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Total Factor Productivity and the Propagation of Shocks; Empirical Evidence and Implications for the Business Cycle

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Total Factor Productivity and the Propagation of Shocks; Empirical Evidence and Implications for the Business Cycle

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Abstract

Using a sign restrictions approach, we document that total factor productivity (TFP) moves counter-cyclically in the aftermath of supply and demand side shocks. To interpret our empirical results, we conduct counter-factual simulations, based on a New Keynesian DSGE model in which TFP fluctuates endogenously due to time-varying labor effort. The simulations show that the decline in the output gap, following an adverse shock, is dampened by the endogenously improving TFP as long as the nominal interest rate remains strictly positive during the downturn. If the economy hits the zero lower bound, the decline in the output gap is amplified when TFP improves endogenously.

Keywords: TFP, labor effort, zero lower bound

JEL codes: E24, E30, E32, E40.

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1 Introduction

In business cycle models, exogenous shocks to total factor productivity (TFP) are typically viewed as a driving force behind cyclical fluctuations. In fact, in real business cycle theory it holds that exogenous TFP shocks are the main driving force behind business cycles. In this paper, we go beyond this interpretation of TFP as an exogenous source of shocks and study the role of TFP as part of the transmission mechanism. In other words, we study the endogenous response of TFP to identified macroecononomic shocks and explore its implications for the business cycle. We proceed in two steps: First, we empirically characterize the response of TFP to structural shocks using a sign restrictions approach as in Faust (1998) and Uhlig (2005). And second, we study the implications of endogenously fluctuating TFP through simulation exercises based on a modified version of the New Keynesian model of Galí et al. (2012b).

In our empirical analysis, we document that TFP starts to rise quickly after adverse supply and demand shocks, which result in declining output. Note that this counter-cyclicality of TFP may seem at odds with the well-documented observation that TFP as well as labor productivity are pro-cyclical in the raw data. Starting with Solow (1964), pro-cyclical labor productivity has been interpreted as an indication for labor hoarding in the sense that profit-maximizing firms may refrain from adjusting employment due to adjustment costs and as a consequence, labor productivity and also TFP, if the latter is defined to capture the intensity with which inputs are employed, are pro-cyclical.[1] In fact, at a descriptive level, TFP is also positively correlated with detrended GDP in our data set.[2] Nevertheless, the endogenous response of TFP to identified shocks is generally in the opposite direction of GDP after some quarters.

While our empirical results do not provide much support for a dominant role of factor hoarding, the evidence is consistent with the view that firms implement productivity enhancing measures in a counter-cyclical way. For instance, Philippon (2006) argues that corporate governance improves counter-cyclically, which plausibly also raises productivity, and Berger (2012) emphasizes that corporate restructuring also occurs counter-cyclically. The idea that improvements in productivity occur counter-cyclically is also closely related to the debate on whether recessions should generally be viewed as periods during which outdated technologies are eliminated and resources are shifted to more productive uses (see e.g. Schumpeter, 1934). This view

[1] Galí and van Rens (2014) argue that due to lower adjustment costs, the pro-cyclicality of labor productivity has declined over time.

[2] The contemporaneous correlation between the log difference of real GDP and our TFP measure (both measured on a quarterly frequency) is 0.64. As we will show in Section 2, this positive correlation is likely to be the result of supply shocks, which give rise to a pro-cyclical effect in the short-run.

is controversial and a number of papers emphasize adverse effects of recessions on the allocation of factors. Caballero and Hammour (2005) point out that an improvement of the allocation requires that factors are shifted from less to more productive occupations and although job destruction, which basically makes resources available for better uses, increases during recessions, job creation slows down.[3] However, even if labor is reallocated only with substantial time lags, productivity may increase in the short-run if it is primarily the most productive worker who is retained during recessions (Berger, 2012).[4]

To provide a more structural interpretation of our empirical results, we study the business cycle implications of endogenously improving TFP during downturns in a New Keynesian model. We model counter-cyclical fluctuations in TFP in a simple and tractable way by assuming that corporate restructuring gives rise to counter-cyclical incentives for providing higher effort at the household level. Despite the focus on workers' incentives, we interpret this mechanism primarily as a short-cut to model the impact of counter-cyclical restructuring in a broader sense.

Model simulations show that counter-cyclical fluctuations in TFP generally attenuate the drop in output after adverse shocks. However, the decline in employment is amplified since the higher labor effort serves as a substitute for employment during a downturn. 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, which originates from the higher TFP, increases the real interest rate and dampens demand. In this sense, our paper is closely related to Eggertsson (2010), Eggertsson et al. (2014), and Fernández-Villaverde et al. (2014) who point out potentially adverse consequences of supply side improvements when the economy is operating at the zero lower bound. In contrast to these two contributions, we focus on endogenously improving TFP, rather than exogenous changes due to e.g. structural reforms.

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

[3]See Barlevy (2002), Barlevy (2003) and Ouyang (2009) for alternative views on how recessions may adversely influence the allocation of resources. Beaudry et al. (2014) argue that although past over-accumulations are corrected during recessions, which should improve the allocation, inefficiencies may still emerge due to the increase in uncertainty associated with re-allocations.

[4]Jaimovich and Siu (2012) show that routine, middle-skill jobs are lost especially during downturns. See Field (2003) for a discussion of labor hoarding and selective firing during the Great Depression.

2 Data and Estimation

We consider a reduced form VAR model:

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

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 $j = 1, ..., p$ and ε_t are the reduced form residuals. Estimation and inference is performed by Bayesian techniques, which is a natural approach to implement sign restrictions on impulse response functions (see e.g. Granziera et al., 2011; Uhlig, 2005) and allows us to take parameter uncertainty into account. We use a Normal-Wishart prior with $1,000$ draws as in Koop and Korobilis (2010).

The vector of endogenous variables includes the log of per capita real GDP, $\texttt{RGDP}_t$, log employment, $\texttt{EMPL}_t$, the Federal Funds rate, $\texttt{FFR}_t$, the log price level, $\texttt{PRICES}_t$, the log of real compensation per employed worker, $\texttt{COMP}_t$,[5] and the log level of TFP, $\texttt{TFP}_t$:

$$X_t = [\ \texttt{RGDP}_t\ \texttt{PRICES}_t\ \texttt{FFR}_t\ \texttt{COMP}_t\ \texttt{EMPL}_t\ \texttt{TFP}_t\ ]'. \tag{2}$$

We use the TFP series from Fernald (2012), who generates this series based on a growth accounting exercise. Since hours worked are used for the labor input, this series has the advantage that variations of labor input at the intensive margin are purged from this series.[6]

We estimate the VAR on quarterly US data ranging from 1984Q1 to 2007Q4.[7] The starting point of our sample coincides with the start of the Great Moderation period, which is 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, 2014; Hagedorn and Manovskii, 2011; Galí et al., 2012a, among others). We choose 2007Q4 to be the end point of our sample due to the start of the Great Recession. Prior to estimation, we detrend all data series by regressing them on a linear time trend. We set the lag-length to $p = 3$ lags, which minimizes the final prediction error.[8]

[5] Note that we include compensation per employed worker, rather than compensation per hour worked, to be consistent with the model in Section 3.

[6] Fernald (2012) also provides a TFP series, which is corrected for the utilization of inputs (Basu et al., 2006). We use the uncorrected series since changes in TFP, which result as a consequence of e.g. corporate restructuring, may give rise to movements in 'pure' TFP as well as in utilization. Hence, by using the overall TFP series, we remain agnostic with respect to how exactly restructuring influences TFP.

[7] See Appendix A for a detailed data description.

[8] Qualitatively, our results are rather robust to different lag-lengths.

2.1 Identification of Structural Shocks

We impose sign restrictions on the impulse responses to identify structural shocks (see e.g. Faust, 1998; Canova and de Nicolo, 2002; Peersman, 2005; Uhlig, 2005). The structural shocks, η_t, and the reduced form residuals, ε_t, are related through the linear mapping:

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

where $B = U\Sigma_\eta^{1/2}Q$. $U\Sigma_\eta^{1/2}$ is one Cholesky factor from our Bayesian estimation exercise, and $\mathbb{E}$ denotes the expectation operator. Since Σ_η is a diagonal matrix, we obtain mutually orthogonal structural shocks. Identification through sign restrictions consists of finding random matrices Q, such that candidate shocks, η_t, produce impulse response functions, $\phi_{j,t+k} = A(L)^{-1}B_j\eta_t$, which satisfy imposed restrictions, where L denotes the lag operator. Drawing from a standard-normal density, $\mathcal{N}(0,1)$, delivers a random matrix Z and applying the QR decomposition to Z generates an ortho-normal matrix Q, such that $QQ' = I$. Thus we obtain a variety of matrices B for each Bayesian draw and therefore a different structural model for each Q.

It is well accepted that output and prices move in the same direction after a demand shock, whereas supply shocks move these two variables in opposite directions (see e.g. Fry and Pagan, 2011). Although these restrictions suffice to disentangle supply and demand shocks, we also restrict the responses of the interest rate and of real compensation to improve the identification (see Table 1). Specifically, we restrict real compensation to decline after adverse supply and demand shocks and the interest rate to decline in response to a negative demand shock. Following a negative supply shock, we restrict the interest rate to increase.[9]

Table 1: Imposed Sign Restrictions

	$\texttt{RGDP}_t$	$\texttt{PRICES}_t$	$\texttt{FFR}_t$	$\texttt{COMP}_t$	$\texttt{EMPL}_t$	$\texttt{TFP}_t$
Supply Shock	≤ 0	≥ 0	≥ 0	≤ 0		
Demand 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. Peersman and Straub, 2009).

As shown by Paustian (2007), identification can be improved further by identifying additional shocks. Thus although we are primarily interested in characterizing the response of TFP to supply and demand shocks, we also identify a labor market shock (see Galí et al., 2012b). The

[9] We obtain qualitatively similar results when we leave the interest rate unrestricted. The impulse response functions for this case can be found in Appendix B.

distinctive feature of this shock is the reaction of real compensation, which we restrict to be positive. For the remaining variables, the imposed restrictions are identical to those imposed for the supply shock. We summarize the restrictions in Table 1. Overall, the restrictions are consistent with a wide range of DSGE models (see e.g. Erceg et al., 2000; Smets and Wouters, 2003). The advantage of our identification scheme is that TFP, the variable of main interest, remains unrestricted.

2.2 Impulse Responses

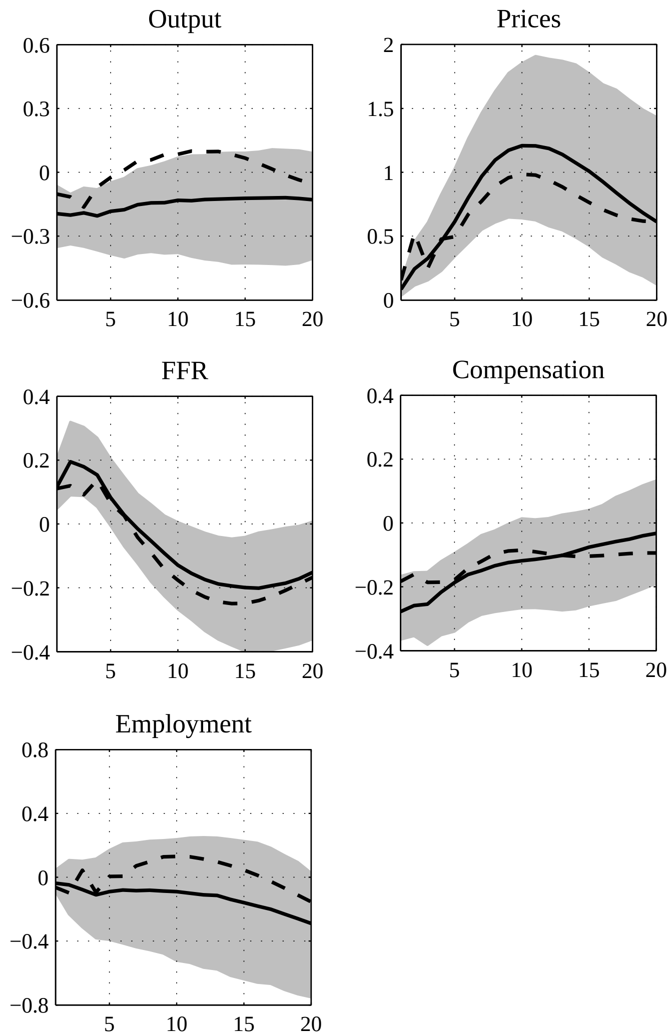
Before exploring how TFP responds to the identified shocks, we present the responses of the non-TFP variables in our VAR to see if the identification generates plausible adjustment patterns. Figures 1, 2, and 3 show the impulse responses of GDP, prices, Federal Funds rate, employment, and compensation to the supply shock, the demand shock, and the labor market shock, respectively. We report the median responses (solid lines) and the median target solutions (broken lines).[10] The shaded areas depict 16 and 84 percent quantiles.

From Figure 1, we see that output declines on impact after an adverse supply shock, while prices increase in line with the imposed restrictions. Output reverts back to its pre-shock level rather quickly. The price level response is substantially more persistent. The Federal Funds rate increases initially, but starts to decline after 6 quarters following the shock. Real Compensation also declines and slowly moves back to its pre-shock level. Employment, which we leave unrestricted, slowly starts to decline after the shock and largely mirrors the response of output. Figure 2 shows that output, prices, the Federal Funds rate, and real compensation decline after a demand shock. All variables, with the exception of the price level, which overshoots its pre-shock level, revert back to their pre-shock levels quickly and also rather monotonically. Employment, the unrestricted variable declines, again mirroring the response of output, although the decline in employment is more persistent. Finally, Figure 3 displays the responses to the labor market shock. Output and prices move in opposite directions and the Federal Funds rate initially increases. Compensation also declines, which distinguishes the labor market shock from the supply shock. Employment turns out to decline stronger as compared to a supply shock, while the response is still less pronounced and also less persistent than following a demand shock.

Figure 4 shows the responses of TFP to each of the three identified shocks. From the first sub-

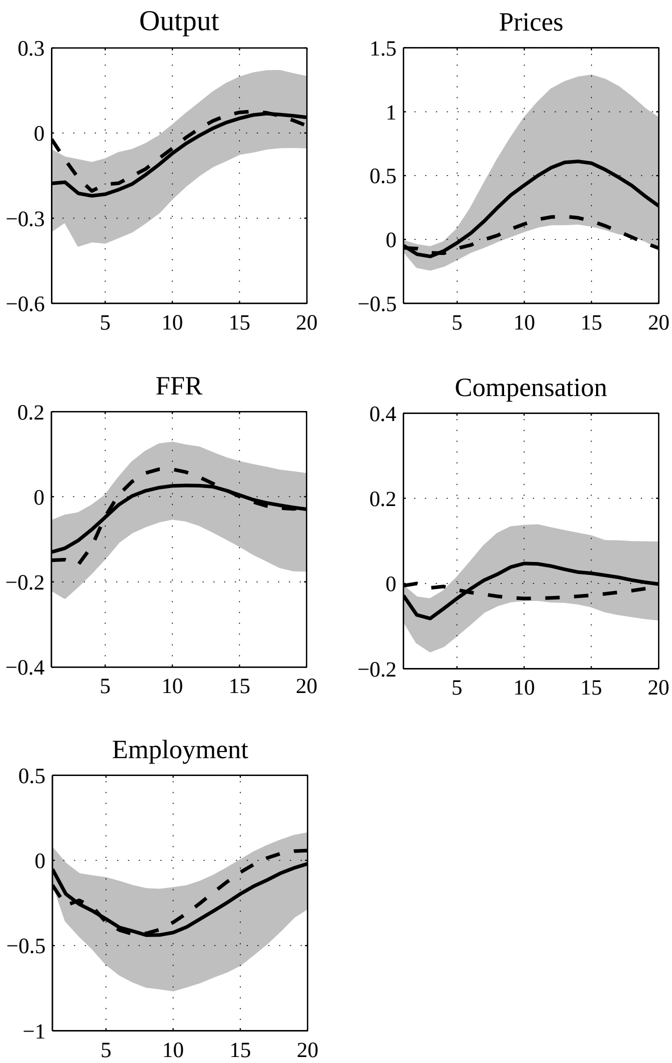
[10] Fry and Pagan (2011) point out that presenting point estimates of the posterior as summarizing statistics is problematic since the median impulse response functions, for instance, do not guarantee that the impulse responses come from the same structural model. They propose to focus on the so-called median target solution, which refers to the impulse responses obtained from a single model that minimizes the standardized deviation from the median model.

Figure 1: Supply Shock



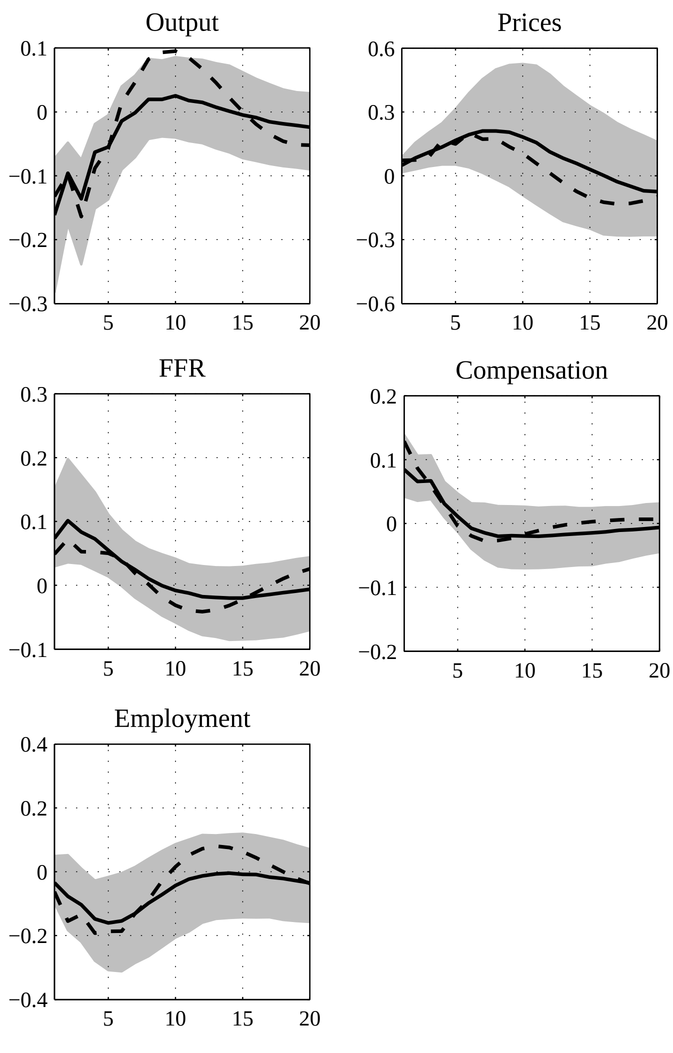
Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

Figure 2: Demand Shock



Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

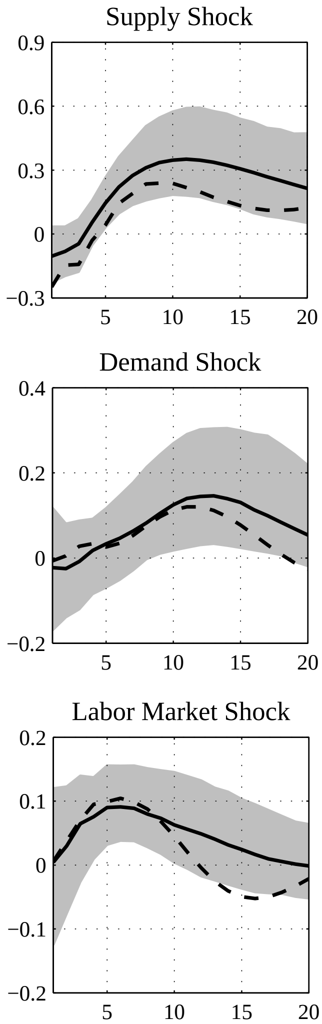
Figure 3: Labor Market Shock



Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

figure, we see that although TFP initially declines after an adverse supply shock, the response turns significantly positive in quarter 5 and improves until around 10 quarters after the shock. The second subfigure shows that TFP also improves after an adverse demand shock. Here, the median response and also the response obtained from the median target model indicate that TFP increases immediately after the adverse demand shock, although being insignificant at the beginning.[11] Finally, turning to the labor market shock, we see that TFP starts to improve endogenously also in response to this shock.

Figure 4: TFP Dynamics after Contractionary Shocks



Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

[11] Note, that this empirical finding is in line with Galí and van Rens (2014), who conjecture that demand shocks trigger counter-cyclical dynamics of (labor) productivity.

Overall, we find that TFP improves endogenously following each of the adverse, macroeconomic shocks we consider. In other words, TFP behaves counter-cyclically in the sense that it moves in the opposite direction as output. Although this counter-cyclical reaction sets in with a lag of a few quarters after a supply shock, it occurs immediately after demand and labor market shocks. The impulse response analysis also suggests that the positive contemporaneous correlation between output and TFP in the raw data is mainly caused by adverse supply shocks due to the initially negative response of TFP. This finding is not surprising since the restrictions imposed for the identification of the supply shock are also consistent with an exogenous shock to TFP.

3 Endogenously Improving TFP and the Business Cycle

In this section, we present the DSGE model, which we use to provide a more structural interpretation of our empirical findings. Since the model is mostly standard, we keep the discussion brief.[12] 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 goods sector produce by employing capital and labor services from the household. Prices are set by the intermediate goods 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 the household's utility (see Galí, 2011).

We augment the model presented in Galí et al. (2012b) to incorporate time varying labor effort, which we interpret as the result of corporate restructuring efforts in a broad sense. In our model, we obtain counter-cyclical behavior of TFP if workers support restructuring measures taken by firms by providing more effort.

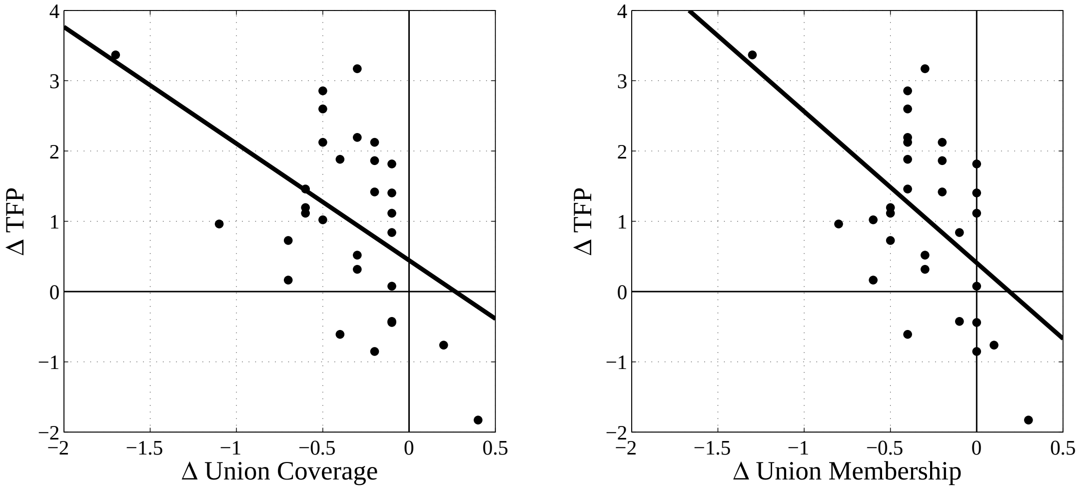
While a detailed empirical analysis of the link between workers resistance to restructuring and TFP is beyond the scope of this paper, we present some suggestive evidence in Figure 5, which plots the change of TFP against either the change of union coverage (left panel) or against the change of union membership (right panel), where the data frequency is annual.[13] We follow Berger (2012) and interpret union coverage and union membership as proxies for the constraints imposed by workers' resistance to restructuring. We see that a decline in either union coverage

[12] For a description of our benchmark model in log-linearized form, we refer to the appendix in Galí et al. (2012b).

[13] Data on union coverage and membership at an annual frequency are obtained from `http://unionstats.com`.

or union membership coincides with increases in TFP, which is consistent with the interpretation that firms are able to successfully restructure and improve productivity when union power is lower.

Figure 5: Changes in Union Coverage/Membership versus Changes in TFP



Notes: The figures plot the annual change in union coverage (left panel) and union membership (right panel) against the annual change in TFP for the period 1984 to 2013 (in percentage points).

In the remainder of this section, we present the optimization problems solved by firms and the household and highlight our model modifications. In general $\widehat{X}_t$ denotes the log-deviation of variable X_t from its steady-state value $\bar{X}$.

3.1 Producers

The firm sector of the model economy consists of intermediate and final goods producers. Intermediate goods producer i produces output $Y_t(i)$ according to:

$$Y_t(i) = \exp(\epsilon_t^A)\tilde{K}_t(i)^\alpha \tilde{N}_t(i)^{1-\alpha} - \Phi. \tag{4}$$

$\tilde{K}_t(i) = u_t(i)K_{t-1}(i)$ is the effectively used capital stock, where $u_t(i)$ denotes the utilization rate of capital, and $\tilde{N}_t(i) = \mathcal{E}_t(i)^{\frac{\psi}{1-\alpha}} N_t(i)$ is a composite of the (observed) employment stock, $N_t(i)$, and the (unobserved) labor effort, $\mathcal{E}_t(i)$. The parameter ψ determines the scale elasticity of effort, α measures the scale elasticity of capital and Φ reflects fixed cost in production. The technology shock, ϵ_t^A, follows a stationary AR(1)-process. Thus firms adjust their production levels through variations either in the effectively used capital stock or the effectively used labor input. Using the definitions of $\tilde{K}_t(i)$ and $\tilde{N}_t(i)$, the production function can be written as:

$$Y_t(i) = \text{TFP}_t K_{t-1}(i)^{\alpha} N_t(i)^{1-\alpha} - \Phi, \tag{5}$$

where we define TFP in the model as $\text{TFP}_t = \exp(\epsilon_t^A) u_t(i)^{\alpha} \mathcal{E}_t(i)^{\psi}$. Thus TFP_t is a weighted composite of $\exp(\epsilon_t^A)$, $u_t(i)$, and $\mathcal{E}_t(i)$, which is consistent with the empirical counterpart from our analysis in Section 2.

The cost function of intermediate good firm i is standard:

$$\text{Cost}_t(i) = \frac{R_t^K}{P_t} \tilde{K}_t(i) + \frac{W_t}{P_t} N_t(i). \tag{6}$$

Cost depend on factor inputs valuated with their economy wide factor prices, the rental rate of capital, R_t^K, and the nominal wage, W_t, respectively, where P_t denotes the price of the final good. Firms in the intermediate goods sector solve the standard cost minimization problem and minimize Equation (6) subject to the production technology from Equation (5). Accordingly, a log-linear approximation of marginal cost reads:

$$\widehat{MC}_t = \alpha \hat{r}_t^K + (1-\alpha)\hat{w}_t - \epsilon_t^A - \psi \hat{\mathcal{E}}_t, \tag{7}$$

The first two arguments are the well known (real) factor prices $\hat{r}_t^K$ and $\hat{w}_t$, weighted by factor shares α and $(1-\alpha)$. The parameter ψ determines the quantitative importance of effort for the cyclical component of marginal cost (see e.g. Galí and van Rens, 2014). Note that effort operates similar to a productivity shock as increasing effort lowers the marginal cost of production.

The price setting behavior of firms is standard. As in Calvo (1983) each period, a fraction θ_P of producers is unable to optimally set prices, but allowed to partially index prices to last period's price inflation as in Smets and Wouters (2003). The first order condition characterizing the firms' optimal behavior determines the price set by optimizers.

As a result of monopolistic competition in the intermediate goods sector, firm i sets prices with a time-varying gross mark-up over marginal cost, MC_t. Final good producers operate under perfect competition and purchase units of intermediate goods $i \in [0,1]$ and bundle them according to $Y_t = \left[\int_0^1 Y_t(i)^{\lambda_{P,t}^{-1}} di\right]^{\lambda_{P,t}}$, where $1 + \lambda_{P,t}$ is the time-varying gross mark-up. Cost minimization implies that the demand for good i is subject to the following demand schedule: $Y_t(i) = (P_t(i)/P_t)^{1+\lambda_{P,t}^{-1}} Y_t$. 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: $P_t = \left[\int_0^1 P_t(i)^{-\lambda_{P,t}^{-1}} di\right]^{-\lambda_{P,t}}$.

3.2 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:

$$\mathbb{E}_t \sum_{k=0}^{\infty} \beta^k \left\{ \log(\tilde{C}_{t+k}) - \chi_{t+k}\Theta_{t+k} \int_0^1 \frac{N_{t+k}(s)^{1+\varphi}}{1+\varphi} ds - \int_0^1 \frac{\mathcal{E}_{t+k}(s)^{1+\kappa}}{1+\kappa} ds - \frac{\mathcal{P}\left(\mathcal{E}_{t+k}(s)\right)}{Y_{t+k}} \right\}. \quad (8)$$

Preferences are separable with respect to the logarithmic consumption level, $\tilde{C}_t$, which is subject to external habit formation, $\tilde{C}_t = C_t - H_t$, 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 $\beta \in (0; 1)$ is the discount factor. χ_t is a disturbance to the disutility of labor. To reconcile the "joint behavior of the labor force, consumption, and the wage over the business cycle" (see Galí et al., 2012b, p.333), we incorporate an endogenous preference shifter Θ_t, 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 ν is a scale parameter determining the wealth effect on household's labor supply decision.

As described above, we model endogenously improving TFP through time-varying labor effort exerted by worker of type s, which we denote by $\mathcal{E}_t(s)$. To do so, the utility function from Equation (8) accounts for the idea that exerting effort reduces the overall level of utility, where κ scales the intensity of this effect. However, we also assume that the disutility associated with a higher effort level varies inversely with the level of output, as captured by the last term, where the strength of this effect is determined by $\mathcal{P}\left(\mathcal{E}_t(s)\right)$, where $\mathcal{P}\left(\mathcal{E}_t(s)\right) = \exp(-\gamma\mathcal{E}_t(s))$, and γ is a scaling parameter. This formulation captures the idea that although workers may prefer to exert low effort, they also have to engage in activities to hide their low effort level in order to avoid adverse consequences.[14] The disutility associated with these activities depends on the intensity of monitoring implemented by the management and since corporate restructuring and the quality of corporate governance, which should be closely related to monitoring intensity, are well known to be counter-cyclical,[15] our formulation can be interpreted as a short-cut to capture these issues in a tractable way.

The utility maximizing level of effort supplied by household members balances the marginal

[14] For instance, a non-monetary cost, which we do not explicitly model.
[15] See Philippon (2006) and the references therein.

benefits to exert effort, $\mathcal{E}_t(s)$, to the marginal cost and is obtained from Equation (8) and equals in a symmetric equilibrium:

$$Y_t = \frac{\gamma \mathcal{E}_t^{-\kappa}}{\exp(\gamma \mathcal{E}_t)}, \tag{9}$$

or in log-linear terms:

$$\hat{Y}_t = -(\kappa + \gamma \bar{\mathcal{E}})\hat{\mathcal{E}}_t. \tag{10}$$

Thus in equilibrium (unobserved) labor effort is high in recessions and low in booms. The parameters κ, γ, and the steady-state level of effort, $\bar{\mathcal{E}}$, 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 $\bar{\mathcal{E}}$), the sensitivity parameter, γ, is high, and when the disutility in effort is strongly convex (high κ).

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

$$P_t(C_t+I_t-T_t)+\frac{B_t}{\exp(\epsilon_t^B)(1+R_t)} \leq B_{t-1}+\int_0^1 W_t(s)N_t(s)ds+R_t^K\tilde{K}_t-P_t\mathcal{J}(u_t)K_{t-1}+Div_t. \tag{11}$$

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. ϵ_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, $\mathcal{J}(.)$, where $\mathcal{J}(.)$ 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:

$$K_t = K_{t-1}(1-\delta) + \exp(\epsilon_t^I)I_t\left[1 - S\left(\frac{I_t}{I_{t-1}}\right)\right]. \tag{12}$$

Capital depreciates with a rate of δ. 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 investment shock, ϵ_t^I, it holds that $\epsilon_t^I = \rho_I \epsilon_{t-1}^I + \eta_t^I$, where $\eta_t^I \sim \mathcal{N}(0, \sigma_I)$.

3.3 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 θ_W. Additionally, partial indexation to past period's average price inflation rate in a backward looking Smets and Wouters (2003) fashion, i.e. $W_t'(s)/W_{t-1}'(s) = \Pi_{t-1}^{\iota_P}$, where $\iota_P \in [0;1]$, 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:

$$\mathbb{E}_t \sum_{k=0}^{\infty} (\beta\theta_W)^k \left\{ \frac{N_{t+k|t}}{C_{t+k}} \left[\frac{W_{t+k|t}^*}{P_{t+k}} - \left(\frac{\epsilon_{t+k}^W}{\epsilon_{t+k}^W - 1} \right) \chi_{t+k} \Theta_{t+k} (\bar{C}_{t+k} - H_{t+k}) N_{t+k|t}^{\varphi} \right] \right\} = 0. \tag{13}$$

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 ϵ_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:

$$\mathcal{M}_{w,t} = \frac{W_t/P_t}{\chi_t Z_t N_{t|t-k}^{\varphi}}, \tag{14}$$

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):

$$\frac{W_t(s)}{P_t} = \chi_t Z_t L_t(s)^{\varphi}. \tag{15}$$

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 Equations (14) and (15), delivers the following result:

$$\mathcal{M}_{w,t} = \mathcal{U}_t^{\varphi}. \tag{16}$$

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.

3.4 Monetary and Fiscal Policy

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

$$R_t = \max\ (Z_t\ ;\ 0). \tag{17}$$

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):

$$Z_t = \beta^{-1} \left\{ \left(\frac{1+Z_{t-1}}{1+\bar{Z}}\right)^{\rho} \left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi_\Pi(1-\rho)} \left(\frac{Y_t}{Y_t^{\text{nat}}}\right)^{\phi_Y(1-\rho)} \left(\frac{Y_t}{Y_{t-1}} \frac{Y_{t-1}^{\text{nat}}}{Y_t^{\text{nat}}}\right)^{\phi_{\Delta Y}} \exp(\epsilon_t^Z) \right\} - 1, \tag{18}$$

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 Equation (18), 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. ρ, ϕ_Π, ϕ_Y and $\phi_{\Delta Y}$ determine the relative importance of the respective policy objective. ϵ_t^Z is a monetary policy shock, where $\epsilon_t^Z = \rho_Z \epsilon_{t-1}^Z + \eta_t^Z$ and $\eta_t^Z \sim \mathcal{N}(0, \sigma_Z)$.

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

$$\frac{B_t}{(1+R_t)} + P_t T_t = B_{t-1} + P_t G_t, \tag{19}$$

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.

3.5 Market Clearing

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

$$Y_t = C_t + I_t + G_t + \mathcal{J}(u_t)K_{t-1}. \tag{20}$$

4 Calibration and Simulation

4.1 Calibration

For the calibration, we draw on the mode estimates reported in Galí et al. (2012b) for the majority of parameters (see Table 2). However, we set the discount factor to $\beta = 0.99$ and the inflation factor to $\bar{\Pi} = 1$, which imply a steady-state interest rate of approximately 4 percent per annum, as it is standard in the literature on the zero lower bound (see e.g. Christiano et al., 2011).

Table 2: Model Calibration

Parameter	Value	Description
β	0.99	Steady-state discount factor
$\bar{\Pi}$	1.00	Steady-state (gross) price inflation
α	0.17	Scale elasticity of capital
δ	0.025	Quarterly depreciation rate
θ_P	0.58	Calvo lottery for prices
ι_P	0.26	Indexation of prices
θ_W	0.47	Calvo lottery for wages
ι_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
φ	3.99	Inverse Frisch elasticity
ν	0.02	Scale parameter for consumption externality
ϕ	0.57	Elasticity of capital utilization cost
Ψ	4.09	Elasticity of capital adjustment cost
ρ	0.85	Taylor rule: Interest rate smoothing
ϕ_Π	1.91	Taylor rule: Inflation stabilization
ϕ_Y	0.15	Taylor rule: Output gap stabilization
$\phi_{\Delta Y}$	0.24	Taylor rule: Changes in the output gap

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

Since the parameters determining the effect of labor effort, ψ, κ, and γ, cannot be readily calibrated, we choose values for these parameters by matching the standard deviation of the quarterly growth rate of our empirical TFP series ($\sigma^{TFP} = 0.58$) with its counterpart in the model.[16] To obtain a plausible TFP series from our DSGE model, we need to simulate the model under a rich number of exogenous disturbances. Therefore, we include eight shocks, as in Galí et al. (2012b), for this analysis, although we conduct the impulse response analysis only with a subset of these shocks. Again, we refer to Galí et al. (2012b) for the calibration of these shocks, except for the productivity shock, ϵ_t^A. We argue that parts of this exogenous innovation could be explained by the introduction of endogenous labor effort. Obviously, implementing a standard Cobb-Douglas technology where labor effort, $\mathcal{E}_t$, is not modeled empirically, fluctuations in effort will probably be picked up by the exogenous productivity shock, ϵ_t^A. Accordingly, as we explicitly account for labor effort, we also re-calibrate the persistence and standard deviation of the productivity shock, ϵ_t^A, when calibrating our three introduced labor effort parameters. The results of this calibration exercise can be found in Table 3.

Table 3: Calibrated Parameters

Parameter	Value	Description
ψ	0.469	Elasticity of output with respect to labor effort
κ	1.874	Disutility of labor effort
γ	0.473	Business cycle sensitivity of effort
σ_A	0.381	Standard deviation of productivity shock
ρ_A	0.918	Persistence of productivity shock

Notes: The table displays the estimates of our newly introduced parameters as well as the persistence and standard deviation of the productivity shock.

In line with our a priori intuition, we find a modest decline in the importance of the productivity shock. With the implementation of effort, ρ_A declines from 0.98 to 0.92 and σ_A reduces from 0.41 to 0.38. Although our matching strategy succeeds to fit the standard deviation of the growth rate of TFP perfectly, it is difficult to evaluate the estimated values of ψ, κ, and γ as we do not find much empirical or theoretical work, which could give us insight about these parameters.[17]

4.2 Simulation

To study the role of endogenous movements in TFP, we analyze the response of the model to an adverse price mark-up and risk premium shock as examples for supply and demand shocks respectively.[18]

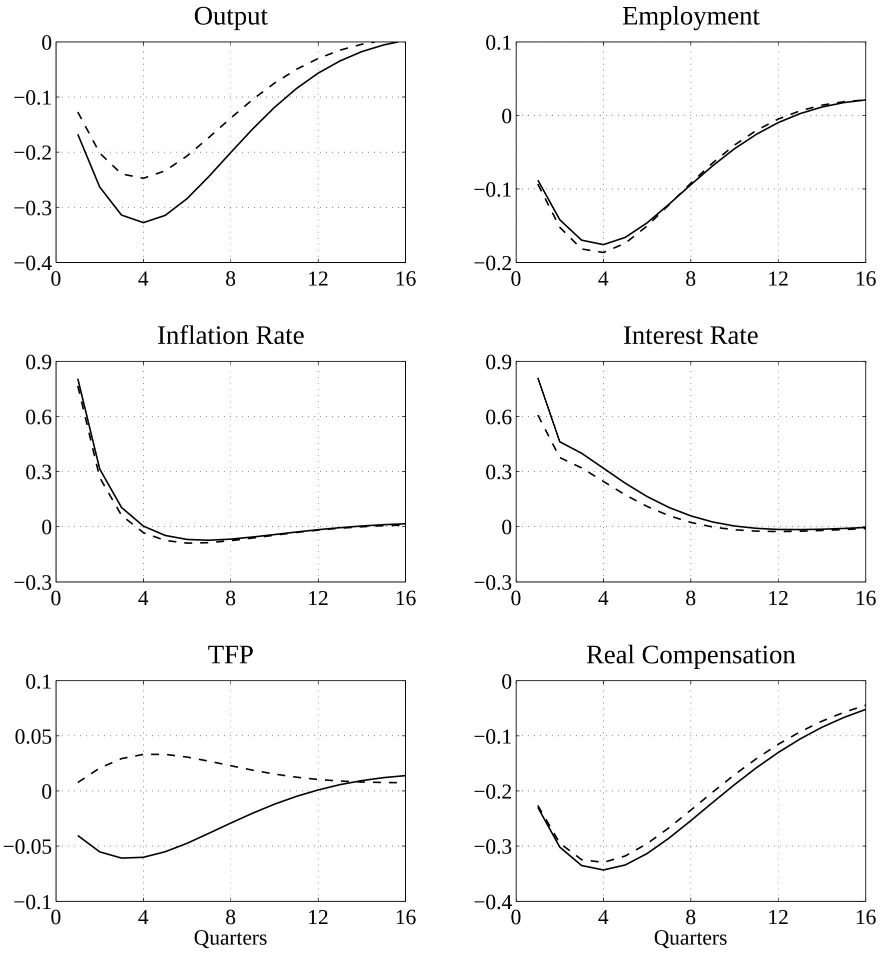
[16] Galí and van Rens (2014) employ a similar approach. They target the relative volatility of employment and output in their calibration strategy. As our primary focus is on the role of TFP for shock transmission, we focus on the second moment of TFP instead.

[17] A notable exception is Galí and van Rens (2014).

[18] Note that the empirically identified supply shock can also represent an exogenous innovation to technology, when interpreted through the lens of a DSGE model (see e.g. Peersman and Straub, 2006, 2009). Similarly, the

Consider first the price mark-up shock. Figure 6 shows the responses for a standard model (solid lines) and for the model incorporating counter-cyclically improving TFP due to endogenous labor effort (broken lines).

Figure 6: Price Mark-Up Shock



Notes: The solid line represents impulse response functions obtained from the benchmark model. The dashed line shows impulse response functions from the economy with endogenous TFP improvements.

We see that while output declines after an adverse price mark-up shock in both variants of the model, the decline is less pronounced when we allow TFP to improve endogenously. Intuitively, the higher productivity allows firms to keep up production. However, since higher TFP also induces firms to reduce labor demand, given the overall demand conditions, employment declines stronger when TFP improves endogenously. In other words, although endogenous improvements in TFP help to maintain a higher level of output the labor market reaction is more pronounced.

identified demand shock can also be an innovation to consumer preferences or government spending (see e.g. Smets and Wouters, 2003; Peersman and Straub, 2006; Galí et al., 2012b).

Quantitatively, however, endogenously improving TFP has only a minor effect on the response of employment to the supply shock. Turning to the response of inflation, we see that the supply shock gives rise to higher inflation, when TFP does not increase. We also see that although the endogenous improvement of TFP dampens the increase in inflation, the effect is quantitatively small. While monetary policy is tightened in response to the supply shock, the less severe decline in output together with the somewhat less pronounced increase in inflation result in a more muted increase in the interest rate when TFP increases endogenously.

Comparing the TFP responses in the models with and without varying labor effort shows that the supply shock leads to lower TFP in the benchmark model in contrast to improvements in the augmented model. The pro-cyclical response in the benchmark model is due to the endogenous reaction of the capital utilization rate (see our definition of TFP in Equation (5)). Finally, the figure shows that real compensation declines after the adverse shocks, with only small differences across the two scenarios.

Figure 7 shows the responses to an adverse shock to the risk premium. Similar to what we find for the price mark-up shock, the output response is muted and the employment response is amplified, when we allow TFP to improve endogenously. Quantitatively the deviations from the baseline model are of a similar order of magnitude for output and employment here. Due to lower demand, inflation declines and the effect is initially more pronounced when TFP increases endogenously, which is again due to the disinflationary effect exerted by the higher TFP. Declining output and a lower inflation rate result in a lower interest rate, where the response of monetary policy is again more accomodative when TFP improves. While TFP improves endogenously in the model with variable effort, it declines to some extent in the benchmark model. Real compensation also declines with only small quantitative differences across models.

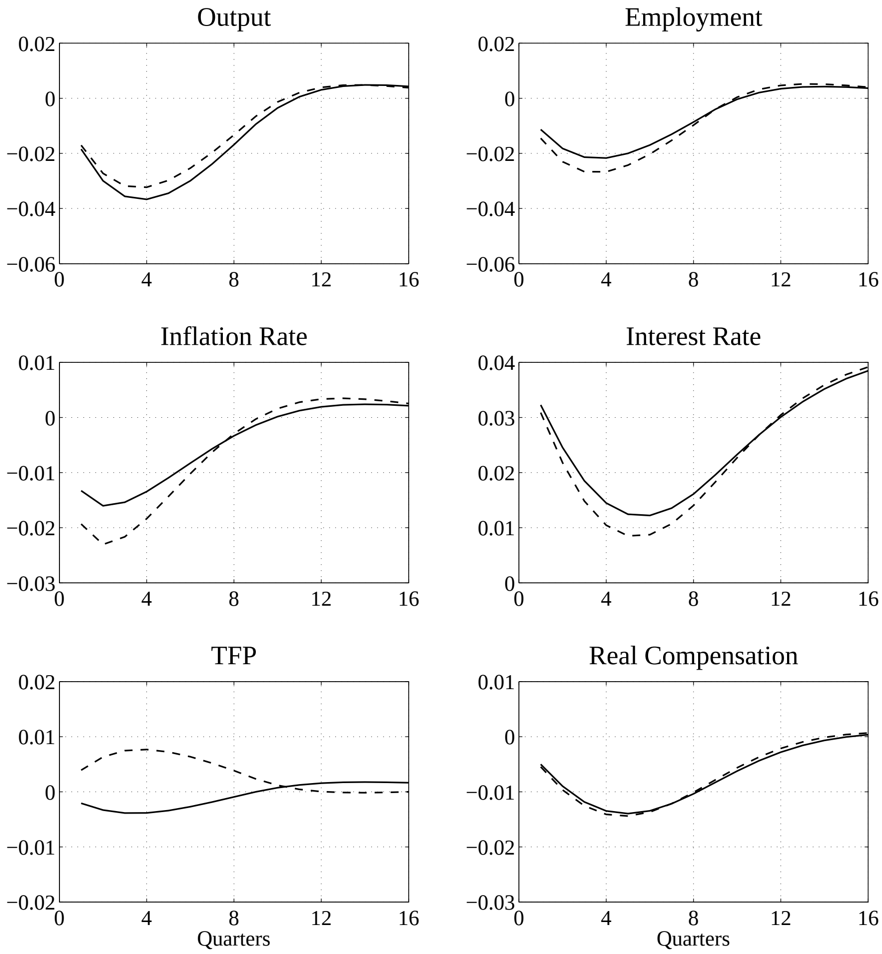
Overall, we see that endogenously improving TFP generally dampens the impact of adverse shocks on output, whereas it amplifies the effect on employment. A crucial element is the reaction of monetary policy. Since the improvement in TFP induces disinflationary pressure, the interest rate reaction is generally more accomodative, which also cushions the decline in output by stimulating demand.

These conclusions change strongly when we consider the responses to a risk premium shock that is strong enough to make the zero lower bound on the nominal interest rate binding in Figure 8.[19] The figure shows that with endogenously improving TFP, output as well as employment

[19] See Amano and Shukayev (2012) for a detailed discussion of the role of risk premium shocks in the context of the zero lower bound.

both decline stronger than in the baseline case when the shock is strong enough to make the zero lower bound binding.[20]

Figure 7: Risk Premium Shock



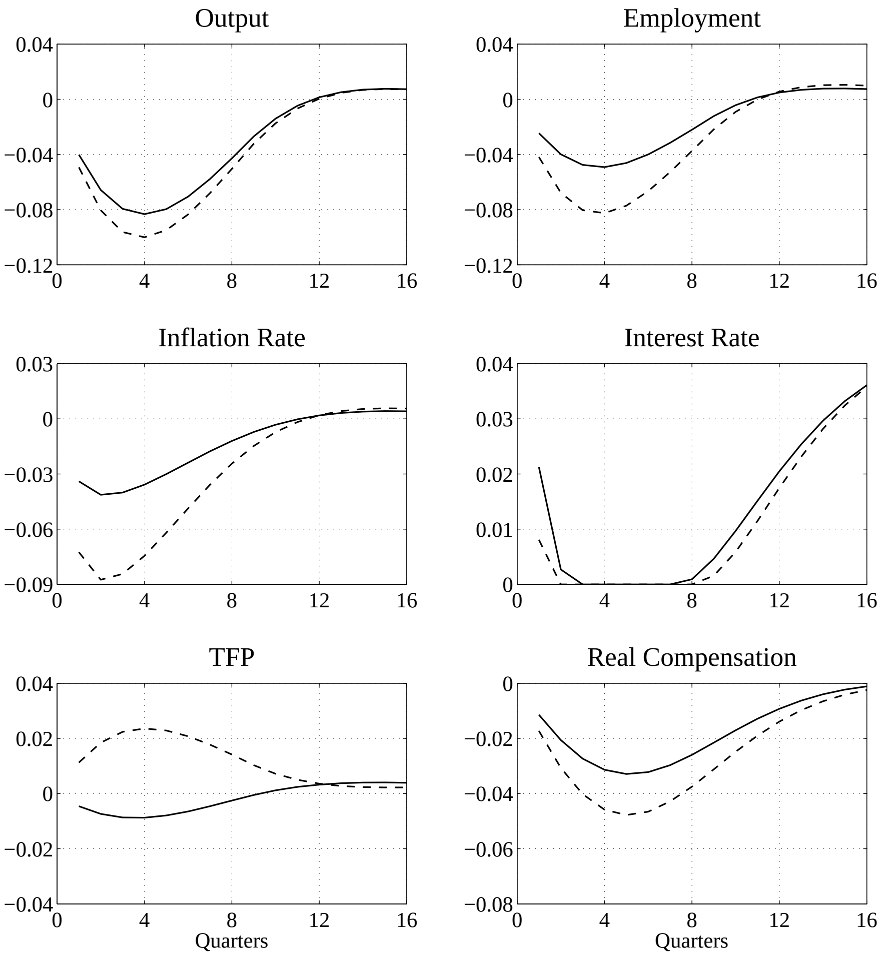
Notes: The solid line represents impulse response functions obtained from the benchmark model. The dashed line shows impulse response functions from the economy with endogenous TFP improvements.

The reason for these differences in the outcomes is the constraint imposed by the zero lower bound on monetary policy. While the additional, disinflationary effect exerted by the increase in TFP allows the central bank to reduce the interest rate more strongly to support the recovery as long as the the shock is sufficiently small, the strong decline in inflation associated with a large demand shock together with the binding zero lower bound result in a relative high real interest rate. As a result, demand declines even further and the decline in output turns out to be more pronounced.[21]

[20]We consider a shock period of 8 quarters for the risk premium shocks in both cases, implemented as a deterministic simulation exercise (see Christiano et al., 2011).

[21]Wieland (2014) studies the implications of negative supply shocks at the zero lower bound. In the New

Figure 8: Strong Risk Premium Shock



Notes: The solid line represents impulse response functions obtained from the benchmark model. The dashed line shows impulse response functions from the economy with endogenous TFP improvements.

We now take a closer look at the individual components of TFP and labor productivity in Figures 9 and 10. Recall that in the model, TFP consists of labor effort, $\mathcal{E}_t$, and capital utilization, u_t.[22] We see from Figure 9 that although magnitudes vary somewhat, effort improves regardless of the type and size of the shock, whereas capital utilization generally declines and the decline is stronger when effort improves endogenously since firms substitute effort for the other input factors, including capital utilization.

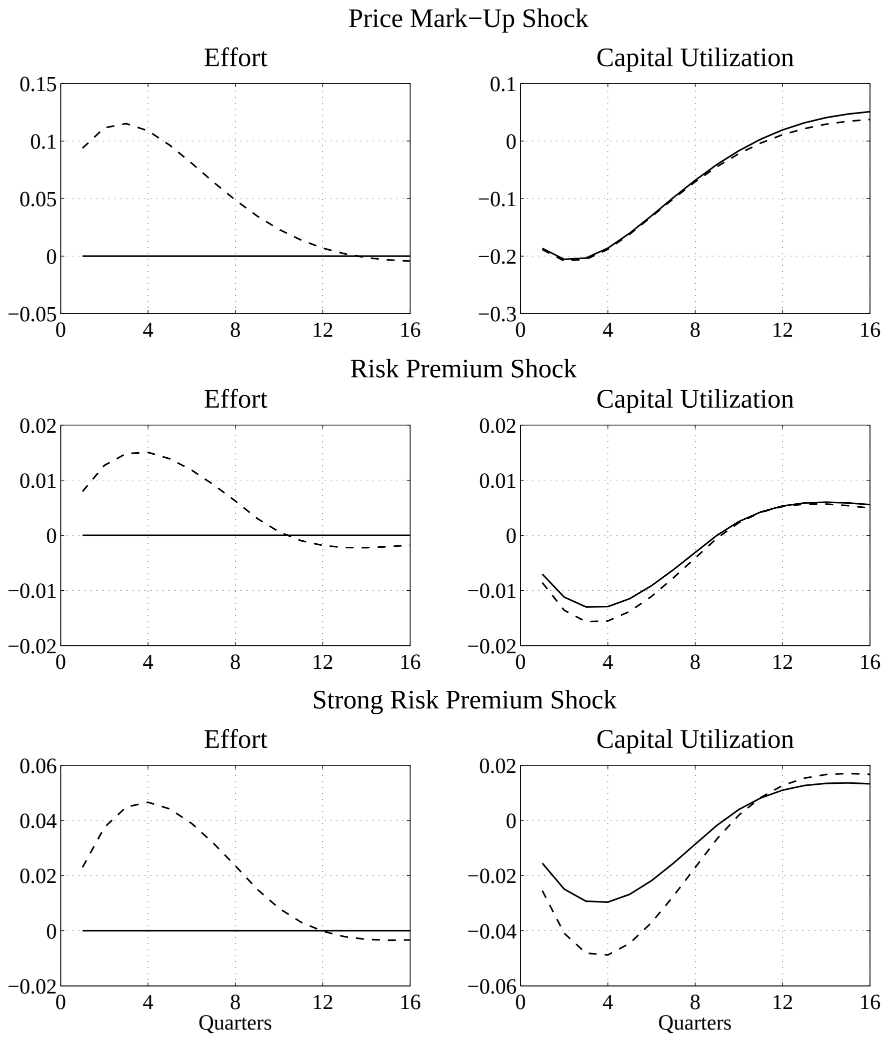
Finally, Figure 10 shows that labor productivity generally responds in a pro-cyclical way after each shock. When we allow effort to improve counter-cyclical, however, the decline in

Keynesian framework, such shocks are expansionary by increasing inflation and thereby lowering the real rate of interest at zero nominal interest rates. Wieland (2014) argues that financial frictions may counteract this effect, which may also dampen the effect when TFP improves endogenously.

[22]Ignoring the exogenous productivity shock for now.

labor productivity is substantially dampened.

Figure 9: A Closer Look at the Responses of TFP Components



Notes: The solid line represents impulse response functions obtained from the benchmark model. The dashed line shows impulse response functions from the economy with endogenous TFP improvements.

5 Summary and Concluding Remarks

In this paper, we show empirically that adverse shocks that give rise to a decline in output are also associated with increases in TFP. At first glance, these productivity improvements during economic downturns may seem beneficial and may be seen as a first step towards the recovery.

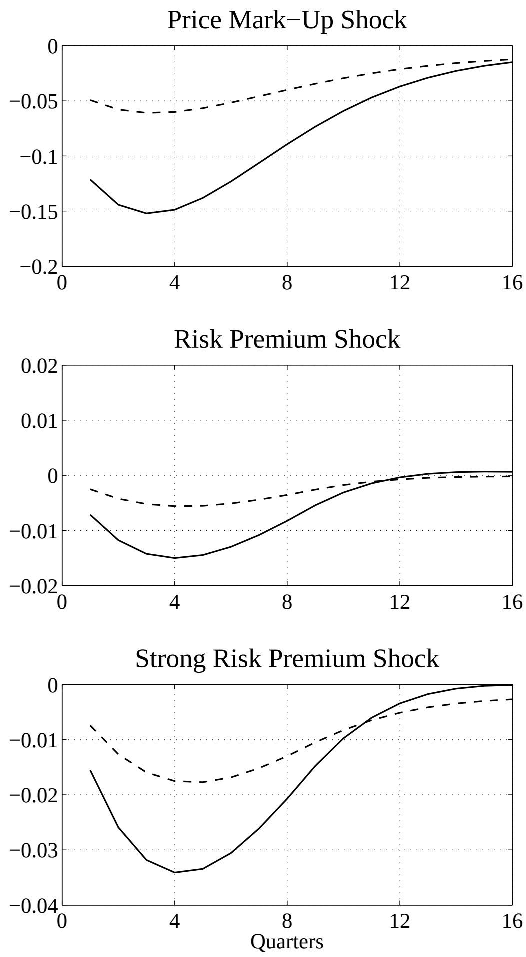
Our simulations based on an augmented New Keynesian model, in which endogenous fluctuations in TFP are triggered by variations in labor effort, provide some support for this view since the decline in output is generally less severe once we allow for endogenous improvements in

TFP. We find, however, that TFP improvements amplify the negative response of employment, which is due to a strong increase in the intensive margin of labor.

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.

While we focus on the US economy in our analysis, the role of TFP for the transmission of shocks may differ across countries due to structural differences, and in particular, due to differences in labor market institutions. Thus studying potential cross-country differences in the endogenous response of TFP to shocks appears to be an interesting avenue for future research.

Figure 10: A Closer Look at the Responses of Labor Productivity



Notes: The solid line represents impulse response functions obtained from the benchmark model. The dashed line shows impulse response functions from the economy with endogenous TFP improvements.

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Appendix A: Data and Sources

All variables enter the model as log-levels exept the interest rate, which is expressed in percent. $\texttt{RGDP}_t$ and $\texttt{EMPL}_t$ are normalized by the Civilian Noninstitutional Population. $\texttt{COMP}_t$ is deflated by the GDP price deflator, $\texttt{PRICES}_t$, and divided by our employment measure, to obtain the compensation per employee series.

Time series were obtained from the following 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.

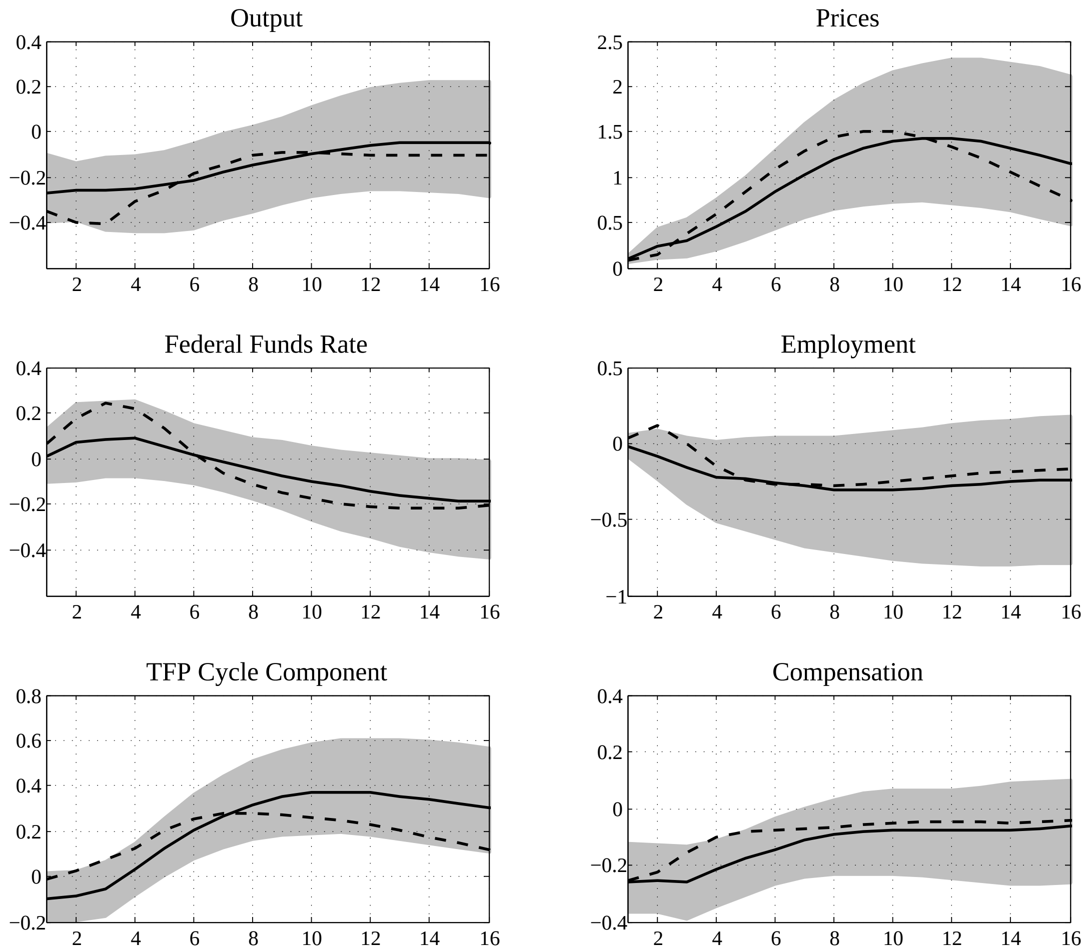
- **Compensation**: Compensation (PRS85006063), Nonfarm Business Sector (All Persons), Quarterly, Seasonally Adjusted. Source: U.S. Department of Labor: Bureau of Labor Statistics.

- **Total Factor Productivity**: Quarterly-TFP series for the U.S. Business Sector, produced by John Fernald. Source: Federal Reserve Bank of San Francisco. We generate an index based on the series of TFP growth rates as provided by the Federal Reserve Bank of San Francisco.

- **Interest Rate**: Federal Funds Rate (FEDFUNDS), Percent, Quarterly. Source: Board of Governors of the Federal Reserve System.

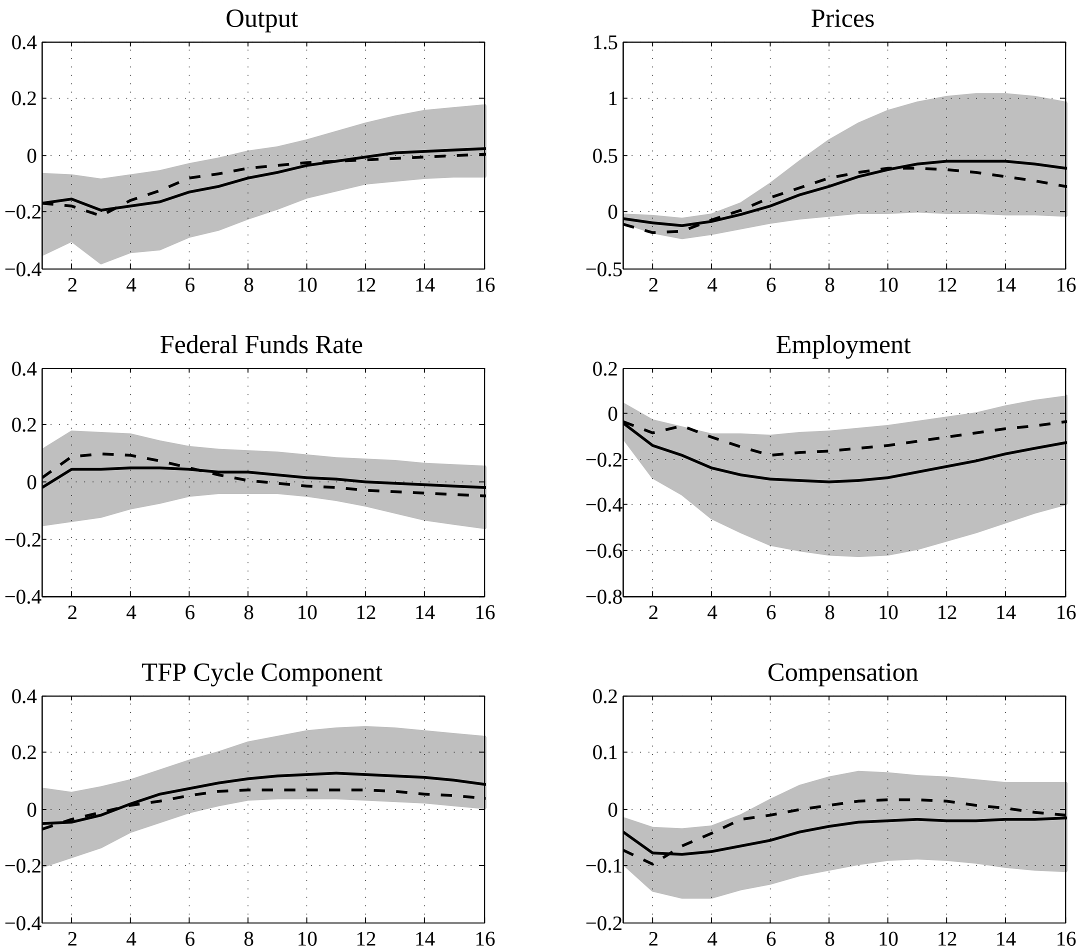
Appendix B: Alternative Identification (Interest Rate Unrestricted)

Figure B.1: Supply Shock with Weaker Restrictions



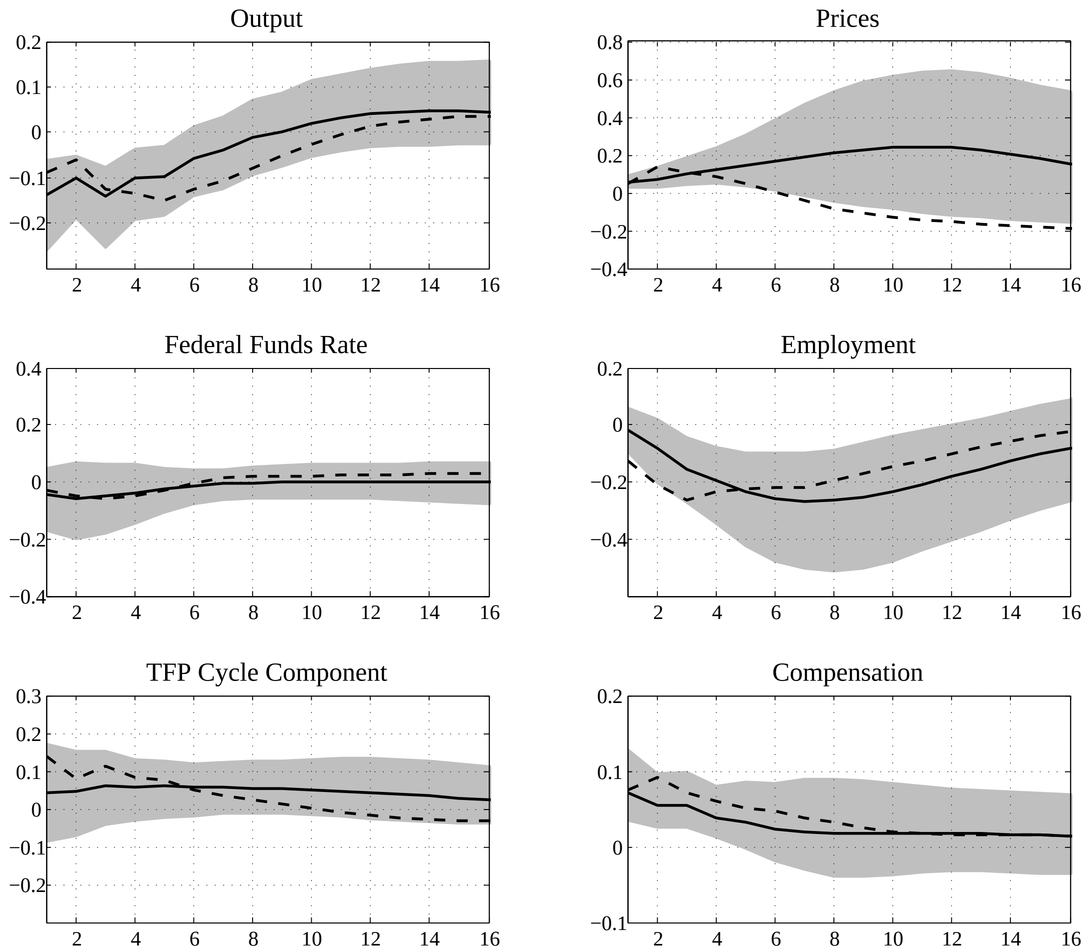
Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

Figure B.2: Demand Shock with Weaker Restrictions



Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.

Figure B.3: Labor Market Shock with Weaker Restrictions



Notes: The solid line represents the median impulse response functions from our Bayesian VAR. The shaded areas display the 16% and 84% quantiles of the posterior distribution and the dashed line denotes the respective median target.