]  
\[ \pi_t = \gamma x_t + \beta \bar{E}_t \pi_{t+1}. \]  

Here, \( x_t \) is the output gap, defined as the log deviation of output, \( y_t \), from its flexible price level, \( y_t = y_t - \gamma_x \). The nominal interest rate, expressed in absolute deviations from steady state, is \( \bar{r}_t \). The hypothetical real interest rate if prices were fully flexible is \( r'_t \). \( \sigma \) is the inverse elasticity of intertemporal substitution. The slope coefficient in the Phillips curve is \( \gamma = \frac{(1 - \phi)(1 - \phi)}{\phi}(1 + \phi) \), where \( \phi \in (0, 1) \) is the probability that firms cannot adjust their price in a given period, \( 0 < \beta < 1 \) is a subjective discount factor, and \( \chi \) is the inverse Frisch elasticity of labor supply. The exogenous driving force in the model is log productivity, \( a_t \), which obeys a stationary AR(1) process:

\[ a_t = \rho_a a_{t-1} + \varepsilon_{a,t}, \quad \varepsilon_{a,t} \sim N(0, \sigma^2). \]  

In terms of exogenous productivity, the flexible price real interest rate and output are

\[ y'_t = \frac{1 + \chi}{\sigma + \chi} a_t, \]  
\[ r'_t = \frac{\sigma(1 + \chi)(\rho_a - 1)}{\sigma + \chi} a_t. \]  

To complete the model, it remains to specify a monetary policy rule. During normal times, we assume that the central bank follows a strict inflation target, adjusting the nominal
Consider a 1-unit positive shock to productivity. The impulse responses of output under various different durations of the interest rate peg are shown in the left panel of figure 1. The solid black line shows the response of output when $H = 0$, so that the central bank targets an inflation rate of 0 in all periods. Given our parameterization of $\sigma = 1$, the impulse response of output is just equal to the impulse response of $a_t$. We consider three additional peg lengths of $H = 3, H = 6$, and $H = 10$. Given the absence of endogenous state variables in the model, after horizon $H$, the response of output is identical to the inflation-targeting case. One observes that the output response on impact is smaller than the inflation-targeting case for $H > 0$. Furthermore, the impact response of output is smaller the bigger is $H$. For $H$ sufficiently large, output can actually decline on impact, as it does here in the case of $H = 10$.

The mechanism for the smaller output response for a longer duration of the interest rate peg lies in the response of expected inflation. Dupor and Li (2015) have termed this the “expected inflation channel.” In particular, a positive productivity shock lowers expected inflation when monetary policy is passive. The longer the nominal interest rate is pegged, the more expected inflation falls. A decline in expected inflation, coupled with a fixed nominal interest rate, results in an increase in the real interest rate. The higher real interest rate chokes off demand and results in a smaller increase in output. These effects can be seen in the right panel of figure 1.

In section C of the online appendix, we show that these qualitative results also hold in a medium-scale model with capital accumulation and several other frictions similar to Smets and Wouters (2007). A temporary rise in productivity leads to an increase in output away from the ZLB but a decrease in output at the ZLB. The mechanism generating the decrease in output is more or less the same as in the basic NK model. Expected inflation decreases by more at the ZLB compared to a Taylor rule, which puts upward pressure on the real interest rate and therefore works to limit demand. The dynamics of the natural rate of interest are somewhat different in the model with capital compared to the simple process shown in equation (5), as we discuss further in the

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// Figure 1: Responses of Output and Expected Inflation to Productivity Shock as a Function of Duration of ZLB

![Figure 1](http://www.mitpressjournals.org/doi/pdf/10.1162/rest_a_00723)
appendix. If the productivity shock is permanent, output may respond more to it at the ZLB compared to normal times. But if that is the case, expected inflation falls by less, not more.

An alternative approach to modeling the effects of the ZLB is to assume that the duration of a pegged nominal interest rate is stochastic rather than deterministic as we have assumed. A stochastic duration of an interest rate peg is the approach taken, for example, in Christiano et al. (2011). In particular, one can assume that in each period, there is a fixed probability, \( p \), with \( p \in [0,1) \), that the nominal interest rate will remain at 0. The expected duration of the peg is then \( 1/(1-p) \) periods. Carlstrom, Fuerst, and Paustian (2014) argue that a deterministic peg length provides much more reasonable results in a textbook NK model with government spending than does a stochastic peg. Carlstrom, Fuerst, and Paustian (2015) examine the effects of forward guidance in a textbook New Keynesian model. When the interest rate is pegged for a stochastic period of time, they find that there are sign reversals in the effects of forward guidance on current inflation and output.\(^4\) In section A of the online appendix, we show the impulse responses of output and inflation to a productivity shock for different expected durations of an interest rate peg. For moderate expected durations of the peg, our results are the same as in the main text: output responds less to a positive productivity shock the longer is the expected duration of the peg, and expected inflation falls more. However, like Carlstrom et al. (2015), if the expected duration of the peg is sufficiently long, we find sign reversals, wherein output responds more to a productivity shock at the ZLB than under an inflation target and the expected inflation response is positive rather than negative.

III. Empirical Analysis

In this section we empirically test the prediction that a positive productivity shock has a smaller, and potentially negative, effect on output when the ZLB binds in comparison to normal times. Given its central role in the transmission of productivity shocks at the ZLB in the textbook NK model, we also examine the effects of productivity shocks on expected inflation. We measure productivity using Fernald’s (2014) quarterly series on utilization-adjusted total factor productivity. Section IIIA describes this data series and makes the case that it can plausibly be considered an exogenous productivity series. Section IIIB outlines our methodology for obtaining impulse responses at and away from the ZLB. Section IIIC presents our main results concerning the effects of productivity shocks on output and expected inflation, both inside and outside the ZLB. Section IIID considers several robustness exercises. Section IIIE studies whether a productivity shock has the same persistence during the ZLB period compared to the period prior and discusses whether and how the answer to this question affects the conclusions one can draw from our empirical exercises.

A. Data

For our empirical analysis, it is critical that we observe a variable that accurately measures exogenous productivity. A traditional Solow residual is likely to be a poor measure of exogenous productivity because of factor hoarding. We therefore use the utilization-adjusted TFP series provided by Fernald (2014). Formally, he assumes an aggregate production function of the form

\[
Y_t = A_t(z_tK_t)^{a_t}(e_tL_t)^{1-a_t},
\]

where \( Y_t \) is output, \( K_t \) is physical capital, and \( L_t \) is aggregate labor hours. \( A_t \) is an exogenous productivity shifter. \( z_t \) denotes capital utilization, and \( e_t \) labor effort. \( a_t \) is a potentially time-varying capital’s share parameter. A traditional measure of TFP is log output less share-weighted capital and labor. In terms of equation (7), this can be written as

\[
\ln TFP_t = \ln Y_t - \alpha_t \ln K_t - (1 - \alpha_t) \ln L_t = \ln A_t + \ln u_t.
\]

Here \( \ln u_t = \alpha_t \ln z_t + (1 - \alpha_t) \ln e_t \) is a composite utilization factor. Only if factor utilization is constant will a traditional TFP series correspond to the exogenous productivity concept in equation (7). Fernald (2014) uses the insights from Basu, Fernald, and Kimball (2006) and follow-up work from Basu et al. (2013) to create an aggregate utilization series, which is used to “correct” a traditional TFP series. In other words,

\[
\ln A_t = \ln TFP_t - \ln u_t.
\]

We will denote the utilization-adjusted TFP series by \( A_t \), the same symbol used to denote exogenous productivity in equation (7). (Interested readers are referred to Fernald, 2014, for more details on the construction of the utilization-adjusted TFP series.)

Table 1 presents some summary statistics on the log first difference of the utilization-adjusted TFP series. For comparison, we also show statistics on the log first difference of a traditional measure of TFP. In addition, we show moments for output growth. Output is measured as real GDP from the NIPA tables. We focus on the full available sample period, 1947Q2 to 2017Q1.

In terms of volatilities, the utilization-adjusted TFP is slightly less volatile than the conventional TFP series. Both the utilization-adjusted and conventional TFP series are less volatile than output growth. Utilization-adjusted TFP growth
Ramey and Zubairy (2017) are examples of two papers that
nonlinear setting. Auerbach and Gorodnichenko (2013) and
than a traditional VAR and it is straightforward to adapt to a
projection method. This is more robust to misspecification
periods where the ZLB binds. To that end, we estimate a
of output to a productivity shock, both inside and outside
is not autocorrelated. Conventional TFP growth, in contrast,
is positively autocorrelated, with an AR(1) correlation of
0.18. Output growth is also quite autocorrelated, with an
AR(1) correlation of 0.37. The lower part of the table
shows the correlation matrix for these variables. Utilization-
adjusted TFP is positively correlated with output growth,
though only mildly so, with a correlation coefficient of 0.13.
In contrast, the conventional TFP series is highly procyclical,
with a correlation with output growth of 0.82.

The fact that the utilization-adjusted TFP series is more
weakly correlated with output than a traditional TFP series
suggests that the utilization-adjustment represents an
improvement over a conventional growth accounting
exercise. It does not, however, prove that Fernald’s series
can be considered exogenous with respect to macroeconomic
conditions. To go a step further, we conduct a sequence
of pairwise Granger causality tests using the first log difference
of Fernald’s utilization-adjusted TFP series and other
macroeconomic shock variables. Under the null hypothesis
that the utilization-adjusted TFP series is a measure of
exogenous productivity, it should not be predictable from
other exogenous shocks. We take four popular measures
of macroeconomic shocks identified in the literature: Romer
and Romer (2004) monetary policy shocks, Romer and Romer
(2010) tax shocks, the defense news shock produced by Ramey
(2011), and an exogenous oil price shock from Kilian
(2008). These shocks are identified using either narrative
methods or time-series models. F statistics and p-values
from the pairwise Granger causality tests are presented in
table 2. The results in table 2 fail to reject the null hypothesis
that any of the series in question do not Granger-cause the
log first difference of utilization-adjusted TFP. These results
are suggestive, but of course not dispositive, that Fernald’s
series can be treated as exogenous.

B. Methodology

Our principal objective is to estimate the impulse response
of output to a productivity shock, both inside and outside
periods where the ZLB binds. To that end, we estimate a
state-dependent regression model using Jordà’s (2005) local
projection method. This is more robust to misspecification
than a traditional VAR and it is straightforward to adapt to a
nonlinear setting. Auerbach and Gorodnichenko (2013) and
Ramey and Zubairy (2017) are examples of two papers that
have used the local projections method to estimate state-
dependent fiscal multipliers.

The basic NK model outlined in section II makes predictions
about the relationship between productivity shocks and output,
and this relationship relies on the behavior of expected inflation. To that end, our local projection of interest is

\[
\text{ln } Y_{t+h} = (1 - Z_t) \left[ \alpha^h + \beta^h \text{ln } A_t + \sum_{s=1}^{p} \gamma^h_s \text{ln } Y_{t-s} + \sum_{s=1}^{p} \phi^h_s \text{ln } A_{t-s} + \sum_{s=1}^{p} \theta^h_s \pi_{t-s} \right] + Z_t \left[ \gamma^h \text{ln } Y_{t-h} + \sum_{s=1}^{p} \phi^h_s \text{ln } A_{t-s} + \sum_{s=1}^{p} \theta^h_s \pi_{t-s} \right] + u_{t+h}. \tag{10}
\]

This regression would be estimated separately for different
leads of log output, ln \(Y_{t+h}\), \(h \geq 0\). \(Z_t\) is a dummy variable that takes on a value of \(Z_t = 0\) when the economy is away from the ZLB and \(Z_t = 1\) when the economy is at the ZLB. The period \(t\) value of log productivity, ln \(A_t\), is included on the right-hand side, reflecting an assumption that utilization-
adjusted TFP is exogenous with respect to output within a period. This variable is interacted with both \(1 - Z_t\) and \(Z_t\).
The right-hand side also includes a constant and \(p\) lags of log
output, log productivity, and a measure of expected inflation, \(\pi_{t-s}\), all of which are also interacted with both \(1 - Z_t\) and \(Z_t\). The estimated impulse response of output at horizon \(h\) to a
shock to productivity in period \(t\) is given by \( (1 - Z_t) \beta^h + Z_t \beta^h \).
When the ZLB is not binding, the response is therefore given by \(\beta^h\). When the ZLB binds, it is \(\beta^h Z_t\).

While the local projections methodology can more easily
accommodate nonlinearities than conventional vector
autoregressions (VARs), in practice impulse responses esti-
minated by local projections are often very choppy (Ramey,
2016). For this reason, for our baseline analysis in the paper,
we adopt the smooth local projections approach proposed by
Barnichon and Brownlees (2016). Intuitively, the smooth
local projections estimator starts with a local projection

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**Table 1.** Empirical Moments

<table>
<thead>
<tr>
<th>Measure/Variable</th>
<th>(\Delta \ln A_t)</th>
<th>(\Delta \ln Y_t)</th>
<th>(\Delta \ln TFP_t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Deviation</td>
<td>0.0082</td>
<td>0.0095</td>
<td>0.0086</td>
</tr>
<tr>
<td>AR(1)</td>
<td>-0.029</td>
<td>0.373</td>
<td>0.177</td>
</tr>
<tr>
<td>Correlation matrix</td>
<td>(\Delta \ln A_t)</td>
<td>1</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td>(\Delta \ln Y_t)</td>
<td>1</td>
<td>0.441</td>
</tr>
<tr>
<td></td>
<td>(\Delta \ln TFP_t)</td>
<td>1</td>
<td>0.819</td>
</tr>
</tbody>
</table>

These moments are calculated for the period 1947Q2 to 2017Q1. \(\Delta\) denotes the first difference of the relevant variable. TFP corresponds to log output less weighted capital and labor, as described in equation (8). \(A_t\) refers to the measure provided by Fernald (2014) described in equation (9). Output, \(Y_t\), is real GDP from the NIPA tables.
like that given in equation (10), but imposes that impulse responses are smooth functions of the forecast horizon. We provide an outline of the smooth local projections estimator in section D of the online appendix, which also uses a Monte Carlo simulation to demonstrate the suitability of the approach.

We estimate the smooth local projection over the sample period 1984Q1 through 2017Q4. The beginning date is chosen to coincide with conventional dating of the Great Moderation. The end of the sample is mandated by current data availability. We consider the ZLB to be binding from 2008Q4 through 2015Q4. This leaves 29 observations where the ZLB binds and 104 observations where it does not (99 observations prior to the beginning of the ZLB period and 5 after it). We estimate the smooth local projections with \( p = 2 \) lags. We estimate the projections at horizons from \( h = 0, \ldots, H = 8 \). Following Jordà (2005) and Barnichon and Brownlees (2016), confidence intervals are constructed using Newey and West (1987) heteroskedasticity and autocorrelation constant (HAC) standard errors.

Output is measured as real GDP from the NIPA accounts, and productivity is the aforementioned utilization-adjusted TFP series provided by Fernald (2014). A number of different measures of aggregate expected inflation exist. A substantial empirical literature studies the properties of survey-based measures of expected inflation, for instance, those collected by the Michigan Survey of Consumers and the Survey of Professional Forecasters. Still other work infers inflation expectations from differences in yields between real and nominal bonds. The Federal Reserve Bank of Cleveland employs a statistical model to measure expected inflation that relies on both survey-based measures and Treasury bond yields. As a benchmark measure, we use the median of the expected inflation series from the Michigan Survey of Consumers. The wording of the question used in the Michigan Survey is as follows. Survey respondents are asked, “By about what percent do you expect prices to go (up/down) on the average, during the next 12 months?” Respondents then give a quantitative point forecast. Desirable features of the Michigan Survey are its relatively long time series, its high frequency, and that it probes actual economic decision makers about their inflation expectations. Undesirable features are that it is ambiguous as to what measure of prices agents are forecasting and that the time frame over which the expectation is given is fixed at a year (whereas in the baseline NK model, one-quarter-ahead expected inflation is what is relevant). These data are available at a monthly frequency going back to 1978. We aggregate the expected inflation series to a quarterly frequency by averaging across months within a quarter.

### C. Results

We graphically display the results from the baseline smooth local projection in figure 2. The line with x markers shows the estimated impulse response of output to a 1 unit productivity shock outside the ZLB; the shaded gray region corresponds to the 90% confidence interval associated with this response. Output increases mildly on impact and continues to rise for several quarters thereafter. The units of the response can be interpreted as an elasticity. Hence, outside of the ZLB on impact, we estimate that a 1% increase in productivity leads to a 0.2% increase in output. The solid line with * markers plots the estimated response when the ZLB binds; the dotted lines with the * markers correspond to the lower and upper bounds of the 90% confidence interval. Contrary to the theory outlined in section II, output is estimated to respond by roughly four times as much to a productivity shock on impact at the ZLB compared to normal times. The point estimate for the output response at the ZLB is larger than away from the ZLB for about six periods, and the confidence intervals for the two responses do not overlap for the first four forecast horizons.

Table 3 shows point estimates and standard errors for the estimated responses away from the ZLB (\( \beta_h^0 \)) and at the ZLB (\( \beta_h^Z \)) for several different horizons. Standard errors are below the point estimates in parentheses. The third column presents test statistics of the null hypothesis of equality of the IRFs at each forecast horizon. \( p \)-values are presented below the test statistics in brackets. \( p \)-values are computed by comparing the test statistic to an F distribution with 1 numerator degree of freedom and \( T - p - h - K \) denominator degrees of freedom, where \( T \) is the sample size and \( K \) is the number of regressors.\(^5\) The null hypothesis of pointwise equality can be rejected at better than the 1% significance level or better.

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\(^5\) For the standard local projection methodology, the maximum available sample size is used in each individual regression. This means that \( T - p - h \) observations are available after accounting for lags (\( p \)) and leads of the left-hand-side variable (\( h \)).
for horizons $h = 0, 1, 2$ and at the 5% significance level for horizon $h = 3$. Beyond this horizon, one cannot reject that the point estimates are the same.

The final column in table 3 considers the null hypothesis of pathwise equality of the estimated impulse response functions. Rather than testing the equality of IRFs across regimes at a forecast horizon, here we test equality of IRFs across regimes up to a particular forecast horizon. For example, in the $h = 1$ row, the pointwise null hypothesis is $H_0 : \beta^1 = \beta^0$, whereas the pathwise test involves a joint null hypothesis of $H_0 : \beta^0 = \beta^0$ & $\beta^1 = \beta^1$. The pathwise test requires computing covariances of estimators across different forecasting regressions. For this reason, in computing these tests, we restrict the sample size to be constant across forecasting regressions instead of varying with the forecasting horizon (see the discussion in note 5). In this system of seemingly unrelated regressions, the right-hand-side variables are identical. The pathwise test statistic would ordinarily be identical to the pointwise statistic at $h = 0$, but it differs slightly here because the sample sizes are different. Nevertheless, we can still reject pathwise equality on impact at better than the 1% significance level. Furthermore, we can easily reject pathwise equality at all subsequent horizons at greater than the 1% significance level.

Our baseline responses and statistical tests are based on the smooth local projections technique of Barnichon and Brownlees (2016). To be sure that the smoothing of the responses is not driving any of our results, in section E of the online appendix, we show estimated responses of output to a productivity shock using the standard local projections technique. The same basic picture emerges regardless of whether the responses are smoothed or not; output responds significantly more to a productivity shock on impact and at short forecast horizons when the ZLB binds than when it does not. Aside from the responses being smoother, the confidence intervals are tighter when using the smooth local projection as opposed to the standard local projection. This arises naturally because of efficiency gains associated with imposing more structure in the estimation.

In the basic NK model, the behavior of expected inflation is the key mechanism by which the output responses to a productivity shock differ at and away from the ZLB. To that end, we estimate a version of equation (10), but place expected inflation, rather than output, on the left-hand side. This regression allows us to estimate the impulse response of expected inflation to a productivity shock across monetary policy regimes. Formally,

$$
\pi^e_{t+h} = (1 - Z_t) \left[ \alpha^h + \beta^h \ln A_t + \sum_{s=1}^{p} \gamma^h \ln Y_{t-s} + \sum_{s=1}^{p} \phi^h \ln A_{t-s} + \sum_{s=1}^{p} \rho^h \pi^e_{t-s} \right] + Z_t \left[ \alpha^h + \beta^h \ln A_t + \sum_{s=1}^{p} \gamma^h \ln Y_{t-s} + \sum_{s=1}^{p} \phi^h \ln A_{t-s} + \sum_{s=1}^{p} \rho^h \pi^e_{t-s} \right] + u_{t+h}.
$$

(11)

Similar to the output projection, $\beta^h_{z,\pi}$ measures the impulse response of expected inflation at horizon $h$ to a productivity shock when the ZLB does not bind, while $\beta^h_{z,\pi}$ measures the response when the ZLB does bind. The specifics of this local projection are the same as when using output on the left-hand side. Figure 3 plots the estimated response.

Outside of the ZLB period, expected inflation falls in response to a productivity shock. The expected inflation series is expressed at a quarterly percentage rate. Hence,
one can interpret the units of the impulse response as suggesting that a 1% increase in productivity results in expected inflation falling by about 0.04 percentage points at a quarterly frequency, or roughly 0.16% annualized.\footnote{The coefficients in the local projection, $\beta^h$ and $\beta_{H,x}^h$, measure the response to a change in log productivity of 1 (or 100%). Hence, the effect of a 1% increase in productivity equals (1/100) times the units of the response on the vertical axis in figure 3.} The response ceases to be statistically different from 0 after about one year. At the ZLB (solid line), we also estimate that expected inflation falls in response to a positive productivity shock. The point estimate on impact is slightly more negative than away from the ZLB, but this difference is not statistically significant. For most subsequent horizons, the point estimate of the response at the ZLB lies below the response away from the ZLB, although these differences are not economically large and for the most part are statistically insignificant.

Table 4 is structured similarly to table 3 but presents coefficients, standard errors, and test statistics when expected inflation is the outcome variable. See also the notes to table 3.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>$\beta^h_{\pi}$</th>
<th>$\beta_{H,x}^h$</th>
<th>$H_0: \beta^h_{\pi} = \beta_{H,x}^h$</th>
<th>$H_0$: Pathwise Equality</th>
</tr>
</thead>
<tbody>
<tr>
<td>$h = 0$</td>
<td>-3.658</td>
<td>-4.490</td>
<td>0.085</td>
<td>0.058</td>
</tr>
<tr>
<td></td>
<td>(1.05)</td>
<td>(2.66)</td>
<td>[0.77]</td>
<td>[0.81]</td>
</tr>
<tr>
<td>$h = 1$</td>
<td>-2.390</td>
<td>-4.385</td>
<td>1.047</td>
<td>2.908**</td>
</tr>
<tr>
<td></td>
<td>(0.71)</td>
<td>(1.82)</td>
<td>[0.31]</td>
<td>[0.06]</td>
</tr>
<tr>
<td>$h = 2$</td>
<td>-1.437</td>
<td>-4.074</td>
<td>2.708</td>
<td>4.905***</td>
</tr>
<tr>
<td></td>
<td>(0.67)</td>
<td>(1.45)</td>
<td>[0.10]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 3$</td>
<td>-0.797</td>
<td>-3.559</td>
<td>2.974*</td>
<td>4.914***</td>
</tr>
<tr>
<td></td>
<td>(0.74)</td>
<td>(1.42)</td>
<td>[0.09]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 4$</td>
<td>-0.470</td>
<td>-2.838</td>
<td>2.164</td>
<td>5.125**</td>
</tr>
<tr>
<td></td>
<td>(0.76)</td>
<td>(1.42)</td>
<td>[0.14]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 5$</td>
<td>-0.458</td>
<td>-1.913</td>
<td>0.971</td>
<td>6.020**</td>
</tr>
<tr>
<td></td>
<td>(0.71)</td>
<td>(1.30)</td>
<td>[0.33]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 6$</td>
<td>-0.759</td>
<td>-0.782</td>
<td>0.000</td>
<td>6.037**</td>
</tr>
<tr>
<td></td>
<td>(0.67)</td>
<td>(1.06)</td>
<td>[0.08]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 7$</td>
<td>-1.374</td>
<td>0.553</td>
<td>1.996</td>
<td>6.032**</td>
</tr>
<tr>
<td></td>
<td>(0.91)</td>
<td>(1.01)</td>
<td>[0.16]</td>
<td>[0.00]</td>
</tr>
<tr>
<td>$h = 8$</td>
<td>-2.302</td>
<td>2.094</td>
<td>4.128**</td>
<td>7.120**</td>
</tr>
<tr>
<td></td>
<td>(1.45)</td>
<td>(1.60)</td>
<td>[0.04]</td>
<td>[0.00]</td>
</tr>
</tbody>
</table>

This table shows estimates, standard errors, and test statistics when expected inflation is the outcome variable. See also the notes to table 3.

We find that output responds significantly more to a productivity shock when monetary policy is constrained by the ZLB than otherwise. Furthermore, the response of expected inflation to a productivity shock is qualitatively similar across monetary regimes. These results stand in contrast to the predictions of a textbook New Keynesian model. In this section, we explore the robustness of these results along several different dimensions.

We begin by considering alternative measures of output. As alternative measures to real GDP, we use the industrial production (IP) index, total hours per capita in the nonfarm business sector, and the civilian unemployment rate. For the IP and unemployment series, the underlying monthly data are converted to quarterly date by averaging observations within the quarter. The sample period for the estimation is the same as our baseline case. Results are displayed in figure 4.

The responses depicted in figure 4 convey a similar message to our baseline results using real GDP. In particular, a positive productivity shock is estimated to be more expansionary on impact and for several quarters thereafter when the ZLB binds compared to when it does not. Somewhat surprisingly, we estimate no economically or statistically significant response of IP to a productivity shock away from the ZLB. But when the ZLB binds, we find that IP increases significantly on impact and for several quarters thereafter before reverting back toward 0.

Because a large literature has investigated the effects of technology shocks on labor market variables (Shapiro & Watson, 1988; Blanchard & Quah, 1989; Gali, 1999; Christiano, Eichenbaum, & Vigfusson, 2004; Basu et al., 2006), it is of particular interest to examine how such variables react to a productivity shock both inside and away from the ZLB. Consistent with much of this literature, we find that hours worked initially decline after a productivity improvement outside the ZLB before turning positive after a little more than a year. The estimated impact decline in hours is statistically significant. Similarly, outside the ZLB, we find that the unemployment rate increases on impact and for a few quarters thereafter when productivity increases, although this response is not statistically significant. In other words, away from the ZLB, a productivity shock seems to be contractionary for labor market variables. When the ZLB binds, in contrast, we find that hours worked increase on impact, albeit statistically insignificantly so. The response continues to grow and quickly turns significant. We also estimate that the unemployment rate declines (significantly) on impact when productivity increases.
Figure 4.—Alternative Measures of Economic Activity

We next consider alternative measures of expected inflation in our local projections. Our baseline measure of expected inflation is the median point estimate from the Michigan Survey of Consumers. We also consider the mean (across households within a period) from the Michigan Survey, the one-year-ahead inflation expectation from the Federal Reserve Bank of Cleveland, the median SPF forecast for one-period-ahead CPI inflation, and the median of one-period-ahead GDP deflator inflation from the SPF.7

Impulse responses obtained from smooth local projections using these alternative series are shown in figure 5. Estimated impulse responses of all four alternative measures of expected inflation are qualitatively similar to our baseline analysis. In normal times (lines with the x markers) expected inflation falls on impact and reverts back to 0 after a few horizons. Estimated responses at the ZLB are insignificantly different from the responses during normal times for all four series over most horizons. Point estimates suggest that expected inflation falls more at the ZLB for the first few quarters after a productivity shock when using the mean from the Michigan Survey and the Cleveland Fed survey. When using either SPF forecast, in contrast, we find that expected inflation falls less on impact at the ZLB in comparison to normal times, though we must stress that these differences are statistically insignificant.

We next consider a number of additional robustness checks, focusing first on output responses. We revert to assuming that the outcome variable of interest is real GDP, but consider several different specifications of the local projection. Results are shown graphically in figure 6.

One might worry that our result that output responds more to a productivity shock at the ZLB compared to normal times is in actuality driven by the fact that the most recent ZLB period coincides with the height of the Great Recession. Put differently, it is conceivable that output responds more to a productivity shock during a recession and that our ZLB dummy variable is simply proxying for periods of recession. We address this concern by augmenting our baseline regression specification, equation (10), with a dummy variable equaling 1 in periods defined by the NBER to be recessions (and 0 otherwise), as well as an interaction between this dummy variable and the period $t$ value of productivity. Responses under this specification are shown in the left panel of the upper row of figure 6. This figure is qualitatively similar to our baseline specification, and if anything, the differences between the estimated output responses at and away from the ZLB are even larger and more statistically significant than in our baseline specification.

Our baseline regression specification is in the levels of the variables. This specification is robust to cointegration between output and productivity. We consider an alternative specification in which output and productivity appear in log first differences rather than log levels (the expected inflation series continues to enter in levels). For example, the regressor of interest on the right-hand side becomes $\Delta \ln A_t$ instead of $\ln A_t$, and lags of both productivity and output appear in first differences as well. The left-hand-side variable is $\ln Y_{t+h} - \ln Y_{t-1}$, which is equivalent to the cumulative sum of growth rates of output from horizons 0 through $h$. The estimated responses are shown in the upper-middle panel.

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7 Details on the Cleveland Fed Survey can be found here. The survey provides forecasts of CPI inflation at forecast horizons of one through thirty years and is available monthly beginning in 1982. We focus on the one-year inflation expectation. For the SPF data, we can access one-quarter and one-year-ahead forecasts of both CPI and GDP deflator inflation. We focus on one quarter ahead, as this frequency most closely matches the theoretical model of section II. Our results are nearly identical when using one-year-ahead forecasts.
of the first row of figure 6. The estimated response outside the ZLB is virtually identical to our baseline result from estimation in levels. The estimated impact effect and the response for several quarters thereafter is again larger at the ZLB than in normal times, albeit the differences between responses at and away from the ZLB are not as statistically significant as in the levels specification.

In the left and middle panels of the bottom row, we revert to including the variables in levels but include a deterministic linear time trend (left panel) and a quadratic time trend (middle panel) in the regressions. There is virtually no effect on the shape of the estimated response of output in normal times. Point estimates on impact and for a few quarters thereafter of the output response at the ZLB are similar to our baseline specification, and the differences between the responses at and away from the ZLB are highly statistically significant. One noticeable difference, apparent in most of the figures where the left-hand-side variable is output, but especially so in these two, is that the response at the ZLB, while larger on impact, seems to be less persistent in comparison to normal times. We return to a discussion of this feature in section IIIE.

In our estimation, we suppose that the ZLB binds from the final quarter of 2008 to the final quarter of 2015. While the effective Federal Funds Rate was below 100 basis points for virtually all of the fourth quarter of 2008, the target range for the funds rate did not formally hit 0 until December. Conversely, while the target funds rate included 0 for most of the fourth quarter of 2015, a movement to a target range of 25 to 50 basis points took place near the end of the quarter. The right panel of the upper row examines the sensitivity of our analysis to a slight modification of our ZLB definition. We suppose that \( Z_t = \frac{1}{3} \) for the final quarter of 2008 (equal to the number of months as a fraction of the total months in the quarter where the ZLB was binding) and \( Z_t = \frac{2}{3} \) for the final quarter of 2015. Output still responds substantially more on impact and for a few quarters at the ZLB compared to normal times. The different definition of the ZLB does result in the output response being somewhat less persistent than in our baseline analysis.

The final panel of the bottom row of figure 6 considers robustness to the assumed number of lags of the control variables in the local projections. The number of lags has a limited effect on the estimated response of output to
a productivity shock during normal times. The estimated response in the ZLB regime on impact and for a few quarters thereafter is similar across different lag lengths. The estimated responses in the ZLB regime do seem to be less persistent the more lags are included in the projection.

We also consider the same set of robustness checks when expected inflation is the left-hand-side variable of interest. For these robustness checks, we use the median of the Michigan Survey of Consumers as our inflation expectations series. Impulse responses are shown in figure 7. The figure is structured similar to figure 6. In most specifications, our results are very similar to the baseline results depicted in figure 3. In all specifications, expected inflation falls when productivity increases outside the ZLB. For most specifications the estimated response when the ZLB binds is qualitatively similar, with expected inflation falling by slightly more on impact and the first several horizons thereafter but being somewhat less persistent. An exception is the growth rates specification, where output and utilization-adjusted TFP appear in first differences on the right-hand side of our local projection. In this specification, the point estimate suggests that expected inflation increases slightly on impact when productivity increases, although this is not statistically significant. Furthermore, after a couple of horizons, the estimated expected inflation response at the ZLB lies significantly below the estimated response when the ZLB does not bind.

E. Is the Productivity Response to a Productivity Shock the Same at the ZLB?

We have documented that output, and a variety of similar measures, seems to react significantly more positively to a positive productivity shock when the ZLB binds than when it does not. In contrast, we find little qualitative difference in the response of expected inflation to a productivity shock at and away from the ZLB. These results are inconsistent with the predictions of a textbook NK model, the simplest version of which predicts that output ought to increase less (or decrease) and expected inflation ought to fall more when productivity increases at the ZLB in comparison to a more active monetary policy regime.

In standard forward-looking macroeconomic models, how output and expected inflation react to a productivity shock depends not only on the stance of monetary policy but also on the persistence of the shock itself. In our state-dependent local projection model, one would hope that the persistence of the productivity shock...
ARE SUPPLY SHOCKS CONTRACTIONARY AT THE ZLB?

**Figure 7.—Alternative Specifications, Expected Inflation**

This figure plots estimated impulse responses of expected inflation to a productivity shock in various specifications of our smooth local projection. See the notes to figure 2. To improve readability, when considering alternative lag lengths (lower right plot), we only show the confidence interval around the estimated response away from the ZLB in the baseline specification with $p = 2$ lags. For the responses generated in this figure, we use the median expectation from the Michigan Survey of Consumers as our inflation expectations series.

is similar across monetary regimes. Nothing in our estimation, however, imposes this. Indeed, a close inspection of the estimated responses of output reveals that the persistence of the productivity shock may in fact not be the same across regimes. Whereas we find that the estimated output response grows with the forecast horizon in normal times, at the ZLB, the response of output seems to be declining with the forecast horizon. This feature is somewhat evident in our baseline specification (see figure 2), but is perhaps even more so in several of the robustness checks considered in section IIID (see, e.g., figure 6).

We therefore examine whether the dynamic paths of productivity in response to a productivity shock are estimated to be similar across monetary regimes. We estimate a smooth, local projections version of equation (10), but with $\ln A_{t+h}$ on the left-hand side in place of leads of output. Results are shown in figure 8.

It is visually apparent that the persistence of the productivity impulse response is quite different across monetary regimes. Whereas the estimated response away from the ZLB is more or less consistent with a random walk process, at the ZLB the productivity response is quickly mean reverting.

**Figure 8.—Baseline SLP, Productivity**

This figure plots the estimated impulse response of productivity to a 1 unit productivity shock at various forecast horizons. See also the notes to figure 2.

This finding does not emerge as a consequence of smoothing and seems to be robust to several different versions of our local projection.
At first pass, the results visually conveyed in figure 8 would seem to call into question the validity of our empirical analysis. The simple theoretical model giving rise to testable empirical predictions holds everything in the model fixed but the stance of monetary policy. If, in addition to monetary policy being constrained by the ZLB, the persistence of productivity shocks has changed, is there any merit to our analysis? We believe there is and argue that in fact, the dampened persistence of the productivity shock during the ZLB regime provides an even more compelling test than would be the case had there been no change in the persistence of the shock.

In a textbook NK model, a binding ZLB has much stronger impacts on the responses of output and expected inflation to a productivity shock the less persistent that shock is. We touch on this point in section C of the online appendix when discussing the medium-scale NK model, and a similar point is also emphasized in Wieland (forthcoming). Here in the body of the paper, we make this point referencing the textbook NK model developed in section II. We compute impulse responses of output and expected inflation to a productivity shock with different peg lengths ($H = 0, H = 3, H = 6,$ and $H = 10$). We do so for two different levels of persistence of the productivity shock, $\rho_a = 0.97$ and $\rho_a = 0.75$. Responses are plotted in figure 9. The left column plots the output (upper row) and expected inflation (bottom row) responses when $\rho_a = 0.97$, and the right column does the same when $\rho_a = 0.75$.

As documented in section II, regardless of the value of $\rho_a$, output reacts less to the productivity shock the longer is the duration of the interest rate peg. What is noteworthy in figure 9 is that the effect of the peg on the output response is substantially larger when the productivity shock is less persistent. For example, when the interest rate is pegged for six periods, output jumps up by about 0.75% on impact when $\rho_a = 0.97$, but actually falls slightly on impact when $\rho_a = 0.75$. Similarly, when $H = 10$, output increases by 0.25% when $\rho_a = 0.97$ but declines by 0.6% on impact when $\rho_a = 0.75$. We observe the same pattern in the expected inflation responses plotted in the lower panel of figure 9. In particular, for a given peg length, expected inflation falls more the less persistent is the productivity shock. The intuition for these findings is fairly straightforward. With forward-looking agents, when the productivity shock is very persistent, there is a fairly large increase in demand. With a given increase in supply, this results in a reasonably sized increase in output and only a small decline in current and expected inflation, which means that there is little resulting change in the real interest rate even though the nominal rate is fixed. When the shock is not very persistent, in contrast, aggregate demand increases very little in response to a productivity shock. With a given increase in supply, current and expected inflation must fall more substantially, which drives up the real interest rate and depresses demand, potentially resulting in a decline in output.
Viewed through the lens of the NK model, then, a less persistent productivity shock in conjunction with a binding ZLB ought to result in an even smaller increase (or bigger decline) in output and a larger decline in expected inflation than if the persistence of the shock were held fixed across monetary regimes. Put another way, our findings that output responds more to a productivity shock at the ZLB and that the response of expected inflation is roughly the same as in normal times, are even more inconsistent with the predictions of the textbook NK model when the persistence of the productivity shock is lower. Rather than invalidating our empirical results, the fact that the persistence of productivity shocks has evidently been lower in the ZLB period compared to earlier times actually makes our empirical results even more puzzling from the perspective of the model.

IV. Discussion

The empirical evidence presented and discussed in section III is inconsistent with the predictions of a textbook NK model, as well as with its more complicated cousin, the medium-scale DSGE model á la Christiano, Eichenbaum, and Evans (2005) or Smets and Wouters (2007). We view our paper as contributing to a growing literature that points out predictions of these models that do not seem to hold up to empirical scrutiny. While our objective is not to propose a new theoretical framework, we use this section to discuss relevant papers that in our view offer promising alterations to the basic NK framework that might help make the model more consistent with our empirical findings.

One avenue we find particularly promising is to replace the assumption of sticky prices or wages (or both) with sticky or imperfect information, as proposed, for example, in Mankiw and Reis (2003). In their model, firms are free to set prices each period and do so optimally given available information, but they can update their information sets only sporadically. This setup implies that the current inflation rate depends on past expectations of current economic conditions, which contrasts with the textbook NK model wherein inflation is purely forward looking.8 The extreme forward-looking nature of inflation lies at the heart of the basic model’s prediction that positive supply shocks might be contractionary at the ZLB. Indeed, Kiley (2016) shows that positive technology shocks are expansionary at the ZLB in a sticky information economy.9 Empirical evidence in support of models of informational rigidities more generally is provided in, for example, Coibion and Gorodnichenko (2012, 2015) and Coibion, Gorodnichenko, and Kamdar (2018).

A related avenue that may prove helpful in reconciling the basic model with the evidence is to discard the assumption of rational expectations altogether. Gabaix (2016) replaces rational expectations with bounded rationality and shows that this can resolve a number of anomalies in the NK model. Angeletos and Lian (2016) show that relaxing the assumption of common knowledge makes expectations of economic outcomes (such as inflation) stickier relative to the baseline NK model. Along similar lines, García-Schmidt and Woodford (2015) use a model in which agents iteratively update their expectations to study the robustness of the so-called neo-Fisherian predictions of the baseline NK model. In the context of our empirical results, these and related departures from the rational expectations benchmark will serve to make inflation expectations stickier (in a way consistent with much of our empirical analysis making use of inflation expectations data), thereby dampening the “expected inflation channel” that lies at the heart of many of the NK model’s paradoxical predictions at the ZLB.

Another promising twist of the model is to assume some type of financial friction so as to make some fraction of agents borrowing constrained or to incorporate ex post heterogeneity via market incompleteness. The introduction of borrowing constraints is discussed, for example, in Wieland (forthcoming). For financially constrained agents, total spending cannot exceed some exogenous nominal debt limit. When productivity increases, there are offsetting effects at the ZLB. On the one hand, expected inflation decreases, which pushes current output down given a fixed nominal interest rate. On the other hand, lower inflation raises the debt limit of the constrained household, thereby allowing them to increase spending, which pushes current output up. Wieland (forthcoming) shows that for a sufficiently low rate of intertemporal substitution, the second channel dominates the first, and output can rise when productivity increases. Recent examples of incorporating nontrivial heterogeneity and market incompleteness into the NK model include Kaplan, Moll, and Violante (2016) and McKay, Nakamura, and Steinsson (2016). Whereas the textbook NK model operates almost entirely through intertemporal substitution, versions of the model with heterogeneous agents and liquidity constraints work much more in line with “old Keynesian” intuition. In particular, a higher-than-average fraction of constrained households during the ZLB period might help rationalize why we empirically find that output reacts more strongly to a productivity shock at the ZLB.

Finally, one could argue that the ZLB has not in actuality imposed much of a constraint on monetary policy. While central banks around the world have been constrained in setting short-term policy rates, they have aggressively moved along other margins in an attempt to influence economic outcomes. One such margin involves promises about future policy. Bundick (2015) shows that if monetary policy follows a “history-dependent” rule, the perverse effects of

8 Sticky price models can, of course, be tweaked to make inflation less forward looking. But these tweaks, a very common one of which is the assumption of indexation to lagged inflation, are often both theoretically and empirically unattractive.

9 An additional desirable feature of sticky information is that the “sign reversals” associated with interest rate pegs, which we discuss in section A of the online appendix and which Carlstrom et al. (2015) call “pathological,” are not present when monetary nonneutrality arises from sticky information instead of sticky prices.
productivity shocks at the ZLB can be mitigated. Although a central bank cannot adjust short-term nominal rates in response to a productivity improvement, it can promise to lower future short-term rates in such a way as to stimulate expected inflation instead of allowing it to decline. Another possibility is to allow for a more intricate central bank balance sheet so as to analyze the term and risk structure of interest rates. Along these lines, Chen, Cúrdia, and Ferrero (2012) build a model with debt instruments of different maturities and segmented markets to study the implications of large-scale asset purchases. While in their theoretical model, quantitative easing has limited effects, in a more empirically oriented approach, Wu and Xia (2016) argue that the Federal Reserve’s unconventional policies during the ZLB period were even more aggressive than historical policies prior to the Great Recession. Relatedly, Wu and Zhang (2016) formalize the notion of a shadow rate for the Federal Funds Rate as a summary statistic for unconventional monetary policies. They argue that the ZLB is not a constraint on monetary policy, and in their model, productivity shocks are expansionary even when the notional ZLB binds. The potential for effective (or, in the case of Wu and Xia 2016, hypereffective) unconventional monetary policies at the ZLB could go a long way in helping to square our results with the predictions of the textbook NK model.

We think all of the different lines of research discussed in this section are promising. The key thread running through our discussion in this section is that it is possible to perturb the assumptions of a standard NK model in such a way as to deliver quite different results when the ZLB binds. However, the model we discuss in section II and its medium-scale cousin are quite prevalent in policy institutions. Our discussion in this section suggests that considering some of these extensions or modifications would be worthwhile in light of our empirical results.

V. Conclusion

The textbook New Keynesian model predicts that the output response to a productivity shock is smaller when the nominal interest rate is constrained by the ZLB compared to periods where monetary policy is active. The mechanism by which this happens is that a positive productivity shock results in a decrease in expected inflation, which drives up the real interest rate when the nominal rate is constrained by the ZLB. The higher real interest rate chokes off demand and limits the output response to a positive supply shock.

We test these predictions of the textbook NK model in the data. We estimate a state-dependent empirical model according to the Barnichon and Brownlees (2016) smoothed version of Jordà’s (2005) local projection method. We measure productivity shocks using Fernald’s (2014) utilization-adjusted total factor productivity series. Contrary to the predictions of the model, we find that output and related measures respond significantly more to positive productivity shocks in periods where the ZLB binds compared to periods where it does not. Further, we find little or no significant difference in the response of a variety of measures of expected inflation to a productivity shock across monetary regimes.

As our empirical results are inconsistent with the predictions of the textbook model, caution seems to be in order when using the model to make predictions about the economic consequences of alternative policies (such as forward guidance or fiscal stimulus) when the ZLB binds. In contrast, more research into alternative model specifications such as those discussed in section IV seems desirable and likely to be fruitful.

REFERENCES

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