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## TFP and the Transmission of Shocks

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# TFP and the Transmission of Shocks

Eric Mayer\*

Sebastian R  th<sup>†</sup>

Johann Scharler<sup>‡</sup>

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## Abstract

We show that TFP reacts counter-cyclically to macroeconomic shocks, which we identify by imposing sign restrictions. Counterfactual simulations, based on a New Keynesian DSGE model, show that firms manage to employ labor more efficiently during downturns, which leads to a muted drop in the output gap as long as the recession is not deep enough to make the zero lower bound on the nominal interest rate binding. If the economy hits the zero lower bound, the reductions in both, employment and output gap, are stronger when we allow TFP to depend on the state of the business cycle.

Keywords: TFP, labor effort, zero lower bound

JEL codes: E32, E40

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\*University of Wuerzburg, Department of Economics, Sanderring 2, 97070 Wuerzburg, Germany, Phone: ++49 931 3182948, Fax: ++49 931 888-7275, e-mail: eric.mayer@uni-wuerzburg.de.

<sup>†</sup>University of Wuerzburg, Department of Economics, Sanderring 2, 97070 Wuerzburg, Germany, Phone: ++49 931 3186398, Fax: ++49 931 888-7275, e-mail: sebastian.rueth1@uni-wuerzburg.de.

<sup>‡</sup>University of Innsbruck, Department of Economics, Universitaetsstrasse 15, A-6020 Innsbruck, Austria, Phone: ++43 (512) 507 7357, Fax: ++43 (512) 507 7357 2980, e-mail: johann.scharler@uibk.ac.at.

# 1 Introduction

The dynamics of productivity over the business cycle have received a tremendous amount of attention in the literature, both empirically and theoretically (see e.g. Galí and van Rens, 2010; Hagedorn and Manovskii, 2011; McGrattan and Prescott, 2012, among others). At a descriptive level, total factor productivity (TFP) is well known to be pro-cyclical.<sup>1</sup> A result that fits nicely together with the predictions of real business cycle theory, where exogenous TFP shocks are viewed the primary driving force behind business cycles. New Keynesian models, while generally allowing for a large variety of shocks, also typically acknowledge an important role of exogenous variations in TFP.

In this paper, we go beyond the usual interpretation of TFP as an exogenous source of shocks and study the role of TFP as part of the transmission mechanism for shocks more generally. In other words, we study the endogenous response of TFP and its implications for the business cycle, rather than the implications of exogenous shocks to TFP.

In our empirical analysis, we estimate a Bayesian vector autoregressive (BVAR) system and impose sign restrictions as in Faust (1998) and Uhlig (2005) to identify supply, demand and labor market shocks. Although the dynamics of TFP differ somewhat depending on the type of shock, we find that adverse shocks give rise to significant increases in TFP in the short to medium run. Nevertheless, at a descriptive level, TFP is pro-cyclical on impact in our sample, as one would expect.<sup>2</sup> Thus, we argue that the overall, pro-cyclical pattern is the result of exogenous shocks to TFP as suggested by real business cycle theory, whereas the endogenous dynamics induced by supply, demand and labor market shocks give rise to counter-cyclical TFP dynamics. To our knowledge, this is the first study demonstrating this counter-cyclical nature of TFP in response to shocks. Moreover, we argue that the counter-cyclical TFP dynamics, which arise endogenously, are most likely to mirror counter-cyclical fluctuations in workers' (unobserved) effort.<sup>3</sup>

Having characterized the endogenous dynamics of TFP empirically, we move on and study the implications of endogenously fluctuating TFP through simulation exercises based on a New Keynesian model framework as in Galí et al. (2012b). To do so, we extend the standard model

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<sup>1</sup>Field (2010) finds that TFP is strongly pro-cyclical and labor productivity is mildly pro-cyclical over the very long run.

<sup>2</sup>Specifically, the log difference of TFP is positively correlated with detrended GDP measures. See Appendix A for details on data.

<sup>3</sup>Basu et al. (2006) show that fluctuations in overall TFP can be decomposed into changes in capital utilization, workers' effort, and productivity shocks. Since capital utilization and productivity shocks are largely pro-cyclical, we conclude that the counter-cyclical dynamics are likely to be driven by fluctuations in labor effort.

to incorporate time-varying labor effort. This modification provides an extra margin for firms to adjust production following the realizations of exogenous shocks. In our model, household members decide on the amount of effort they exert and firms detect low levels of effort only with a certain probability since monitoring is costly. The monitoring cost vary over the business cycle such that monitoring is tight in recessions and loose in booms.<sup>4</sup> While higher effort generally reduces utility, household members can reduce the probability of being caught shirking by exerting a higher level of effort. Given these assumptions, equilibrium labor effort fluctuates counter-cyclically, which translates into endogenous, countercyclical fluctuations in TFP.

Based on the model simulations, we find that although counter-cyclical fluctuations in TFP attenuate the drop in output after adverse shocks, the decline in employment is amplified since increased labor effort during a downturn serves as a substitute for employment. These results are, however, contingent on the economy operating outside of the zero lower bound on the nominal interest rate. If the zero lower bound becomes binding, output declines stronger when labor effort increases, since the additional disinflationary effect that originates from the higher TFP leads to a higher real interest rate. In this sense, our paper is closely related to the recent literature on potentially adverse consequences of supply side improvements when the economy is operating at the zero lower bound (Eggertsson, 2010; Fernández-Villaverde et al., 2011).

The paper is structured as follows: In Section 2, we present the empirical analysis. In Section 3, we introduce an augmented New Keynesian model on which our simulation exercises are based, and Section 4 discusses the calibration and the simulation results. Section 5 summarizes and concludes the paper.

## 2 Empirical Methodology

In this section, we present our empirical model and report results.

### 2.1 Estimation and Data

We consider a reduced form VAR model:

$$X_t = c + \sum_{j=1}^p A_j X_{t-j} + \varepsilon_t, \quad (1)$$

where  $X_t$  is the vector of  $n$  endogenous variables,  $c$  is a  $n \times 1$  vector of intercepts.  $A_j$  is a  $n \times n$  matrix comprising the AR-coefficients at lag  $j = 1, \dots, p$  and  $\varepsilon_t$  are the reduced form

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<sup>4</sup>Philippon (2006) studies corporate governance implications for the business cycle.

residuals. Estimation and inference is performed by Bayesian techniques, where we employed the conjugate Normal-Wishart prior with 1,000 draws along the lines of Koop and Korobilis (2010).<sup>5</sup> The Bayesian approach enables us to consider uncertainty about estimated parameters and is a natural way to implement sign restrictions on impulse response functions (see e.g. Granziera et al., 2011; Uhlig, 2005). Lag-length criteria suggest heterogeneous horizons, so we set two lags,  $p = 2$ , to minimize the final prediction error. Qualitatively our results are, however, robust to different lag-lengths.

Our benchmark VAR model includes the following six quarterly time series for the US economy:

$$X_t = [ \text{RGDP}_t \text{ EMPL}_t \text{ FFR}_t \text{ PRICES}_t \text{ COMP}_t \text{ TFP}_t ]' . \quad (2)$$

The variables included are the log of per capita real GDP,  $\text{RGDP}_t$ , log employment,  $\text{EMPL}_t$ , the federal funds rate,  $\text{FFR}_t$ , the log price level,  $\text{PRICES}_t$ , the log of real compensation per employed worker,  $\text{COMP}_t$ , and the log of TFP,  $\text{TFP}_t$ . We include compensation per employed worker rather than compensation per hour worked to be consistent with the DSGE model we discuss in Section 3. To construct  $\text{TFP}_t$ , we generate an index based on the series of TFP growth rates as provided by the Federal Reserve Bank of San Francisco. Since the provided series of TFP growth rates is based on a growth accounting exercise, which uses hours worked instead of employment, this guarantees that  $\text{TFP}_t$  is not driven by time varying labor utilization (see Fernald, 2012, for details). Appendix A provides a more detailed description of the data and sources. Prior to estimation, we detrend all data series by regressing them on a linear time trend.

Our data sample covers the time period from 1984Q1 to 2007Q4. The starting point of our sample coincides with the start of the Great Moderation period which is generally associated with structural breaks in a number of macroeconomic time series (see e.g. Stock and Watson, 2005). In particular, a bulk of empirical evidence shows that the cyclical properties of (labor) productivity have also changed in the middle of the 1980s (see e.g. Galí and van Rens, 2010; Hagedorn and Manovskii, 2011; Galí et al., 2012a, among others). We choose 2007Q4 to be the end point of our sample due to start of the Great Recession.

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<sup>5</sup>We conduct our estimation exercise in MATLAB. As a starting point, we used the program `BVAR_FULL.m` associated to Koop and Korobilis (2010). This code can be downloaded from Gary Koop's department webpage [http://personal.strath.ac.uk/gary.koop/bayes\\_matlab\\_code\\_by\\_koop\\_and\\_korobilis.html](http://personal.strath.ac.uk/gary.koop/bayes_matlab_code_by_koop_and_korobilis.html).

## 2.2 Identification of Structural Shocks

We impose sign restrictions on impulse responses to identify structural shocks (see e.g. Faust, 1998; Canova and de Nicolo, 2002; Peersman, 2005; Uhlig, 2005).<sup>6</sup> We start with the linear mapping of the form:

$$\eta_t = B^{-1}\varepsilon_t \text{ with } \mathbb{E}[\eta_t] = 0 \text{ and } \mathbb{E}[\eta_t\eta_t'] = \Sigma_\eta, \quad (3)$$

where  $\eta_t$  denotes the structural shocks and  $\varepsilon_t$  stands for the reduced form residuals. Additionally, it holds that  $B = U\Sigma_\eta^{1/2}Q$ , where  $U\Sigma_\eta^{1/2}$  represents one Cholesky factor from our Bayesian estimation exercise. With the diagonal matrix  $\Sigma_\eta$ , we obtain mutually orthogonal and therefore structural shocks,  $\eta_t$ . Accordingly, for the variance-covariance-matrix of the reduced form model,  $\mathbb{E}[\varepsilon_t\varepsilon_t'] = \Sigma_\varepsilon$ , it follows that  $\Sigma_\varepsilon = U\Sigma_\eta U'$ . The rationale of the sign restriction approach is now, to find random matrices  $Q$ , so that candidate shocks,  $\eta_t$ , produce impulse response functions,  $\phi_{j,t+k} = A(L)^{-1}B_j\eta_t$ , meeting the imposed restrictions, where  $L$  denotes the lag operator. Drawing from a standard-normal density,  $\mathcal{N}(0, 1)$ , delivers some random matrix  $Z$ . Applying the QR decomposition to  $Z$  ultimately generates an ortho-normal matrix  $Q$ , so that  $QQ' = I$ . In principle, we are able to generate an infinite number of matrices  $Q$ . This implies a variety of matrices  $B$  for each Bayesian draw and therefore a different model for each  $Q$ .

As suggested by Galí et al. (2012b), we identify three types of macroeconomic disturbances, namely a supply shock, a demand shock, and a labor market shock. Although we are primarily interested in characterizing the TFP response to supply and demand shocks at a general level, we also identify the labor market shock since identifying a larger number of shocks helps to improve the identification (Paustian, 2007). Table 1 summarizes the restrictions we impose to identify the shocks.

Table 1: Imposed Sign Restrictions

	RGDP <sub>t</sub>	PRICES <sub>t</sub>	FFR <sub>t</sub>	EMPL <sub>t</sub>	TFP <sub>t</sub>	COMP <sub>t</sub>
Demand Shock	≤ 0	≤ 0	≤ 0			≤ 0
Supply Shock	≤ 0	≥ 0	≥ 0			≤ 0
Labor Market Shock	≤ 0	≥ 0	≥ 0			≥ 0

*Notes:* We require the sign restrictions to hold simultaneously for all three shocks. The horizon over which we constrain the impulse response functions is equal to  $k = 4$  quarters (see e.g. Uhlig, 2005; Peersman and Straub, 2009).

<sup>6</sup>Fabio Canova provides MATLAB codes for the implementation of sign restrictions. These can be downloaded from <http://www.crei.cat/people/canova/>. We used the program `SVAR_sign.m` for identification.

It is well accepted that output and prices move in the same direction after a demand shock, whereas supply shocks move the two variables into opposite directions (see e.g. Fry and Pagan, 2011). Although this restriction essentially suffices to disentangle supply and demand shocks, we also restrict the responses of the interest rate and real wage to improve the identification. Specifically, we restrict the interest rate to respond negatively after a demand shock and positively after a supply shock, whereas the real wage declines after either type of shock. Furthermore, the so called labor market shock exhibits almost the same restrictions as the supply shock. However, the distinctive feature of this shock is the real wage response, which is assumed to be counter-cyclical for the labor market shock. These restrictions are consistent with a wide range of DSGE models (see e.g. Erceg et al., 2000; Smets and Wouters, 2003) and also with Galí et al. (2012b).

As our main focus is the role of  $TFP_t$  for the transmission of supply and demand shocks, we do not restrict the response of  $TFP_t$ . We also leave the response of employment,  $EMPL_t$ , unrestricted, which allows us to remain agnostic with respect to labor productivity. In particular, the latter can be calculated as the difference between the responses of output and employment.

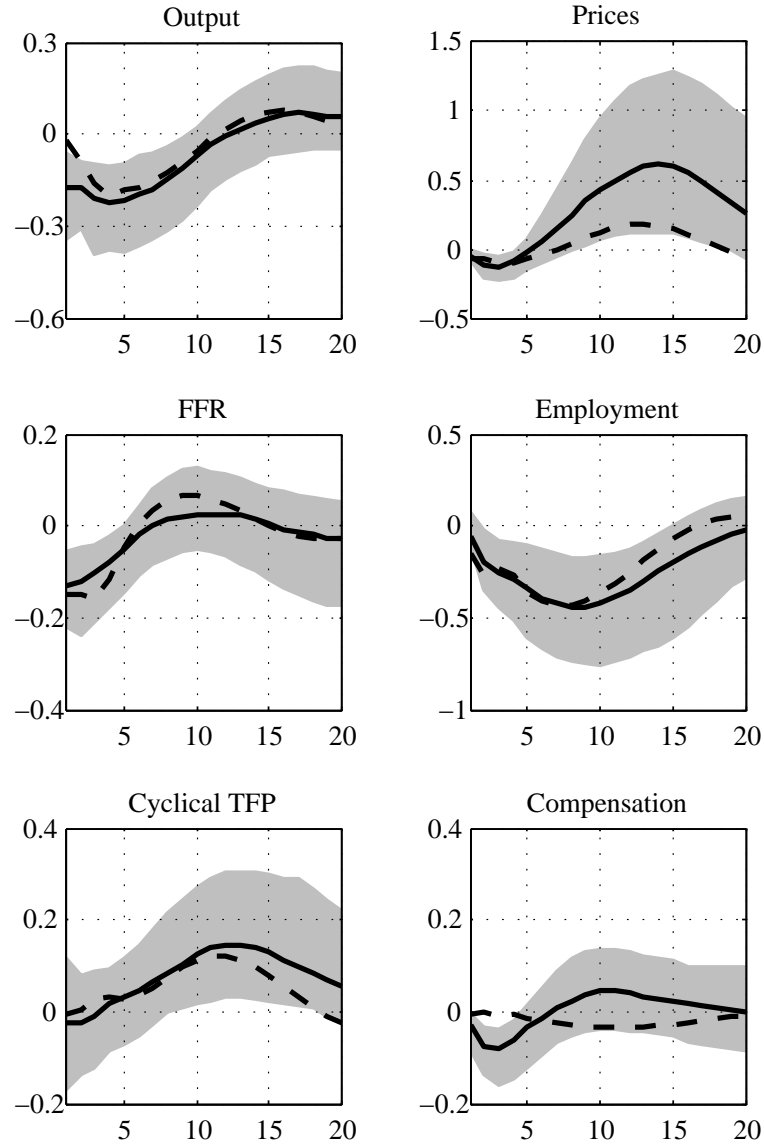
Interpreted through the lens of a structural DSGE model, the ultimate source of the identified demand shock is consistent with a number of disturbances, such as innovations to risk premia, consumer preferences, or government spending (see e.g. Smets and Wouters, 2003; Peersman and Straub, 2006; Galí et al., 2012b). Similarly, the supply shock may be either a price mark-up disturbance or an exogenous innovation to technology (see e.g. Peersman and Straub, 2006, 2009). The labor market shock could reflect a shock to the wage mark-up or to the labor supply (see e.g. Galí et al., 2012b). Since we are interested in how TFP generally responds to exogenous shocks, and not the shocks per se, we basically remain agnostic with respect to the precise sources of the identified shocks.

Fry and Pagan (2011) question the approach to present point estimates of the posterior as summarizing statistics for different models. They argue that evaluating e.g. the median impulse response functions does not imply that the impulse responses to an identified shock come from the same structural model. To solve this shortcoming of the median model, they propose a "*median target*" (see Fry and Pagan, 2011, p.950) solution. Following their suggestion, we also present the "*median target*" (see Fry and Pagan, 2011, p.950) solutions, by selecting the impulse responses of a single model, which minimize the standardized deviations from the median model.

## 2.3 Impulse Responses

Figure 1 reports impulse responses to a demand shock. The median responses are displayed by the solid lines and the shaded areas depict 16 and 84 percent percentiles.

Figure 1: Demand Shock



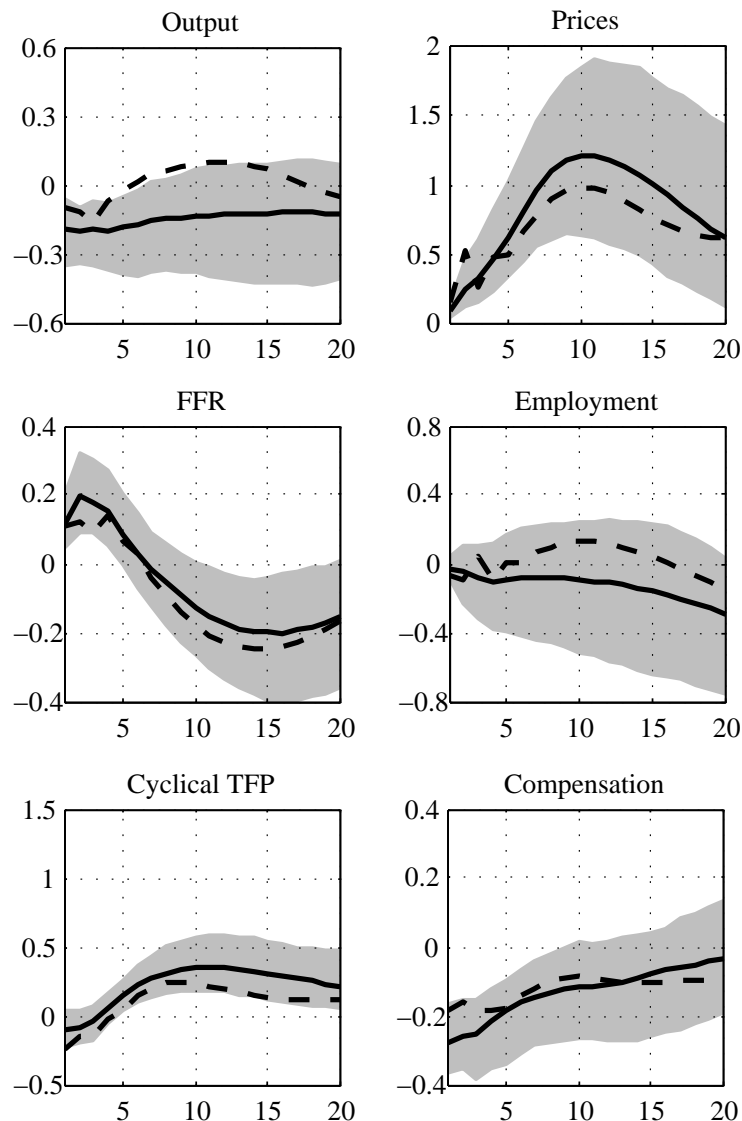
*Notes:* The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% percentiles of the posterior distribution and the dashed line denotes the respective "median target" (see Fry and Pagan, 2011, p.950) solution.

The dashed lines refer to the median target model. After an adverse demand shock output, prices, the Federal Funds rate and employment decline. These responses remain negative for between 5 quarters (Federal Funds rate, prices, and compensation) and 15 quarters (employment).



Overall, these responses are qualitatively in line with the existing literature. TFP, our variable of main interest, improves for around 11 quarters before it reverts back to the pre-shock level.

Figure 2: Supply Shock

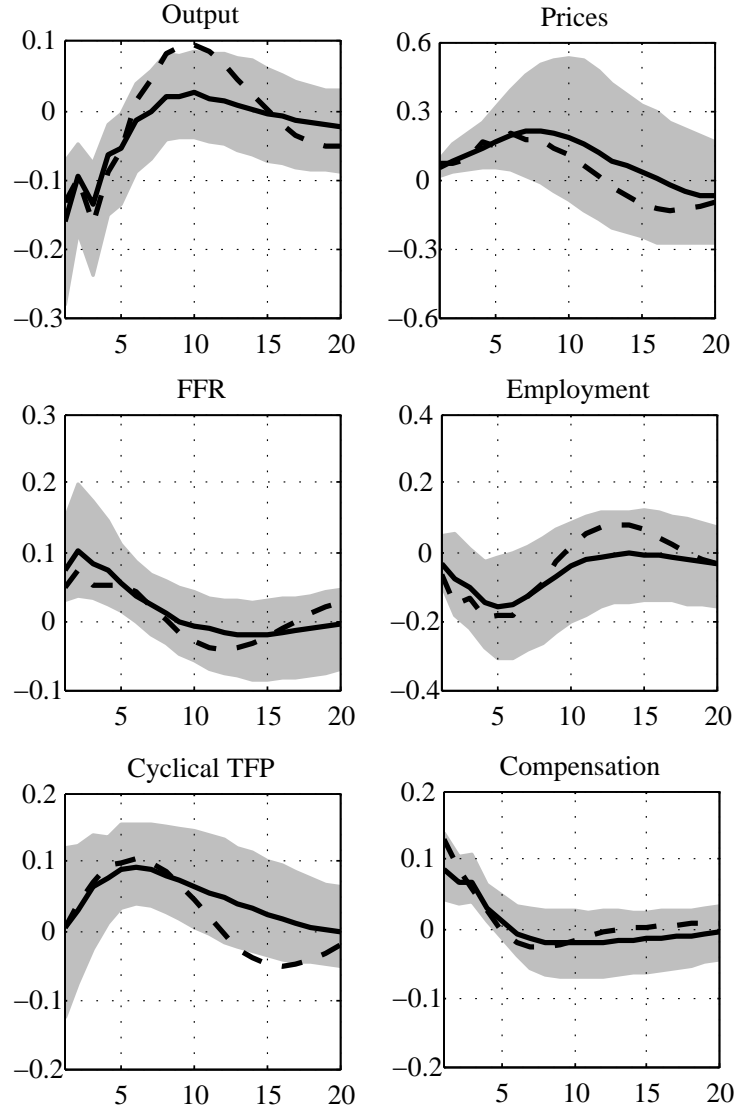


*Notes:* The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% percentiles of the posterior distribution and the dashed line denotes the respective "median target" (see Fry and Pagan, 2011, p.950) solution.

From Figure 2 we see that after a negative supply shock, output and prices move in opposite directions. The Federal Funds rate initially improves, but declines below zero after 6 quarters. While employment declines only slowly after the shock, compensation declines quickly. The response of TFP is slightly negative on impact, but turns positive after 2 quarters and improves until around 8 quarters after the shock.

For the labor market shock in Figure 3, we find similar results as for the supply shock. An exception is the real compensation response, which is restricted to react positively. The negative employment response is a bit more pronounced and significant for 2 quarters, the TFP response is insignificant on impact and stays positive for quarters 4 to 10.

Figure 3: Labor Market Shock



*Notes:* The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% percentiles of the posterior distribution and the dashed line denotes the respective "median target" (see Fry and Pagan, 2011, p.950) solution.

In summary, our empirical analysis provides evidence that TFP responds endogenously and significantly to all three identified shocks. In fact, we find that after contractionary (in terms of output) supply, demand and labor market shocks, TFP improves. To see if and how these TFP

dynamics influence business cycle fluctuations, we will now interpret these empirical findings through the lens of a DSGE model.

### 3 The Model

In this section, we discuss an augmented version of Galí et al. (2012b) with additional features such as labor effort, that will give rise to the notion of endogenous changes in TFP after shocks. We will then calibrate and simulate the model to see how endogenous fluctuations in TFP influence the transmission of shocks.

The composition of the firm-sector is standard. There exists a continuum of intermediate goods producers that operate under monopolistic competition as well as final good producers that are perfect competitors. Firms in the intermediate good sector produce by employing capital and labor services from households. Prices are set by the intermediate good sector either by indexation as in Christiano et al. (2005) or in a staggered fashion as in Calvo (1983). The model features a (large) representative household with a continuum of members that derive utility from consumption and disutility from labor supply. Labor services supplied by members are specialized and workers choose wages in order to maximize household utility, in contrast to individual utility.

In the remainder of this section, we present the optimization problems solved by households and firms and highlight our model modifications.<sup>7</sup>

#### 3.1 Household

As in Galí (2011), heterogeneity of household members is twofold. Individual members differ in the type of labor service  $s$  they supply as well as in the disutility they face when supplying these specialized services. However, individuals completely share their idiosyncratic income risks à la Merz (1995) and therefore choose the same consumption level,  $C_t$ , in every period  $t$ . The preferences of the (large) household read:

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left\{ \log(C_t - H_t) - \chi_t \Theta_t \int_0^1 \frac{N_t(s)^{1+\varphi}}{1+\varphi} ds - \frac{1}{1+\kappa} \int_0^1 \mathcal{E}_t(s)^{1+\kappa} ds - \mathcal{P}(\mathcal{E}_t(s)) Y_t^{-1} \right\}. \quad (4)$$

Preferences are separable with respect to the logarithmic consumption level,  $C_t$ , which is subject to external habit formation,  $H_t = h\bar{C}_{t-1}$ , and the fraction of employed type  $s$  workers,  $N_t(s)$ .  $\varphi \geq 0$  measures the elasticity of workers' labor supply related to real wage fluctuations and

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<sup>7</sup>For a description of our benchmark model in log-linearized form, we refer to the appendix in Galí et al. (2012b).

$\beta \in (0; 1)$  is the discount factor. The disturbance affecting the disutility of labor is denoted by  $\chi_t$ . An endogenous preference shifter  $\Theta_t$  is defined as  $\Theta_t = Z_t(\bar{C}_t - H_t)^{-1}$ , with  $Z_t = Z_{t-1}^{1-\nu}(\bar{C}_t - H_t)^\nu$ , where  $\nu$  is a scale parameter determining the wealth effect on household's labor supply decision. This feature is required to reconcile the "joint behavior of the labor force, consumption, and the wage over the business cycle" (see Galí et al., 2012b, p.333).

To account for (unobserved) time-varying labor effort  $\mathcal{E}_t(s)$  exerted by worker of type  $s$ , we enhance the utility function along two dimensions. On the one hand, we take into account that workers are not indifferent, how hard they have to toil. Thus, increasing the amount of effort,  $\mathcal{E}_t(s)$ , reduces household's period utility,  $U_t$ , and thus imposes a disutility.  $\kappa$  scales the intensity of this channel. On the other hand, households have an interest to supply effort as it reduces the probability  $\mathcal{P}(\mathcal{E}_t(s))$ , with  $\mathcal{P}(\mathcal{E}_t(s)) = \exp(-\mathfrak{F}\mathcal{E}_t(s))$  of being observed to shirk. We impose, that in equilibrium all working household members exert the same level of effort  $\mathcal{E}_t(s) = \mathcal{E}_t$ . As in Philippon (2006), we assume that monitoring by firms moves counter-cyclical to the state of the business cycle, i.e. monitoring is tight in recessions and loose in booms. Accordingly, households are willing to supply more effort when corporate governance is tight and vice versa. As a shortcut, we model that the intensity to monitor is inversely related to the output gap,  $Y_t^{-1}$ . The level of effort exerted is chosen optimally by the large household. The utility maximizing level of effort supplied by household balances the marginal benefits to exert effort,  $\mathcal{E}_t$ , to the marginal cost and is obtained from (4) and equals in equilibrium:

$$Y_t = \frac{\mathfrak{F}\mathcal{E}_t^{-\kappa}}{\exp(\mathfrak{F}\mathcal{E}_t)}, \quad (5)$$

or in log-linear terms:

$$\hat{\mathcal{E}}_t = -(\kappa + \mathfrak{F}\mathcal{E})^{-1}\hat{Y}_t. \quad (6)$$

Thus, in equilibrium (unobserved) labor effort is high in recessions and low in booms. The parameters  $\kappa$ ,  $\mathfrak{F}$  and the steady-state level of effort,  $\mathcal{E}$ , scale the quantitative importance of the effort channel. Unobserved effort will have a strong impact on the cycle, when its steady-state level is high (high  $\mathcal{E}$ ), the probability of punishment strongly decreases in the level of exerted effort (low  $\mathfrak{F}$ ), and when the disutility in effort is only mildly convex (low  $\kappa$ ).

The household budget constraint is standard as in Smets and Wouters (2007):

$$P_t(C_t + I_t - T_t) + \frac{B_t}{\epsilon_t^B(1 + R_t)} \leq B_{t-1} + \int_0^1 W_t(s)N_t(s)ds + R_t^K \tilde{K}_t - P_t \mathcal{J}(u_t)K_{t-1} + Div_t \quad (7)$$

$I_t$  stands for purchased investment goods.  $T_t$  are lump-sum taxes (or transfers) and  $Div_t$  represents profits, obtained from firms. The household holds bonds,  $B_t$ , issued by the government. These financial claims yield the risk-free (net) rate,  $R_t$ .  $\epsilon_t^B$  is a risk premium shock. Since risk premium shocks have been attributed to be one of the driving forces behind the Great Recession (see Galí et al., 2012a), we use this disturbance for later zero lower bound simulations. The household owns the capital stock,  $K_t$ , and rents it out to the intermediate goods producers. Adjusting the intensive margin of capital, namely capital utilization, is associated with cost,  $\mathcal{J}(\cdot)$ , where  $\mathcal{J}(\cdot)$  is a convex and increasing function, such that  $\mathcal{J}(1) = 0$  and  $\bar{u} = 1$  (see Christiano et al., 2005, p. 15).

The evolution of the capital stock,  $K_t$ , is along the lines of Christiano et al. (2005) and can be expressed as:

$$K_t = K_{t-1}(1 - \delta) + \epsilon_t^I I_t \left[ 1 - S \left( \frac{I_t}{I_{t-1}} \right) \right]. \quad (8)$$

Capital depreciates with a rate of  $\delta$ . Investment,  $I_t$ , is subject to adjustment cost,  $S \left( \frac{I_t}{I_{t-1}} \right)$ . The latter depend on the change in investment and satisfy the following functional characteristics  $S(1) = S'(1) = 0$  and  $S''(1) > 0$ . For the exogenous shock,  $\epsilon_t^I$ , it holds that  $\ln(\epsilon_t^I) = \ln(\epsilon_{t-1}^I)^{\rho_I} + \eta_t^I$ , where  $\eta_t^I \sim \mathcal{N}(0, \sigma_I)$ .

### 3.2 Firms Producing Intermediate Goods

Intermediate goods producers,  $Y_t(i)$ , face the following restriction in production:

$$Y_t(i) = \epsilon_t^A \tilde{K}_t(i)^\alpha \tilde{N}_t(i)^{1-\alpha} - \Phi = \left\{ \epsilon_t^A u_t(i)^\alpha \mathcal{E}_t(i)^\psi \right\} \left\{ K_{t-1}(i)^\alpha N_t(i)^{1-\alpha} \right\} - \Phi. \quad (9)$$

Thus, firms adjust their production levels through variations either in the effectively used capital stock,  $\tilde{K}_t(i) = u_t(i)K_{t-1}(i)$ , where  $u_t(i)$  is the utilization rate of capital or the effectively used labor stock,  $\tilde{N}_t = \mathcal{E}_t(i)^\psi N_t(i)^{1-\alpha}$ , which is a composite of the (observed) employment stock,  $N_t(i)$ , and the (unobserved) labor effort,  $\mathcal{E}_t$  (see Galí and van Rens, 2010, p. 11, for the concept of "effective labor"). The parameter  $\psi$  measures the scale elasticity of effort and  $\alpha$  measures the scale elasticity of capital. The technology shock,  $\epsilon_t^A$ , follows an AR(1)-process. Thus, in line

with the empirical counterpart from (2), the TFP measure is a weighted composite of  $\epsilon_t^A$ ,  $u_t(i)$  and  $\mathcal{E}_t(i)$  and  $\Phi$  reflects fixed costs in production.

The cost function of intermediate good firm  $i$  is standard:

$$\text{Cost}_t(i) = R_t^K \tilde{K}_t(i) + W_t N_t(i). \quad (10)$$

Nominal cost,  $\text{Cost}_t(i)$ , depend on factor inputs valued with their economy wide factor prices, the rental rate of capital,  $R_t^K$ , and the real wage,  $W_t$ , respectively. Firms in the intermediate good sector solve the standard cost minimization problem and minimize (10) subject to the production technology from (9). Accordingly, a log-linear approximation of marginal cost reads:

$$\widehat{MC}_t = \alpha \hat{r}_t^K + (1 - \alpha) \hat{w}_t - \hat{\epsilon}_t^A - \psi \hat{\mathcal{E}}_t, \quad (11)$$

The first two arguments are the well known (real) factor prices  $\hat{r}_t^K$  and  $\hat{w}_t$ , weighted by factor shares  $\alpha$  and  $(1 - \alpha)$ . The parameter  $\psi$  scales the quantitative importance of effort for the cyclical component of marginal cost (see e.g. Galí and van Rens, 2010). Qualitatively increasing effort lowers the marginal cost of production as effort operates like a productivity shock from the perspective of the firm.

The price setting behavior of firms is standard. Each period, a fraction  $\theta_P$  of producers is not able to optimize prices as in Calvo (1983), but allowed to partially index them to last period's price inflation as in Smets and Wouters (2003). The first order condition resulting from firms' price-setting problem determines the price set by optimizers,  $P_t^*(i)$ :

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_P)^k \left\{ \lambda_{t+k} Y_{t+k}(i) \left[ \frac{P_t^*(i)}{P_t} \left( \frac{(P_{t-1+k}/P_{t-1})^{\gamma_P}}{P_{t+k}/P_t} \right) - (1 + \lambda_{P,t+k}) MC_{t+k} \right] \right\}. \quad (12)$$

As a result of monopolistic competition in the intermediate goods sector, firm  $i$  sets prices with a time-varying gross mark-up,  $1 + \lambda_{P,t}$ , over marginal cost,  $MC_t$ .  $\gamma_P$  determines the degree of indexation to the aggregate price level,  $P_t$ , and therefore the sluggishness of gross price inflation,  $\Pi_t = \frac{P_t}{P_{t-1}}$ .  $\lambda_t$  measures the consumption Lagrangian.

### 3.3 Final Good Packers

Perfectly competitive final good producers purchase units of intermediate goods  $i \in [0, 1]$  and bundle them according to the following technology:

$$Y_t = \left[ \int_0^1 Y_t(i)^{\lambda_{P,t}^{-1}} di \right]^{\lambda_{P,t}}, \quad (13)$$

where  $Y_t(i)$  denotes the input of intermediate good  $i$ . Cost minimization implies that the demand for good  $i$  is subject to the following demand schedule:

$$Y_t(i) = \left( \frac{P_t(i)}{P_t} \right)^{1+\lambda_{P,t}^{-1}} Y_t. \quad (14)$$

Given zero profits in equilibrium in the final good sector, the following relationship between the price of the final good and the price of intermediate goods holds:

$$P_t = \left[ \int_0^1 P_t(i)^{-\lambda_{P,t}^{-1}} di \right]^{-\lambda_{P,t}}. \quad (15)$$

### 3.4 Labor Market

Wages are set within staggered contracts as in Erceg et al. (2000). A Calvo (1983) lottery hereby decides, whether the nominal wage of type  $s$  worker can be optimally adjusted. The probability for not being able to optimize is  $\theta_W$ . Additionally, partial indexation to past period's average price inflation rate in a backward looking Smets and Wouters (2003) fashion, i.e.  $W'_t(s)/W'_{t-1}(s) = \Pi_{t-1}^{\gamma_P}$ , where  $\gamma_P \in [0; 1]$ , takes place.

Given a demand schedule for their type of labor service, optimizing workers negotiate the nominal wage,  $W_{t|t-k}^*$ , so as to maximize the utility of the household as opposed to individual welfare. The notation  $t|t-k$  indicates that there has been no optimization of these workers' wages for a time interval of  $k$  periods. The respective first order condition of (wage) optimizers' program is given by:

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\beta \theta_W)^k \left\{ \frac{N_{t+k|t}}{C_{t+k}} \left[ \frac{W_{t+k|t}^*}{P_{t+k}} - \left( \frac{\epsilon_{t+k}^W}{\epsilon_{t+k}^W - 1} \right) \chi_{t+k} \Theta_{t+k} (\bar{C}_{t+k} - H_{t+k}) N_{t+k|t}^{\varphi} \right] \right\} = 0. \quad (16)$$

Due to monopolistic competition in the labor market, wages are set above the marginal rate of substitution,  $\chi_t \Theta_t (\bar{C}_t - H_t) N_{t|t-k}^{\varphi}$ . The time-varying natural mark-up in the flex-price economy

is  $\mathcal{M}_{w,t}^{\text{nat}} = \epsilon_t^W / (\epsilon_t^W - 1)$ , where  $\epsilon_t^W$  defines the elasticity of substitution between differentiated types of labor (see Galí et al., 2012b). For the overall wage level,  $W_t$ , the mark-up is:

$$\mathcal{M}_{w,t} = \frac{W_t/P_t}{\chi_t Z_t N_{t|t-k}^\varphi}, \quad (17)$$

on average. Following the footsteps of Galí (1996, 2011), we are now able to make a precise statement about involuntary unemployment. A necessary condition that a household member will supply his type  $s$  labor service is a real wage exceeding or at least equaling his disutility from work (measured in consumption goods):

$$\frac{W_t(s)}{P_t} = \chi_t Z_t L_t(s)^\varphi. \quad (18)$$

This equality in conjunction with  $L_t = \int_0^1 L_t(s) ds$  defines the labor force,  $L_t$ . Whenever the economy wide labor force,  $L_t$ , and the employment rate diverge, unemployment,  $\mathcal{U}_t$ , arises. The latter can easily be approximated by  $\mathcal{U}_t = L_t/N_t$ . Combining the last expression with (17) and (18), delivers the following result:

$$\mathcal{M}_{w,t} = \mathcal{U}_t^\varphi. \quad (19)$$

Thus, non-competitive wage mark-up's,  $\mathcal{M}_{w,t}$ , can be identified as the driving force behind fluctuations of the unemployment rate,  $\mathcal{U}_t$ , in the economy.

### 3.5 Government Sector

Monetary policy is subject to a standard non-negativity restriction for the policy instrument (see Christiano et al., 2011).

$$R_t = \max (Z_t ; 0). \quad (20)$$

As long as the zero lower bound on the nominal interest rate is not binding, the central bank follows an empirically motivated instrument rule as in Smets and Wouters (2007):

$$Z_t = \beta^{-1} \left\{ \left( \frac{1 + Z_{t-1}}{1 + \bar{Z}} \right)^\rho \left( \frac{\Pi_t}{\bar{\Pi}} \right)^{\phi_\Pi(1-\rho)} \left( \frac{Y_t}{Y_t^{\text{nat}}} \right)^{\phi_Y(1-\rho)} \left( \frac{Y_t}{Y_{t-1}} \right)^{\phi_{\Delta Y}} \left( \frac{Y_t^{\text{nat}}}{Y_{t-1}^{\text{nat}}} \right)^{-\phi_{\Delta Y}} \epsilon_t^Z \right\} - 1, \quad (21)$$

where  $\bar{Z}$  is the steady-state net interest rate. With the simplifying assumptions of a zero growth



rate in productivity and zero steady-state inflation, i.e.  $\bar{\Pi} = 1$ , it holds that  $\bar{Z} = (\beta^{-1} - 1)$ . According to (21), the central bank engages in interest rate smoothing, inflation and output stabilization, and takes care of changes in the conventional and the natural output level.  $\rho$ ,  $\phi_{\Pi}$ ,  $\phi_Y$  and  $\phi_{\Delta Y}$  determine the relative importance of the respective policy objective.  $\epsilon_t^Z$  is a monetary policy shock, where  $\ln(\epsilon_t^Z) = \ln(\epsilon_{t-1}^Z)^{\rho_Z} + \eta_t^Z$  and  $\eta_t^Z \sim \mathcal{N}(0, \sigma_Z)$ .

Fiscal policy has to satisfy the following sequence of governmental budget constraints:

$$\frac{B_t}{(1 + R_t)} + P_t T_t = B_{t-1} + P_t G_t, \quad (22)$$

where  $G_t$  denotes government spending and  $B_{t-1}$  is accumulated past debt. Spending can be financed either by lump-sum taxes,  $T_t$ , or by issuing new bonds,  $B_t$ .  $(1 + R_t)^{-1}$  is the price of current debt.

### 3.6 Market Clearing

Using  $\tilde{K}_t(i) = \int \tilde{K}_t(i) di$  and  $N_t = \int N_t(i) di$ , we finally obtain the subsequent resource constraint (see Smets and Wouters (2007)):

$$Y_t = C_t + I_t + G_t + \mathcal{J}(u_t)K_{t-1}. \quad (23)$$

## 4 Calibration and Simulation

In this section, we describe our calibration strategy and present simulation results.

### 4.1 Calibration

As our baseline model builds on Galí et al. (2012b), we draw on the mode estimates of their benchmark estimation for almost all parameters (see Table 2). We deviate from their results with respect to the discount factor and the growth rate of price inflation. As common praxis in the zero lower bound literature (see e.g. Christiano et al., 2011), we set  $\beta = 0.99$  and  $\bar{\Pi} = 1$ , which implies a steady-state (net) interest rate of approximately 4 percent per annum. However, describing labor effort, we introduce three parameters,  $\psi$ ,  $\kappa$  and  $\mathfrak{F}$ , which cannot be readily calibrated. To choose values for these parameters, we match the standard deviation of the quarterly growth rate of our empirical TFP series ( $\sigma^{TFP} = 0.58$ ) with our model's counterpart.<sup>8</sup> We argue, that parts of the exogenous productivity shock in the model,  $\epsilon_t^A$ , could be explained by

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<sup>8</sup>Galí and van Rens (2010) target the relative volatility of employment and output in their calibration strategy. As our primary focus is on the role of TFP for shock transmission, it is straightforward to use the second moment of TFP in our case.

the introduction of endogenous labor effort. When estimating the three introduced parameters, we therefore re-estimate the persistence and standard deviation of the productivity shock. The results of this calibration exercise can be found in Table 3.

Table 2: Model Calibration

Parameter	Value	Description
$\beta$	0.99	Steady-state discount factor
$\bar{\Pi}$	1.00	Steady-state (gross) price inflation
$\alpha$	0.17	Scale elasticity of capital
$\delta$	0.025	Quarterly depreciation rate
$\theta_P$	0.58	Calvo lottery for prices
$\gamma_P$	0.26	Indexation of prices
$\theta_W$	0.47	Calvo lottery for wages
$\gamma_W$	0.16	Indexation of wages
$\mathcal{M}_p$	1.74	Steady-state mark-up: Prices
$\mathcal{M}_w$	1.18	Steady-state mark-up: Wages
$h$	0.78	Degree of habit formation
$\varphi$	3.99	Inverse Frisch elasticity
$\nu$	0.02	Scale parameter for consumption externality
$\phi$	0.57	Elasticity of capital utilization cost
$\Psi$	4.09	Elasticity of capital adjustment cost
$\rho$	0.85	Taylor rule: Interest rate smoothing
$\phi_\Pi$	1.91	Taylor rule: Inflation stabilization
$\phi_Y$	0.15	Taylor rule: Output gap stabilization
$\phi_{\Delta Y}$	0.24	Taylor rule: Reaction to changes in output gap

*Notes:* The table displays mode estimates of model parameters from the estimation in Galí et al. (2012b, p.340).

In line with our prior intuition, we find a modest decline in the importance of the productivity shock. With the implementation of effort,  $\rho_A$  declines from 0.98 to 0.92 and  $\sigma_A$  reduces from 0.41 to 0.38. At this point, however, it is difficult to evaluate the estimated values of  $\psi$ ,  $\kappa$  and  $\mathfrak{F}$  as we do not find much empirical or theoretical work, which could give us insight about these parameters.<sup>9</sup>

Table 3: Estimated Parameters

Parameter	Value	Description
$\psi$	0.469	Elasticity of output with respect to labor effort
$\kappa$	1.874	Disutility of labor effort
$\mathfrak{F}$	0.473	Scale parameter in probability function
$\sigma_A$	0.381	Standard deviation of productivity shock
$\rho_A$	0.918	Persistence of productivity shock

<sup>9</sup>A notable exception is Galí and van Rens (2010).

## 4.2 Simulation

To study the role of endogenous movements in TFP, we subject the model to two types of adverse shocks. Concerning the demand side of the economy, we analyze a risk premium shock and for the supply side, we simulate a price mark-up disturbance.

Figure 4: Price Mark-Up Shock

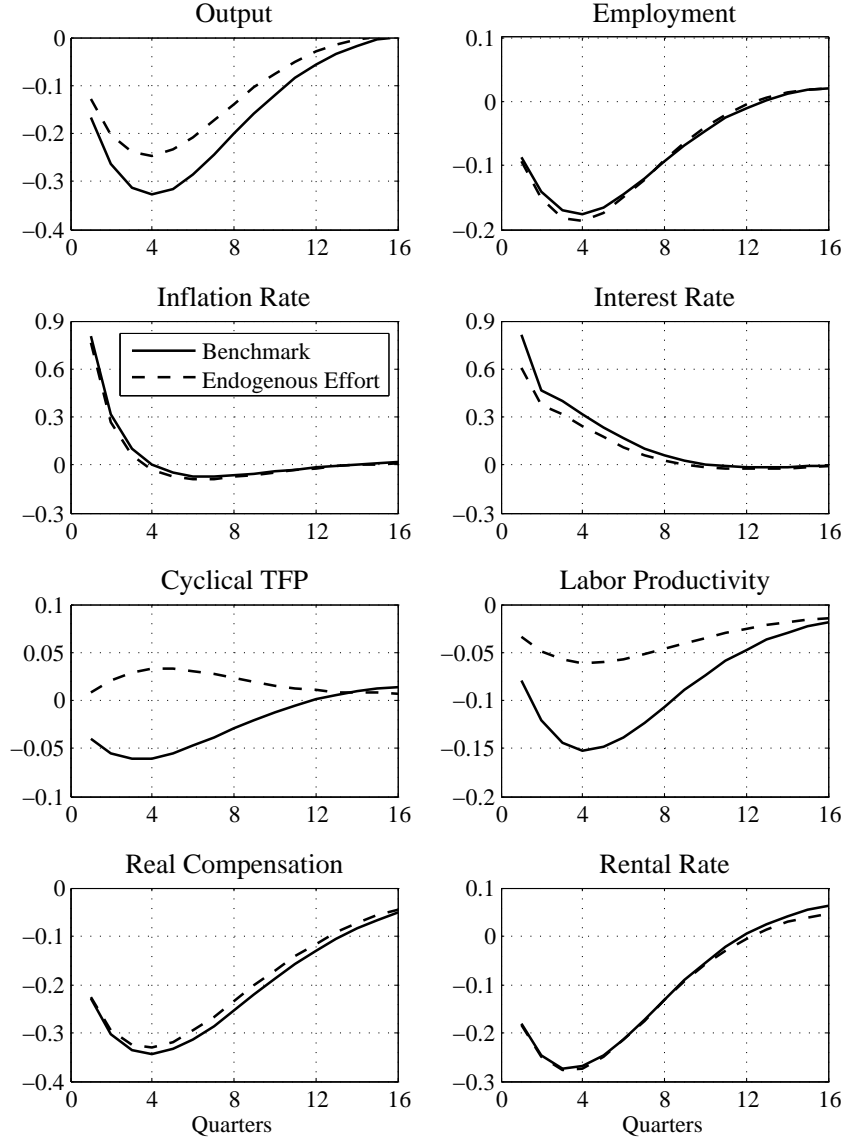


Figure 4 shows the responses to a price mark-up shock for a standard model without endogenous responses of TFP and for the model incorporating endogenous movements in TFP. We see that regardless of the TFP dynamics, output declines after an adverse price mark-up shock. However, the decline is less pronounced once we allow TFP to improve endogenously in the

model. Intuitively, the higher productivity allows firms to keep up production.<sup>10</sup> Along with the decline in output, employment also declines. The reduction is more pronounced when TFP improves, which shows that the relatively higher output is due to higher TFP. This higher TFP induces firms, given the demand conditions, to reduce labor demand. Quantitatively, however, TFP dynamics play only a minor role for employment. We also see that the increase in inflation is slightly less pronounced when TFP increases, although only marginally. The rise in the interest rate is also less pronounced in the variant of the model with endogenous TFP.

Overall, endogenously improving TFP dampens the impact of the adverse mark-up shock on output and also on inflation, while the decline in employment is slightly amplified. Intuitively, higher TFP allows firms to reduce labor demand while still keeping up activity to a greater extent and at lower cost. In other words, the TFP improvement lowers inflationary pressure, which leads to a less severe monetary tightening. The smaller rise in the interest rate, in turn, weakens aggregate demand to a lesser extent and thereby reduces the magnitude of the downturn. Note that higher TFP basically reduces the decline in output through two channels. First, *directly*, since higher productivity allows firms to increase output even without increasing labor input. And second, *indirectly*, since relatively lower marginal cost translate into lower inflation and a relatively small increase in the interest rate, which also limits the decline in output by stimulating demand.

For the risk premium shock, we consider two experiments. In the first experiment, the simulated increase in the asset premium is relatively weak. In particular, weak enough such that the nominal interest rate remains strictly positive. In the second experiment, the risk premium shock is strong enough to drive the nominal interest rate into the zero lower bound.<sup>11</sup>

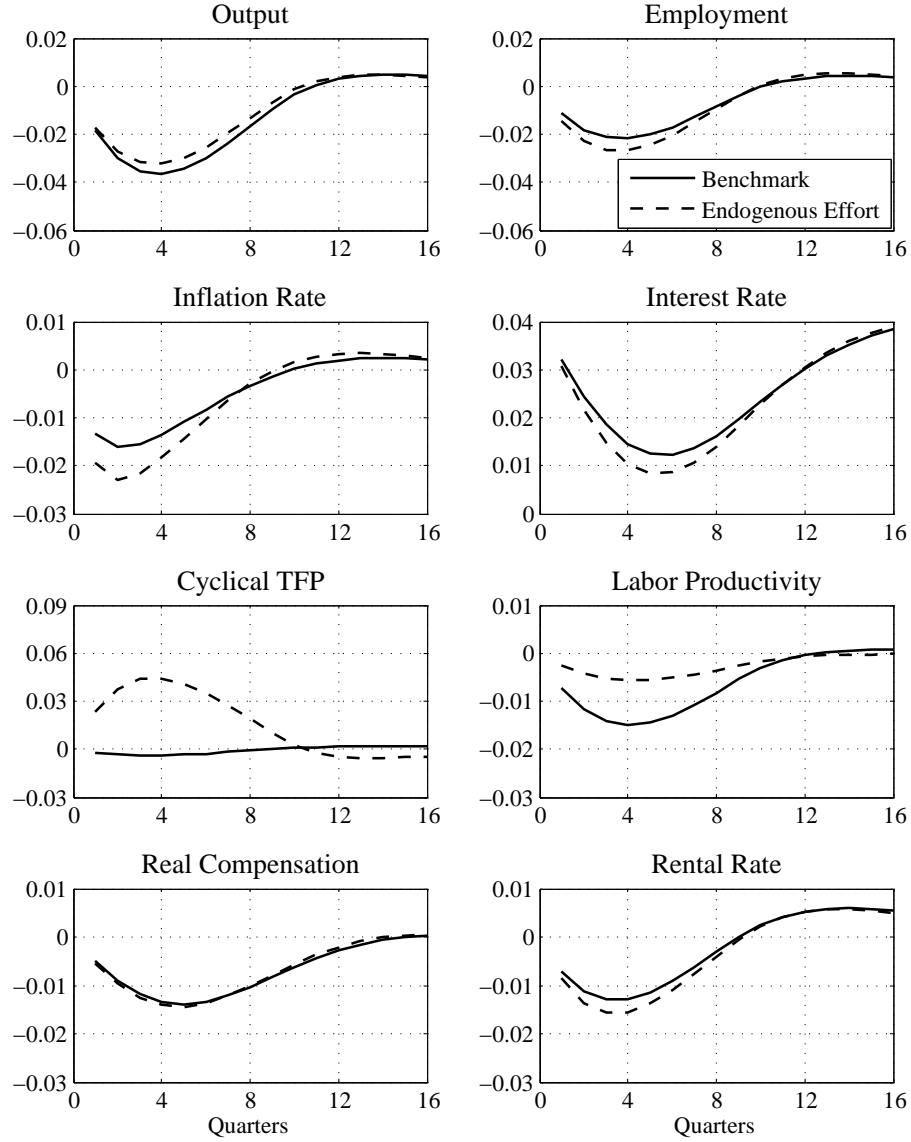
Figure 5 shows the responses to the weak risk premium shock. As in the case of the price mark-up shock, the output response is muted and the employment response is larger when we allow TFP to improve endogenously. Due to the disinflationary effect of higher TFP, the decline in the inflation rate is amplified and the interest rate declines more strongly due to the same logic as in the case of the mark-up shock. In short, the downturn in economic activity is again cushioned, *directly* and *indirectly*, by higher TFP at the expense of a more pronounced decline in employment.

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<sup>10</sup>Note that in the benchmark model, TFP also changes endogenously and declines slightly. This is due to the endogenous reaction of the capital utilization rate, which is one component of the TFP measure. Though, the negative effect of capital utilization is overcompensated by increased labor effort in the endogenous TFP economy, so that TFP turns positive in this case.

<sup>11</sup>In both cases, we consider a shock period of 8 quarters for the risk premium shock. This is implemented by a deterministic simulation exercise as in Christiano et al. (2011).

Figure 5: Weak Risk Premium Shock

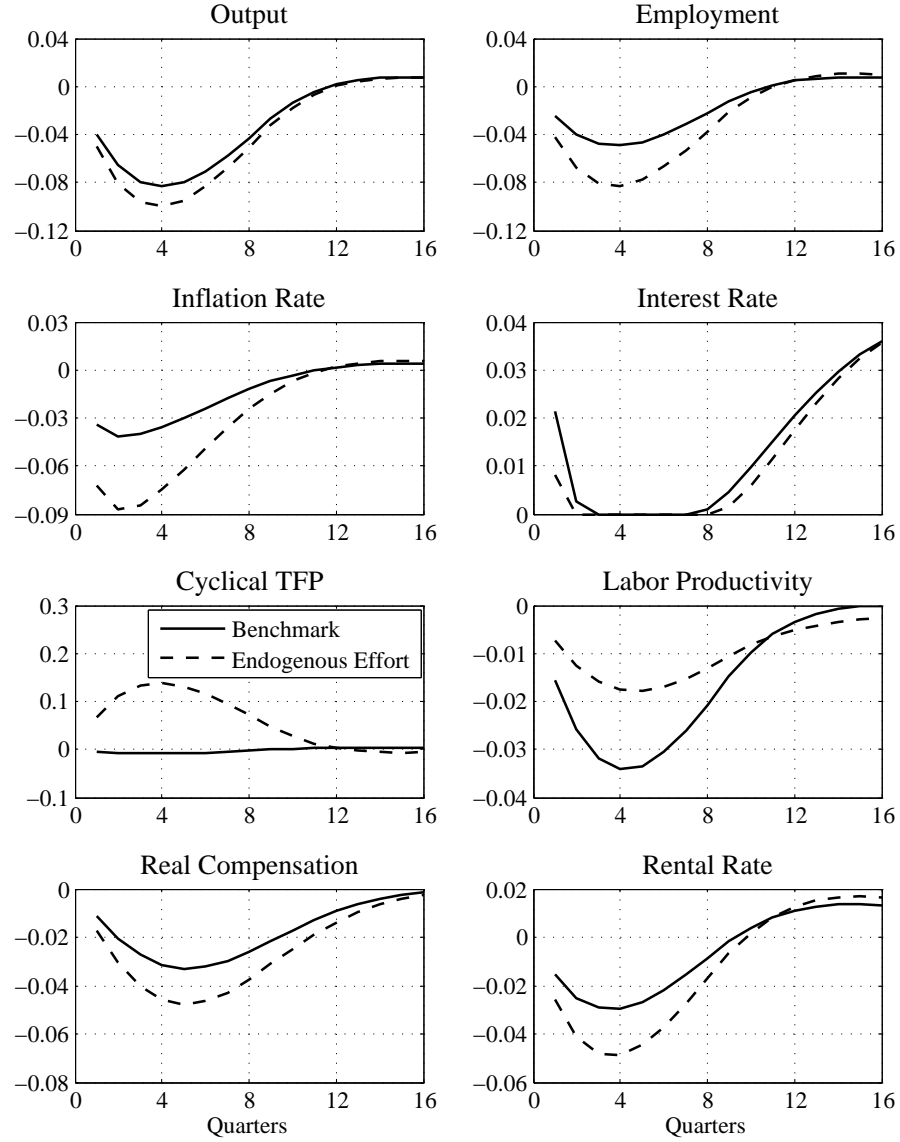


From Figure 6, we see that these conclusions change once we allow the risk premium shock to be large enough to make the zero lower bound on the nominal interest rate binding. In this case, both employment as well as output decline stronger when TFP improves in response to the shock. The reason is that the disinflationary effect of rising TFP, which, as long as the nominal interest rate remains positive, allows the central bank to implement a policy which is more expansionary,<sup>12</sup> and by doing so counteracts the effect of the adverse shock on output. This indirect channel is no longer active once the interest rate hits the zero lower bound. Here,

<sup>12</sup>Or less contractionary, in the case of an adverse supply shock.

the real interest rate increases, due to the disinflationary effect of higher TFP, and puts additional downward pressure on demand. Consequently, the adverse effects of the initial shock are amplified.

Figure 6: Strong Risk Premium Shock



## 5 Summary

In this paper, we analyze how endogenous fluctuations in TFP triggered by variations in labor effort influence the dynamics after adverse shocks hit the economy. At first glance, productivity improvements may seem beneficial and may be seen as a first step towards the recovery. Our

analysis provides some support for this view since the output decline is generally less severe once we allow for endogenous improvements in TFP. Albeit in this case, we find TFP improvements amplify the negative response of employment, which is due to a strong increase in the intensive margin of labor, labor effort. This contractionary effect on employment caused by TFP improvements is in stark contrast to the predictions of a standard RBC model, but in line with the predictions of a sticky price model.

We also find that if the economy is operating at the zero lower bound on the nominal interest rate, then the output decline becomes more pronounced once we allow for endogenous improvements in TFP arising from enhanced labor effort. The reason for this strong amplification is the additional disinflationary effect that originates from the higher TFP.

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## A Data and Sources

We use six quarterly time series for the US in our BVAR model. All variables enter the model as log-levels except the interest rate, which is expressed in percent.  $RGDP_t$  and  $EMPL_t$  are normalized by the Civilian Noninstitutional Population.  $COMP_t$  is deflated by the GDP price deflator,  $PRICES_t$ , and divided by our employment measure, to obtain the compensation per employee series. Concretely, we used the following data and sources:

- **Aggregate Output:** Real Gross Domestic Product, 1 Decimal (GDPC1), Billions of Chained 2005 Dollars, Quarterly, Seasonally Adjusted. Source: U.S. Department of Commerce: Bureau of Economic Analysis.
- **Employment Measure:** Civilian Employment (CE16OV), Thousands of Persons, Quarterly, Seasonally Adjusted. Source: U.S. Department of Labor: Bureau of Labor Statistics.
- **Price Deflator:** Gross Domestic Product: Implicit Price Deflator (GDPDEF), Index 2005=100, Quarterly, Seasonally Adjusted. Source: U.S. Department of Commerce: Bureau of Economic Analysis.
- **Compensation:** Compensation (PRS85006063), Nonfarm Business Sector (All Persons), Quarterly, Seasonally Adjusted. Source: U.S. Department of Labor: Bureau of Labor Statistics.
- **Total Factor Productivity:** Quarterly-TFP series for the U.S. Business Sector, produced by John Fernald. Source: Federal Reserve Bank of San Francisco.
- **Interest Rate:** Federal Funds Rate (FEDFUNDS), Percent, Quarterly. Source: Board of Governors of the Federal Reserve System.