

Born, Benjamin; Pfeifer, Johannes

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# Uncertainty-driven business cycles: assessing the markup channel\*

Benjamin Born

Johannes Pfeifer

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## Abstract

A growing recent literature relies on a precautionary pricing motive embedded in representative agent DSGE models with sticky prices and wages to generate negative output effects of uncertainty shocks. We assess whether this model channel is consistent with the data. We build a New Keynesian DSGE model with time-varying wage and price markups and document the predicted conditional comovement of output and markups following demand and supply uncertainty shocks. Using the model as a business cycle accounting device, we also construct aggregate markup series from the data. Time-series techniques are used to identify uncertainty shocks in the data and to study whether the conditional comovement between markups and output is consistent with the one implied by the model. The response to uncertainty shocks is found to be consistent with precautionary wage setting, but not price setting, putting the role of sticky wages into the focus.

*JEL-Classification:* E32, E01, E24

*Keywords:* Uncertainty; risk shocks; labor wedge; markups.

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\*Born: University of Bonn and CEPR, born@uni-bonn.de, Pfeifer: University of Mannheim, pfeifer@uni-mannheim.de. We would like to thank Angela Abbate, Matthias Hartmann, Keith Kuester, Gernot Müller, Morten Ravn, Mirko Wiederholt, and seminar audiences at Barcelona University, University College London, Tübingen University, the 2015 “Frankfurt-Mannheim Macro Workshop”, and the 2015 “CIRET/KOF/RIED WSE Workshop on Economic Cycles and Uncertainty” for helpful comments and suggestions.

# 1 Introduction

Since the seminal study of Bloom (2009), many studies have focused on the effect of uncertainty shocks on economic fluctuations (e.g. Bloom et al., 2012; Born and Pfeifer, 2014; Fernández-Villaverde et al., 2011). While time-series approaches regularly find negative effects of uncertainty shocks on output (e.g. Baker et al., 2015; Carrière-Swallow and Céspedes, 2013; Gilchrist et al., 2014; Jurado et al., 2015), it has proven surprisingly difficult to generate negative outputs effects after uncertainty shocks in representative agent models. As shown by Basu and Bundick (2014), uncertainty shocks are expansionary in the standard RBC model. The reason is the presence of a “precautionary labor supply” motive. When faced by higher uncertainty, the household does not only self-insure by consuming less and investing more, but also by working more. From the neoclassical production function where TFP is unaffected by uncertainty and capital is predetermined, this increase in labor results in an output expansion that fuels higher savings.

The solution to generate contractionary effects of uncertainty is to break this tight link between labor supply and production. As also shown by Basu and Bundick (2014), this can be achieved by introducing monopolistic competition in labor and goods markets, which gives rise to time-varying markups. In the presence of sticky prices and wages, firms and households in their price and wage-setting decisions face a convex marginal revenue product, giving rise to inverse Oi (1961)-Hartman (1972)-Abel (1983)-effects and precautionary pricing when faced with uncertainty about future economic variables. Price-setters face the following choice: If prices/wages are set too low, more units need to be sold at too low a price, which is both negative. In contrast, if prices are set too high, the higher prices compensate for being able to sell fewer units. Due to this asymmetric, nonlinear effect, price and wage-setters prefer to err on the side of too high prices and increase their markups. If this increase in markups after uncertainty shocks is strong enough, it dampens demand and decreases output. Prominent recent studies that rely on this mechanism include Fernández-Villaverde et al. (2015), Born and Pfeifer (2014), Basu and Bundick (2014), Leduc and Liu, 2012, Başkaya et al. (2013), Mumtaz and Zanetti (2013), Plante and Traum (2012), Cesa-Bianchi and Fernandez-Corugedo (2014),

Johannsen (2013), and Nguyen (2014).<sup>1</sup>

While these studies rely on a countercyclical movement of price and/or wage markups conditional on uncertainty shocks, direct evidence on the presence of this transmission channel is limited. In the present study we provide this evidence. To this end, we collect data on aggregate markups and uncertainty. There are two markups to consider: the price markup over marginal costs and the wage markup over the marginal disutility of work. We thus construct a prototypical DSGE model with price and wage rigidities, supply and demand uncertainty, CES production, and overhead labor that can be used as both an accounting device to construct markups and to generate the business cycle predictions following aggregate uncertainty shocks.

The construction of the price markup is related to Nekarda and Ramey (2013) (NR henceforth) who have argued that aggregate price markups are pro- to acyclical unconditionally and also regularly do not show the conditional movement shocks predicted by standard New Keynesian models. However, they did not consider uncertainty shocks and only focused on the price markup, while the main effect might work through wage markups. This is important as e.g. Karabarbounis (2014) has argued that about 90% of the cyclical movement in the labor wedge derives from movements in the household component of this wedge, i.e. the gap between the marginal rate of substitution and the real wage. We follow Karabarbounis (2014) in the construction of the wage markup (see also Shimer, 2010).<sup>2</sup>

To measure aggregate uncertainty, we use the general macroeconomic uncertainty measure of Jurado et al. (2015) (JLN) and identify them via a recursive ordering. Given that the uncertainty measure is available at monthly frequency while we only have quarterly markup data, we will employ two different approaches to deal with this mixed-frequency problem. A Bayesian mixed-frequency VAR estimated following Eraker et al. (2015) and

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<sup>1</sup>Notable exceptions in the aggregate uncertainty literature are Christiano et al. (2014) and Chugh (2014), who embed uncertainty in a financial accelerator mechanism.

<sup>2</sup>Our paper is also related to earlier papers studying the (unconditional) cyclical movement of (price) markups (e.g. Bils, 1987; Rotemberg and Woodford, 1991), surveyed in Rotemberg and Woodford (1999), as well as “business cycle accounting” studies like Chari et al. (2007), Hall (1997), and Parkin (1988). Galí et al. (2007) is an influential recent study that decomposes the labor wedge into a firm and household component to study the welfare implications.

a two-step frequentist procedure following Kilian (2009) and Born et al. (2014).

We find that in the data, contrary to the model's prediction, price markups tend to fall after uncertainty shocks. However, wage markups increase. These findings are robust to different identification schemes and markup measures, suggesting that future studies should focus on the role of sticky wages instead of sticky prices.

Section 2 provides a detailed exposition on the mechanism embedded in New Keynesian models that gives rise to contractionary uncertainty effects. Section 3 presents a baseline New Keynesian DSGE with time-varying wage and price markups and shows the predicted conditional comovement of output and markups following demand and supply uncertainty shocks. The model also provides an accounting framework, which is used in Section 4 to construct markups from the data. Section 5 then identifies uncertainty shocks from the data, studies whether the conditional comovement between markups and output is consistent with the one implied by the model, and provides robustness checks. Section 6 concludes.

## 2 Intuition

To understand why higher uncertainty leads to contractionary output effects in sticky price models, consider the following stylized partial equilibrium example. A firm  $i$  of a continuum of identical firms chooses its optimal price  $p_{it}$  subject to its demand function  $y_{it} = \left(\frac{p_{it}}{p_t}\right)^{-\varepsilon} y_t$ , where  $y_t$  is aggregate demand and  $p_t$  the aggregate price level, and a constant returns to scale production function that is linear in labor:  $y_{it} = l_{it}$ . The labor market is assumed to be competitive with the economy-wide wage being given by  $w_t$ . From cost minimization then follows that the marginal costs are equal to  $mc_{it} = \frac{\varepsilon-1}{\varepsilon} \frac{w_t}{p_t}$ . Firm profits are then given by

$$\pi = \left[ \frac{p_{it}}{p_t} - \underbrace{\frac{\varepsilon-1}{\varepsilon} \frac{w_t}{p_t}}_{mc_{it}} \right] \left( \frac{p_{it}}{p_t} \right)^{-\varepsilon} y_t \quad (2.1)$$

Assuming without loss of generality  $p_t = y_t = w_t = 1$ , this simplifies to

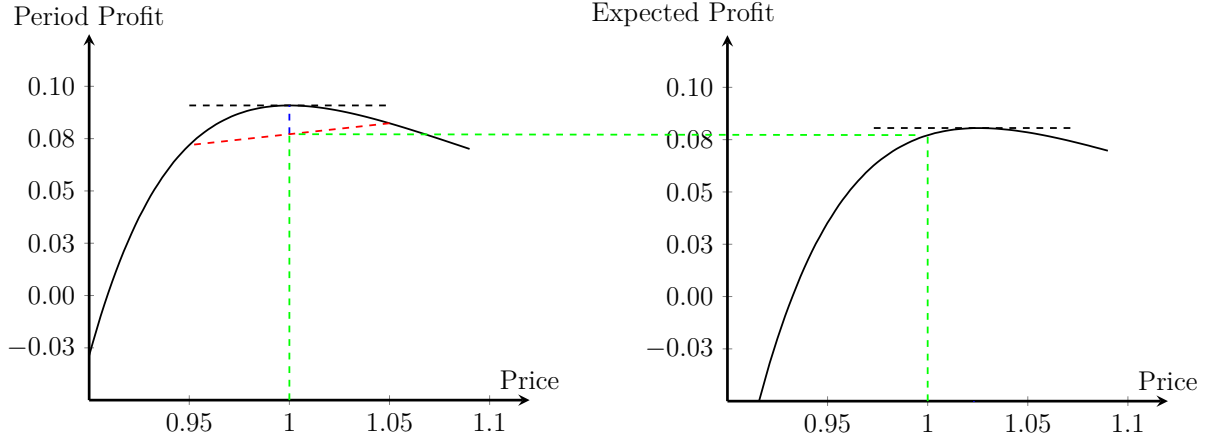


Figure 1: Stylized example

$$\pi = \left[ p_{it} - \frac{\varepsilon - 1}{\varepsilon} \right] p_{it}^{-\varepsilon} \quad (2.2)$$

The expression shows that there are two different channels through which prices affect profits. First, a higher price  $p_{it}$  has an immediate price impact on the revenue, while leaving the marginal costs unaffected. But second, there is an additional impact on the quantity sold. The left panel of 1 shows the profit function for  $\varepsilon = 11$ . As is well-known, in the absence of nominal rigidities the firm will optimally charge a markup over marginal costs, resulting in a profit-maximizing price of  $p_{it} = 1$ .

Now consider the case where the firm faces uncertainty about tomorrow's optimal price, because tomorrow's aggregate price level is with probability  $1/2$  either  $p_{t+1} = 1/1.05$  or  $p_{t+1} = 1/0.95$ , so that in the absence of pricing frictions, either  $p_{it+1} = 0.95$  or  $p_{it+1} = 1.05$ . Thus, compared to the previous situation, the optimal price is subject to a mean-preserving spread.<sup>3</sup> But setting the price at the expected optimal  $p_{it} = 1$  would be suboptimal, because it leads to lower expected profits due to the marginal profit being convex in the price. This is shown in the right panel. Rather, the optimal price in this case would be slightly higher. The reason for this that setting too low a price implies having to sell more goods when the price is too low, while setting too high a price means selling fewer goods, but still at a relatively high profit. Anticipating this, firms will opt for a higher price,

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<sup>3</sup>For ease of exposition we consider a mean preserving spread to the endogenous variable. The same effect would arise following a mean-preserving spread to  $p_t$ , but in this case an additional Jensen's Inequality effect would complicate matters due to the price level entering in the denominator.

increasing markups already today.

The same mechanism is at work in the household sector where the households have to maximize utility by setting a nominal wage subject to a equivalent demand function for their labor services.

### 3 Model

In this section we construct a prototypical model that embeds the previously outlined mechanism on the firm and household side. We can then use this model to conduct experiments and as a Chari et al. (2007) business cycle accounting-type framework.

#### 3.1 Firms

The final good  $Y_t$  is assembled from a continuum of differentiated intermediate inputs  $Y_t(i)$ ,  $i \in [0, 1]$ , using the constant returns to scale Dixit-Stiglitz-technology

$$Y_t = \left[ \int_0^1 Y_t(i)^{\frac{\theta_p-1}{\theta_p}} di \right]^{\frac{\theta_p}{\theta_p-1}}, \quad (3.1)$$

where  $\theta_p > 0$  is the elasticity of substitution between intermediate goods. It is sold in a competitive market at cost  $P_t$

$$P_t = \left[ \int_0^1 P_t(i)^{1-\theta_p} di \right]^{\frac{1}{1-\theta_p}}, \quad (3.2)$$

where  $P_t(i)$  is the price of intermediate good  $i$ . Profits

$$P_t Y_t - \int_0^1 P_t(i) Y_t(i) di \quad (3.3)$$

are then maximized subject to the production technology by choosing the optimal bundle of input goods. This results in the demand for good  $i$ :

$$Y_t(i) = \left[ \frac{P_t(i)}{P_t} \right]^{-\theta_p} Y_t. \quad (3.4)$$

There is a continuum of monopolistically competitive intermediate goods firms  $i$ ,  $i \in [0, 1]$ , which produce differentiated intermediate goods  $Y_t(i)$  using capital  $K_t(i)$  and a

hired composite labor bundle  $N_t(i)$ , defined in the next subsection, according to a CES production function

$$Y_t(i) = Y^{norm} \left( \alpha (K_t(i))^\psi + (1 - \alpha) \left( e^{Z_t} (N_t(i) - N^o) \right)^\psi \right)^{\frac{1}{\psi}} - \Phi . \quad (3.5)$$

Here,  $0 \leq \alpha \leq 1$  parameterizes (but is not equal to) the labor share and  $Y^{norm}$  is a normalization factor that makes output equal to one in steady state.<sup>4</sup>  $\psi \in [-\infty, 1]$  is a parameter indexing the elasticity of substitution between capital and labor, which is given by  $1/(1 - \psi)$ , with  $\psi = 0$  being the Cobb-Douglas case. The fixed cost of production  $\Phi$  is set to reduce economic profits to zero in steady state, thereby ruling out entry or exit (Christiano et al., 2005).  $N^o = \phi_o N$ , where  $N$  denotes steady state labor, is overhead labor used in the production of goods.<sup>5</sup>  $Z_t$  denotes a stationary, labor-augmenting technology process specified below. Each intermediate goods firm owns its own capital stock, whose law of motion is given by

$$K_{t+1}(i) = \left( 1 - \delta - \frac{\phi_K}{2} \left( \frac{I_t(i)}{K_t(i)} - \delta \right)^2 \right) K_t(i) + I_t(i) , \quad \phi_K \geq 0 , \quad (3.6)$$

where  $\delta$  denotes the quarterly steady-state depreciation of the capital stock. Equation (3.6) includes capital adjustment costs at the firm level of the form introduced by Hayashi (1982).

Intermediate goods producers are owned by households. They maximize the present discounted value of per period profits subject to the law of motion for capital and the demand from the final goods producer:

$$\left[ \frac{P_t(i)}{P_t} \right]^{1-\theta_p} Y_t - \frac{W_t}{P_t} N_t(i) - I_t(i) - \frac{\phi_P}{2} \left( \frac{P_t(i)}{P_{t-1}(i)} - \Pi \right)^2 Y_t , \quad (3.7)$$

where  $N_t(i)$  is hired in a competitive rental market at given rate  $W_t$  and the last term denotes price adjustment costs as in Rotemberg (1982). For discounting, firms use the households' stochastic discount factor. From the firms' cost minimization problem follows

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<sup>4</sup>Note that both parameters are not structural parameters in the sense that they depend on the units of measurement for input factors. For more details on how to deal with such dimensional constants, see Cantore and Levine (2012).

<sup>5</sup>See Ratto et al. (2009) for one of the earliest DSGE models with overhead labor.



the first order condition for labor inputs as

$$\frac{W_t}{P_t} = \Xi_t MPL_t, \quad (3.8)$$

where  $\Xi_t$  are marginal costs. Due to monopolistic competition,  $\Xi_t$  will generally not be equal to 1 as firms set a markup over marginal costs. Time-variation in this markup is a central element of shock transmission in the New Keynesian model.

### 3.2 Households

Following Erceg et al. (2000), we assume that the economy is populated by a continuum of monopolistically competitive households, supplying differentiated labor  $N_t(j)$  to a labor bundler who then supplies the composite labor input to the intermediate goods producers. Formally, the aggregation technology follows a Dixit-Stiglitz form

$$N_t = \left[ \int_0^1 N_t(j)^{\frac{\theta_w-1}{\theta_w}} dj \right]^{\frac{\theta_w}{\theta_w-1}}, \quad \theta_w > 0. \quad (3.9)$$

The bundler takes households' wages  $W_t(j)$  as given and sells the composite labor input at cost

$$W_t = \left[ \int_0^1 W_t(j)^{1-\theta_w} dj \right]^{\frac{1}{1-\theta_w}}, \quad (3.10)$$

to the intermediate goods firms. Expenditure minimization yields the optimal demand for household  $j$ 's labor as

$$N_t(j) = \left[ \frac{W_t(j)}{W_t} \right]^{-\theta_w} N_t \quad \forall j. \quad (3.11)$$

Households have Epstein and Zin (1989)/Weil (1989) preferences

$$V_t(j) = \max \left[ e^{\xi_t^{pref}} V^{norm} \left( C_t(j)^\eta (1 - N_t(j))^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} + \beta \left( \mathbb{E}_t V_{t+1}(j)^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{1-\sigma}}, \quad (3.12)$$

which allow separately specifying the risk aversion and the intertemporal substitution.

The parameter  $\sigma \geq 0$  measures the risk aversion, while  $\chi$  is the intertemporal elasticity of substitution with  $\theta_V \equiv \frac{1-\sigma}{1-\chi}$ .  $0 \leq \beta \leq 1$  is the discount rate,  $0 \leq \eta \leq 1$  denotes the share of the consumption good in the consumption-leisure Cobb-Douglas bundle, and  $\xi_t$  denotes a shock to the discount factor which can be interpreted as a demand shock and is

specified in the next section.<sup>6</sup>  $V^{norm}$  is a normalizing constant used to scale discounted lifetime utility in the deterministic steady state to 1.<sup>7</sup>

The household faces the budget constraint

$$(1 + \tau_t^c)C_t(j) + \frac{B_t(j)}{P_t} \leq (1 - \tau_t^l)\frac{W_t(j)}{P_t}N_t(j) + R_{t-1}\frac{B_{t-1}(j)}{P_t} + \Xi_t(j) - \frac{\phi_w}{2} \left( \Pi^{-1} \frac{W_t(j)}{W_{t-1}(j)} - 1 \right)^2 Y_t + T_t, \quad (3.13)$$

where the household earns income from supplying differentiated labor  $l_t(j)$  at the nominal wage rate  $W_t(j)$ , which is taxed at rate  $\tau_t^l$ . In addition, it receives profits  $\Xi_t(j)$  from owning a share of the firms in the economy and a real gross return  $R_{t-1}(B_{t-1}(j)/P_t)$  from investing in a zero net supply riskless nominal bond. The household spends its income on consumption  $C_t(j)$ , taxed at rate  $\tau_t^c$ , real savings in the private bond  $B_t(j)/P_t$ , and to cover the costs of adjusting its wage (the second to last term on the right hand side). Finally, the revenues from consumption and labor taxes are rebated lump-sum via  $T_t$ .

The optimization problem of the household involves maximizing (3.12) subject to the budget constraint (3.13) and the demand for the household's differentiated labor input (3.11).

### 3.3 Monetary Policy

The model is closed by assuming that the central bank follows a Taylor rule that reacts to inflation and output:

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\phi_{R\pi}} \left( \frac{Y_t}{Y_t^{HP}} \right)^{\phi_{Ry}} \right)^{1-\rho_R}. \quad (3.14)$$

Here,  $\rho_R$  is a smoothing parameter introduced to capture the empirical evidence of gradual movements in interest rates,  $\Pi$  is the target inflation rate set by the central bank, and the parameters  $\phi_{R\pi}$  and  $\phi_{Ry}$  capture the responsiveness of the nominal interest rate to deviations of inflation from its steady state value and output from its model-consistent

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<sup>6</sup>Due to this preference shock only affecting the intertemporal margin, it is immaterial for the business cycle accounting exercise as it cancels in the intra-temporal equilibrium condition for labor.

<sup>7</sup>While inconsequential for the results, this improves the numerical behavior of the model solution. See e.g. Rudebusch and Swanson (2012).

Hodrick and Prescott (HP) filter trend  $Y_t^{HP}$ , respectively. The HP filtered output gap is embedded into the dynamic rational expectations model following the approach of Cúrdia et al. (2014) and is implicitly defined through the recursion:<sup>8</sup>

$$\begin{aligned} Y_t^{HP}(1 + 6 \times 1600) + Y_{t-1}^{HP}(-4 \times 1600) + E_t Y_{t+1}^{HP}(-4 \times 1600) + Y_{t-2}^{HP} \times 1600 + E_t Y_{t+2}^{HP} 1600 \\ = Y_t(6 \times 1600) + Y_{t-1}(-4 \times 1600) + E_t Y_{t+1}(-4 \times 1600) + Y_{t-1} 1600 + E_t Y_{t+1} 1600 \end{aligned} \quad (3.15)$$

### 3.4 Shock Processes

The two exogenous processor for the preference shock and the TFP shock follow AR(1)-processes with stochastic volatility:

$$Z_t = \rho_z Z_{t-1} + e^{\sigma_z^z} \varepsilon_t^z \quad (3.16)$$

$$\sigma_t^z = (1 - \rho_{\sigma^z}) \bar{\sigma}^z + \rho_{\sigma^z} \sigma_{t-1}^z + \sigma^{\sigma^z} \varepsilon_t^{\sigma^z} \quad (3.17)$$

$$\xi_t^{pref} = \rho_{pref} \xi_{t-1}^{pref} + e^{\sigma_t^{pref}} \varepsilon_t^{pref} \quad (3.18)$$

$$\sigma_t^{pref} = (1 - \rho_{\sigma^{pref}}) \bar{\sigma}^{pref} + \rho_{\sigma^{pref}} \sigma_{t-1}^{pref} + \sigma^{\sigma^{pref}} \varepsilon_t^{\sigma^{pref}}, \quad (3.19)$$

where the  $\varepsilon_t^i, i \in \{z, pref, \sigma^z, \sigma^{pref}\}$  are standard normally distributed i.i.d. shock processes.

### 3.5 Equilibrium

The use of Rotemberg price and wage adjustment costs implies the existence of representative firm and representative household.<sup>9</sup> We consider a symmetric equilibrium in which all intermediate goods firms charge the same price, labor input and capital stock. Similarly, all households set the same wage, supply the same amount of labor, and will choose the same consumption and savings.

The resource constraint then implies that output is used for consumption, investment

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<sup>8</sup>See their online appendix for details.

<sup>9</sup>This implies that, in contrast to Erceg et al. (2000), we do not need to assume complete markets and separable utility.

and to pay for price and wage adjustment costs:

$$Y_t = C_t + I_t + \frac{\phi_w}{2} \left( \Pi^{-1} \frac{W_t}{W_{t-1}} - 1 \right)^2 Y_t + \frac{\phi_p}{2} \left( \Pi^{-1} \frac{P_t}{P_{t-1}} - 1 \right)^2 Y_t \quad (3.20)$$

### 3.6 Parametrization

Table 1 displays the parametrization of our model. The capital share  $\alpha$  is set to one third and the depreciation rate  $\delta$  to imply an annual depreciation rate of 10 percent. The discount factor  $\beta = 0.99$  implies an interest rate of 4 in steady state. The capital adjustment costs parameter  $\phi_k$  is set to 20, which implies an elasticity of the investment to capital ratio with respect to Tobin's marginal q of 2.<sup>10</sup>

The price adjustment cost parameter  $\phi_p$  is chosen to imply the same slope of the linear New Keynesian Phillips Curve as a Calvo model with a price duration of 1 year (see e.g. Keen and Wang, 2007). Similarly, the wage adjustment costs parameter is chosen to imply the same slope of the linear wage Phillips Curve as a Calvo model with a wage contract duration of 1 year. The two substitution elasticity parameters  $\theta_p$  and  $\theta_w$  are set to 10, which implies a steady state markup of 11% and is an intermediate value between the 5 percent markup estimated in Altig et al. (2011) and the 20 percent found in Justiniano et al. (2013).<sup>11</sup>

We consider a zero inflation steady state, i.e.  $\Pi = 1$ . The Taylor rule parameters are taken from Born and Pfeifer (2014). The risk aversion parameter is set to  $\sigma = 66$ , the value estimated in Binsbergen et al. (2012), while the intertemporal elasticity of substitution,  $\psi$ , is set to 0.5, which is consistent with the estimates in e.g. in Basu and Kimball (2002), Vissing-Jørgensen (2002) and Yogo (2004). The leisure share in the Cobb-Douglas utility bundle  $\eta$  is set to imply a Frisch elasticity of 1.<sup>12</sup> We set the share of overhead labor to 11%, following the evidence of Levitt et al. (2013) that adding a second shift in car manufacturing plants increases labor by 80%. Given that automobile plants run two shifts most of the time, this means overhead labor accounts for  $20/180 = 0.11$  (see Nekarda and

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<sup>10</sup>See Appendix D.

<sup>11</sup>See Born and Pfeifer (2014) for a discussion of the importance of this parameter for the size of uncertainty effects.

<sup>12</sup>See Appendix C.1.

Table 1: Model Parametrization

Parameter	Description	Value	Target
$\alpha$	Capital share parameter	0.0898	Capital share of 1/3
$\beta$	Discount factor	0.99	4% interest rate
$\delta$	Depreciation rate	0.025	10% per year
$\phi_k$	Capital adjustment costs	20	I/K to q elasticity of 2
$\phi_p$	Price adjustment costs	105	Duration of 1 year
$\phi_w$	Wage adjustment costs	593	Duration of 1 year
$\theta_w$	Wage substitution elasticity	10	11% markup
$\theta_p$	Intermed. goods substitution elasticity	10	11% markup
$\Pi$	Steady state gross inflation	1	zero inflation
$\rho_r$	Interest rate smoothing	0.836	Born and Pfeifer (2014)
$\phi_{R\pi}$	Inflation feedback	1.78	Born and Pfeifer (2014)
$\phi_{Ry}$	Output feedback	0.32	Born and Pfeifer (2014)
$\sigma$	Risk aversion	66	Binsbergen et al. (2012)
$\tau^c$	Consumption tax rate	0.094	Sample mean 1964Q2:2014Q4
$\tau^l$	Labor tax rate	0.220	Sample mean 1964Q2:2014Q4
$\chi$	Elasticity of intertemporal substitution	0.5	Basu and Kimball (2002)
$\eta$	Leisure share	0.4582	Frisch elasticity of 1
$\phi^o$	Overhead labor share	0.11	Levitt et al. (2013)/NR
$\psi$	Substitution elasticity CES	0.5	Chirinko (2008)
$\Phi$	Fixed costs	0.0296	0 steady state profits
$Y^{norm}$	PF normalization	1.3578	Steady state output of 1
$V^{norm}$	Util. normalization	0.0015	Steady state output of 1
Exogenous processes			
$\rho_{pref}$	Pref. shock autocorrelation	0.9	Basu and Bundick (2014)
$\rho_{\sigma^{pref}}$	Pref. shock volatility autocorrelation	0.83	Basu and Bundick (2014)
$\bar{\sigma}_{pref}$	Pref. shock volatility	0.02	Basu and Bundick (2014)
$\sigma_{\sigma^{pref}}$	Pref. volatility shock volatility	0.015	Basu and Bundick (2014)
$\rho_z$	TFP. shock autocorrelation	0.99	Basu and Bundick (2014)
$\rho_{\sigma^z}$	TFP. shock volatility autocorrelation	0.83	Basu and Bundick (2014)
$\bar{\sigma}_z$	TFP shock volatility	0.01	Basu and Bundick (2014)
$\sigma_{\sigma^z}$	Pref. volatility shock volatility	0.00372	Basu and Bundick (2014)

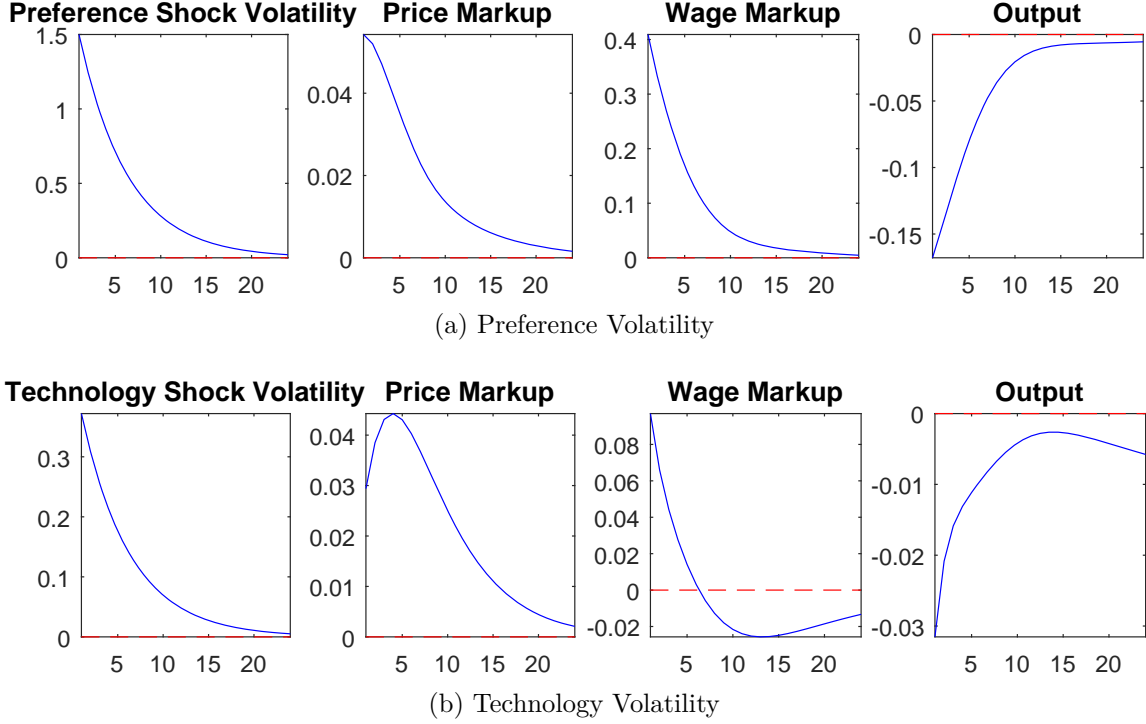


Figure 2: Notes: Model responses are in percentage deviations from the stochastic steady state to a one-standard deviation shock

Ramey, 2013). The fixed costs  $\Phi$  are set to imply 0 profits in steady state, thereby ruling out entry and exit.<sup>13</sup> The substitution elasticity between capital and labor is set to 0.5, the midpoint of the estimates surveyed in Chirinko (2008), implying  $\psi = -1$ . Finally, the exogenous processes are taken from Basu and Bundick (2014).

### 3.7 Model Responses

Figure 2 displays the impulse responses to a one-standard deviation preference uncertainty shock  $\varepsilon_t^{\sigma^{pref}}$  (top panel) and to a one-standard deviation technology uncertainty shock  $\varepsilon_t^{\sigma^z}$  (bottom panel).<sup>14</sup> As predicted by theory, an increase in uncertainty leads to an increase in wedges, both on the firm side and the household side. As output is demand-determined in the short run, output drops.

<sup>13</sup>Note that in contrast to e.g. Smets and Wouters (2007), these fixed costs are non-labor related fixed costs as the latter are captured in the overhead labor share.

<sup>14</sup>IRFs are generalized impulse response functions, shown as percentage deviations from the ergodic mean, computing using third-order perturbation techniques with the pruning algorithm of Andreasen et al. (2013).

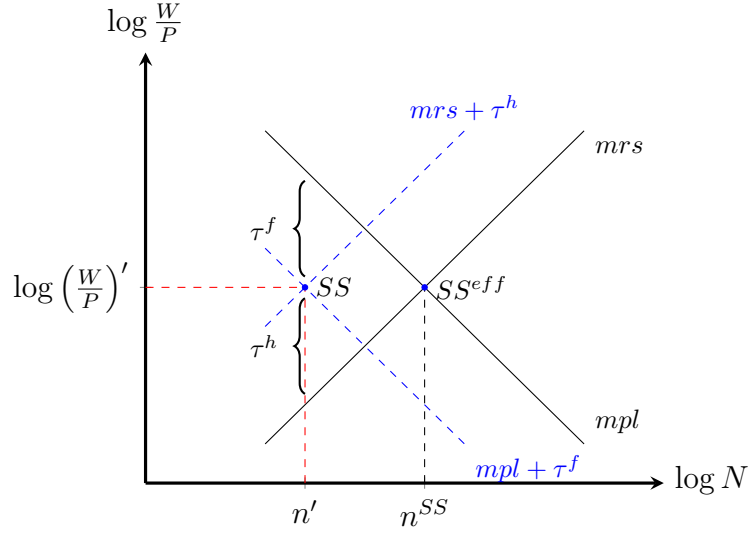


Figure 3: Stylized labor market. Labor supply is characterized by the condition that the log marginal rate of substitution ( $mrs$ ) is equal to the log real wage, while for labor supply curve is characterized by the log marginal product of labor ( $mpl$ ) being equal to the log real wage. The point  $SS^{eff}$  denotes the efficient steady state both are equal. The presence of a household and firm wedge ( $\tau^h$  and  $\tau^f$ ) drives a wedge between the two curves and the real wage, shifting both to the left. In the new equilibrium at  $SS$ , output will be lower due to lower hours worked.

## 4 Constructing Markup Data

In a frictionless model like the basic RBC model, the first order condition governing optimal labor supply is given by

$$MRS_t \frac{1 + \tau_t^c}{1 - \tau_t^l} = \frac{W_t}{P_t} = MPL_t, \quad (4.1)$$

that is, the tax-adjusted marginal rate of substitution is equal to the real wage, which is in turn equal to the marginal product of labor. At a conceptual level, there can be two reasons for this efficiency condition failing in the data. First, on the household side, there may be a wedge between the marginal rate of substitution and the real wage. We denote this household wedge with  $\tau_t^h$ . Similarly, on the firm side, there may be a wedge  $\tau_t^f$  between the marginal product of labor and the real wage. By the definition of these wedges it holds in the data that

$$MRS_t \frac{1 + \tau_t^c}{1 - \tau_t^l} e^{\tau_t^h} = \frac{W_t}{P_t} = e^{-\tau_t^f} MPL_t. \quad (4.2)$$

A schematic description is shown in Figure 3.

Using assumptions on the functional forms governing both the marginal rate of substitution and the marginal product, both wedges can be constructed from the data. Using the felicity function from Section 3, the household wedge is given by

$$e^{\tau_t^h} \frac{1-\eta}{\eta} \frac{C_t}{1-N_t} = \frac{1-\tau_t^l}{1+\tau_t^c} \frac{W_t}{P_t} . \quad (4.3)$$

Expanding this fraction and taking logs,  $\tau_t^h$  can be computed from

$$\tau_t^h = \log \left( \frac{1-\tau_t^l}{1+\tau_t^c} \right) + \log \left( \frac{W_t N_t}{P_t Y_t} \right) + \log \left( \frac{Y_t}{C_t} \right) - \log \left( \frac{1-\eta}{\eta} \right) + \log \left( \frac{1-N_t}{N_t} \right) , \quad (4.4)$$

where the first term after the equal sign is the labor share.<sup>15</sup>

The firm-side wedge  $\tau_t^f$  can be constructed using the CES-production function (3.5). The marginal product of labor is, hence, given by

$$MPL_t = Y^{norm} \left[ \alpha K_t^\psi + (1-\alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}-1} \frac{(1-\alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi}{N_t - N^o} . \quad (4.5)$$

As shown in Appendix G, this can be rewritten as

$$\log(MPL_t) = \log \left( (1-\alpha) (Y^{norm})^\psi \right) + \psi \log \left( e^{Z_t} \right) + (1-\psi) \log \left( \frac{Y_t + \Phi}{N_t - N^o} \right) . \quad (4.6)$$

Thus, the firm wedge can be computed as

$$\tau_t^f = \log \left( (1-\alpha) (Y^{norm})^\psi \right) + \psi \log \left( e^{Z_t} \right) + (1-\psi) \log \left( \frac{Y_t + \Phi}{N_t - N^o} \right) - \log \left( \frac{W_t}{P_t} \right) . \quad (4.7)$$

Figure 4 shows the linearly detrended wedges over time. As already documented in Nekarda and Ramey (2013), the firm wedge tends to have its trough during or shortly after recessions, while its peak happens in the middle of expansions. In contrast, the household wedge tends to peak during recessions. This finding is consistent with evidence presented by Karabarbounis (2014), Shimer (2010), and Galí et al. (2007). But even after subtracting a linear trend, there is still significant low-frequency movement left. Thus, Figure 5 shows the cyclical components of the wedges together with the one of output, obtained by HP-filtering the quarterly series with  $\lambda = 1600$ . Here, the acyclical comovement of the firm wedge and the countercyclical movement of the labor wedge

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<sup>15</sup>Appendix H describes the data sources.



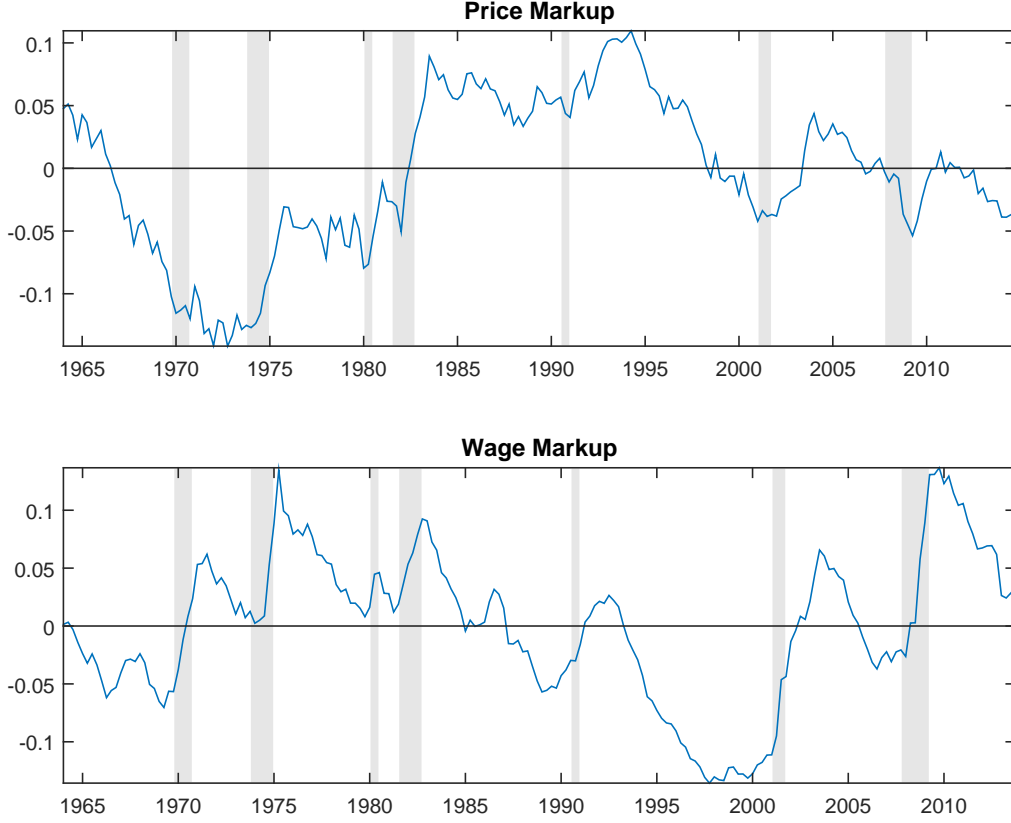


Figure 4: Notes: Evolution of the linearly detrended firm wedge  $\tau_t^f$  and the household wedge  $\tau_t^h$  over time. Grey shaded areas denote NBER recessions.

become clearly visible. This is confirmed by the cross-correlograms depicted in Figure 6. While the firm wedge is acyclical, the correlation becomes negative for leads: a drop in GDP today signals an increase in the price markup in the future. In contrast, the household wedge shows a pronounced countercyclicality.

A first look at the relation between price markups and uncertainty already yields interesting results. As the bottom panel of Figure 6 shows, the picture is the reverse of the comovement with output. The firm wedge is contemporaneously negatively correlated with uncertainty while the household wedge is uncorrelated with it. This does not square well with the model that would predict a positive correlation between these wedges and our measure of uncertainty. To trace out whether the same holds true for the conditional response, we have to employ more sophisticated econometric tools in the next section.

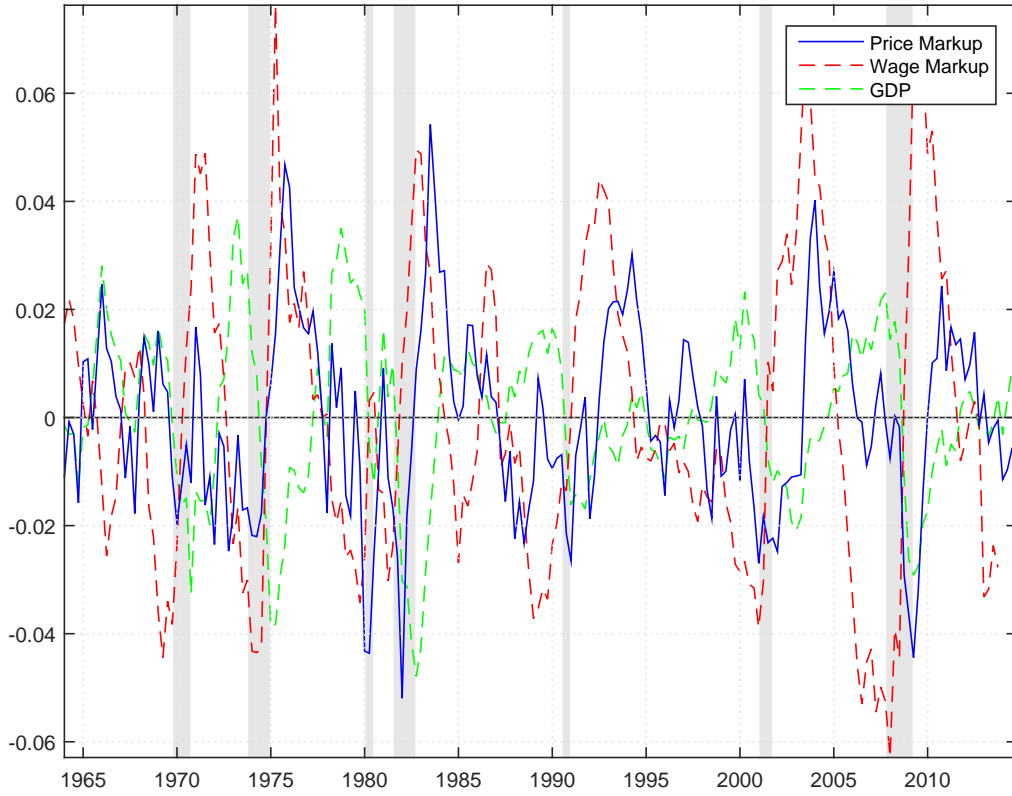
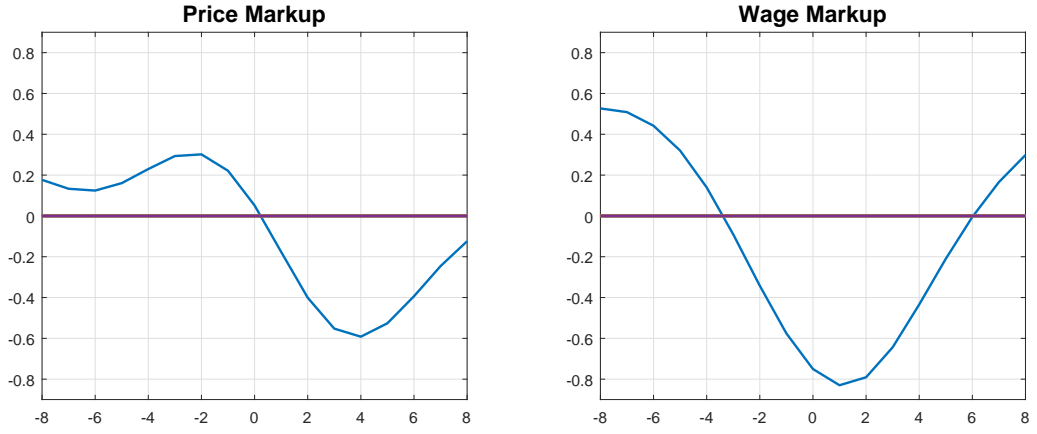
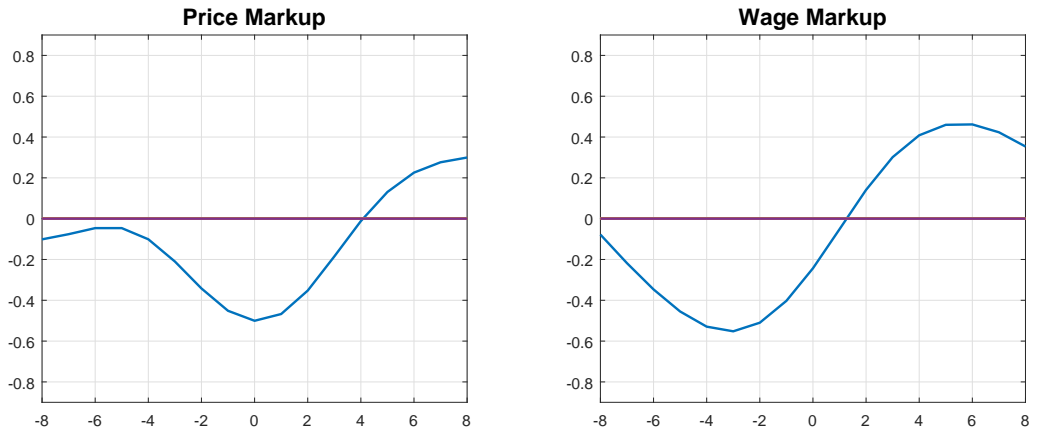


Figure 5: Cyclical component of the firm wedge  $\tau_t^f$  and of the household wedge  $\tau_t^h$  over time. Grey shaded areas denote NBER recessions. Cyclical components are extracted using an HP-filter with  $\lambda = 1600$ .



(a) Cross-correlation with output



(b) Cross-correlation with JLN 12-month ahead uncertainty

Figure 6: Correlation of the cyclical components of  $\tau_{t+j}^f$  and  $\tau_{t+j}^h$  with output  $y_t$  and uncertainty  $\sigma_t$ .

## 5 Empirical approach

Recently, Jurado et al. (2015) proposed an uncertainty measure that is closely linked to the concept of forecast error uncertainty employed in business cycle models. Jurado et al. (2015) stress that it is important to isolate the unpredictable component of uncertainty. They estimate a factor-based forecasting model on 279 monthly economic and financial time series. Given their estimated factors, they then compute forecast errors for 132 of these variables and subsequently use the forecast errors to construct an uncertainty time series for each variable based on the assumption that these follow a stochastic volatility process. Their macroeconomic uncertainty measure is then a common factor of the uncertainty connected to the individual variables. We think that this is currently the broadest and at the same time cleanest uncertainty measure available. Measures like the policy uncertainty index by Baker et al. (2013) have a very narrow focus, while financial market based measures like the VIX or realized (return) volatility are likely to be contaminated by changes in risk aversion and financial market conditions (see e.g. Bekaert et al., 2013; Caldara et al., 2014; Stock and Watson, 2012).

We are ultimately interested in the dynamic response of markups to innovations, or “shocks”, to uncertainty. However, given that the uncertainty measure is available at monthly frequency while we only have quarterly markup data, we will employ two different approaches to deal with this mixed-frequency problem. A Bayesian mixed-frequency VAR estimated via Gibbs sampler following Eraker et al. (2015) and a two-step procedure following Kilian (2009) and Born et al. (2014).

### 5.1 Mixed-frequency VAR

We follow Bloom (2009) and Jurado et al. (2015) and employ a Cholesky-ordering within a monthly VAR framework. The monthly time horizon of the VAR makes the recursive timing assumption more plausible than in a quarterly VAR. Our sample ranges from 1964M1 to 2013M12 for the tax wedge and household wedge and from 1964M1:2014M11 for the firm wedge. As in Jurado et al. (2015), we estimate a 12-variable VAR where

we add our quarterly markup measures as an additional variable observed every third month.<sup>16</sup> The variables in our VAR are 1) the log of real industrial production, 2) the log of total non-farm employment, 3) real personal consumption expenditures, 4) the log of the personal consumption expenditure deflator, 5) the log of real new orders, computed as the sum of the Value of Manufacturers New Order: consumer goods and materials and Value of Manufacturers New Orders: nondefense capital goods, 6) the log of the real wage (real Average Hourly Earnings of Production and Nonsupervisory Workers: Manufacturing), 7) the level of hours worked (Average Weekly Hours of Production and Nonsupervisory Workers: manufacturing), 8) the level of the effective federal funds rate, 9) the logarithm of the S&P 500 Index, 10) the growth rate of the M2 money stock, 11) the 1-step ahead Jurado et al. (2015) uncertainty proxy, and 12) our respective markup measure.<sup>17</sup>

Formally, we estimate the following VAR

$$Y_t = \mu + \alpha t + A(L)Y_{t-1} + \nu_t, \quad (5.1)$$

where  $\mu$  and  $\alpha t$  are constant and time trend, respectively,  $A(L)$  is a lag polynomial of degree  $p$ , and  $\nu_t \sim \mathcal{N}(0, \Sigma)$ . We use  $p=6$ . As mentioned before, the constructed markups are only available at quarterly frequency. To use all available monthly information on the other variables, we assume that we cannot observe the monthly realizations of the markup measure and treat these data as missing values. Following the Bayesian VAR framework outlined in Eraker et al. (2015), we can then employ the Gibbs sampler to deal with these missing observations by sampling the missing data from their conditional distribution. Our priors are of the natural conjugate Normal Inverse Wishart form (see e.g. Koop and Korobilis, 2010; Uhlig, 2005)

$$\alpha | \Sigma \sim \mathcal{N}(\alpha, \Sigma \otimes V^{prior}) \quad (5.2)$$

$$\Sigma \sim IW(S^{prior}, \nu^{prior}) \quad (5.3)$$

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<sup>16</sup>Results are very similar when we estimate Bloom's (2009) 8-variable VAR with uncertainty ordered second.

<sup>17</sup>See McCracken and Ng (2015) for a detailed description of the macro dataset.

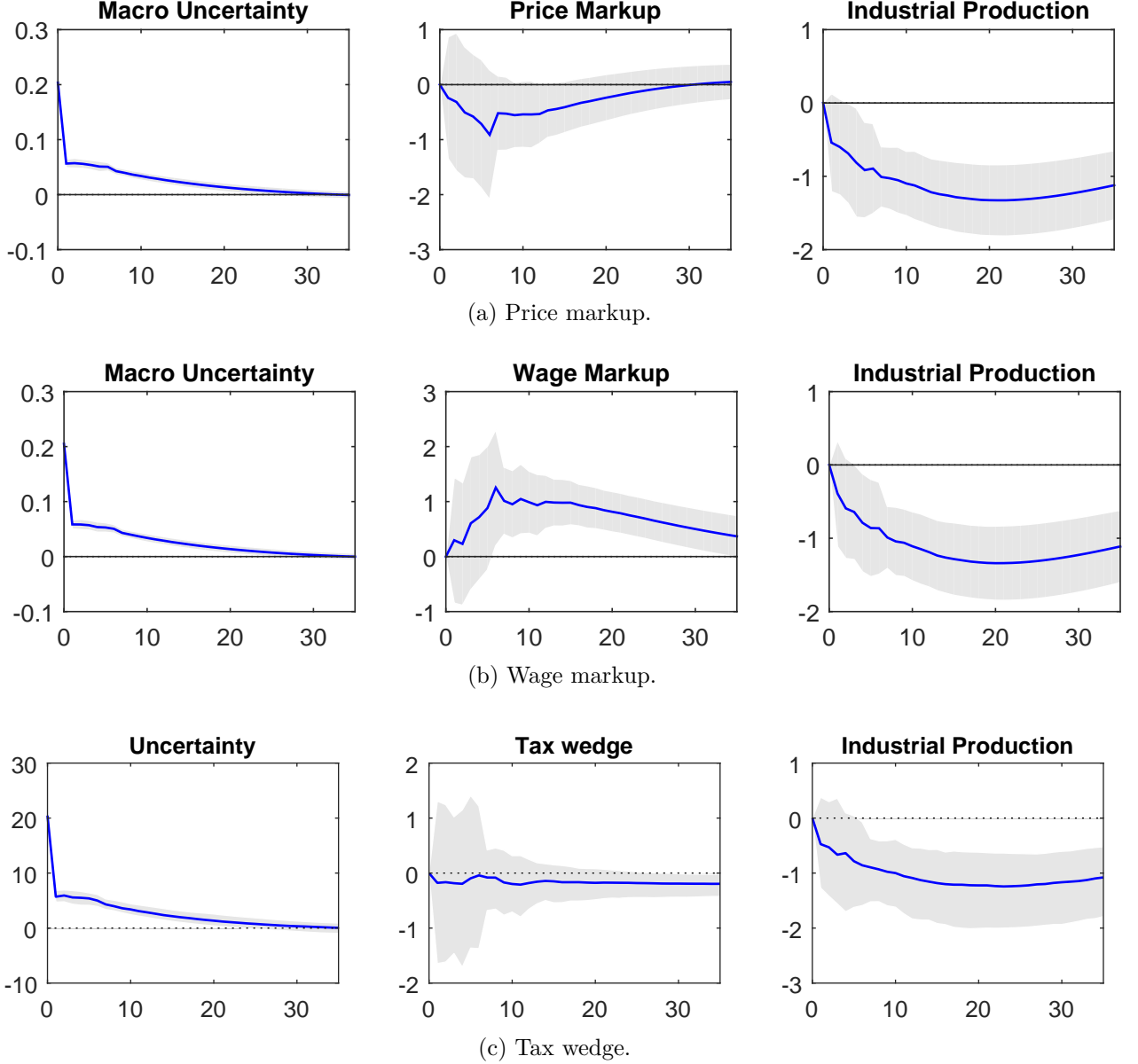


Figure 7: Responses to uncertainty shock in the mixed-frequency VAR. Bands are pointwise 90% HPDIs. The respective wedges are rotated into the VAR as the 12th variable.

where  $\alpha = \text{vec}(A)$ . We set diffuse priors for the constant and linear time trend with a mean of 0 and variance 100. For the lag coefficients, we set the prior means to zero and their variances to 0.5. The hyperparameter  $\nu$  is set to 40. In the Gibbs sampler, 7000 draws are sufficient for convergence. We discard the first 2000 draws as a burn-in.

In terms of identification, we assume a lower-triangular matrix  $B$ , which maps reduced-form innovations  $\nu_t$  into structural shocks  $\varepsilon_t = B\nu_t$ .

Figure 7 presents the impulse responses of the wage and price markup following an economic uncertainty shock. As expected, an increase in uncertainty is associated with a

drop in industrial production. However, the conditional markup response from the VAR partially differs from the one predicted by the model. On impact, the price markup tends to fall. In contrast, the DSGE model implies that the price markup quickly peaks and then declines back to its ergodic mean as the effect of price stickiness subsides over time.

18

However, the movement of the wage markup squares better with the model: it increases after an uncertainty shock and then slowly declines back to steady state. While the model does not predict the same hump-shaped movement, it predicts the same countercyclical movement of the wage markup. This is reassuring for the markup channel in New Keynesian models and the role of uncertainty shocks more generally as empirically most of the movement in the labor wedge comes from this margin.

Lastly, consistent with our modeling assumptions, the tax wedge does not respond to the uncertainty shock (panel c of Figure 7).

Our results suggest that futures studies should focus on the role of sticky wages instead of sticky prices.<sup>19</sup>

## 5.2 Robustness

### Two-step approach

To check the robustness of our results, we also consider a two step approach where, in the first step, in order to identify shocks to uncertainty, we estimate the monthly VAR excluding the markup measures with OLS. In the second step, we then take the identified structural uncertainty innovations and use them to explain fluctuations in quarterly markups and GDP. To this end, we first calculate quarterly averages  $\bar{e}_t = 1/3 \times \sum_{m \in t} \nu_m$  of the monthly uncertainty innovations  $\nu_m$  belonging to the current quarter  $t$ , and then estimate a local projection model (Jordá, 2005) of the form

$$x_{t+h} = \alpha_h + \beta_h t + \gamma_h \bar{e}_t + \Pi_h(L) X_{t-1} + \eta_{t,h} . \quad (5.4)$$

---

<sup>18</sup>This conditional markup response is consistent with the conditional comovement Nekarda and Ramey (2013) found after other types of shocks, which also contradicted the sticky price model.

<sup>19</sup>See also Barattieri et al. (2014), Daly and Hobijn (2014), and Galí (2011) on the importance of sticky wages.

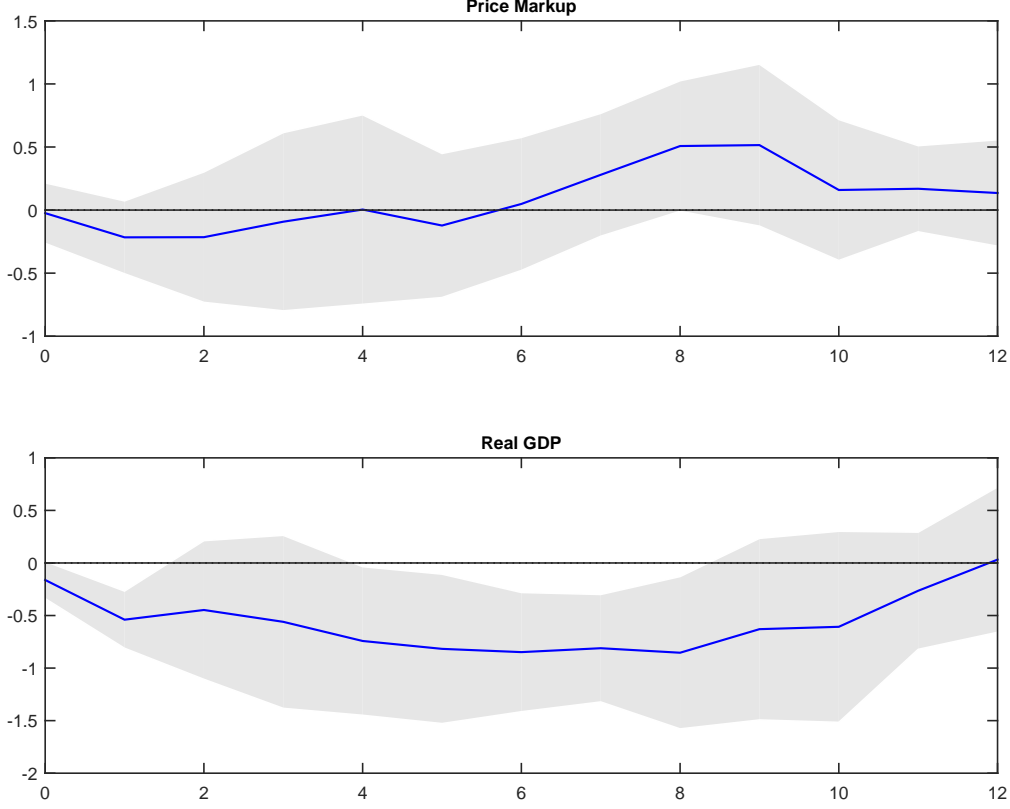


Figure 8: Price markup response to volatility shock from the two-step approach.

Here,  $\gamma_h$  denotes the response of a particular variable  $x_{t+h}$  at horizon  $h$  to an exogenous variation in uncertainty at time  $t$ ,  $\bar{e}_t$ .  $\alpha_h$  and  $\beta_h t$  are constant and time trend, respectively. The matrix  $X_{t-1}$  contains lags of variables we want to control for at quarterly frequency, i.e.  $X_{t-1}$  contains lags of the respective wedge and of quarterly GDP, which has a broader coverage than IP used in the monthly VAR. The error term  $\eta_{t,h}$  is assumed to have a zero mean and strictly positive variance. We estimate model (5.4) using OLS where, in order to improve the efficiency of the estimates, we include the residual of the local projection at  $t + h - 1$  as an additional regressor in the regression for  $t + h$  (see Jordá, 2005).

The advantage of this local projection approach compared to the mixed frequency VAR is that the IRFs to our identified uncertainty shock do not involve the potentially problematic cross-equation restrictions of a VAR. The drawback of course is that we cannot make full use of the information embedded in monthly observations.

Figures 8 and 9 show that the two-step approach yields a similar conclusion to the mixed-frequency VAR.



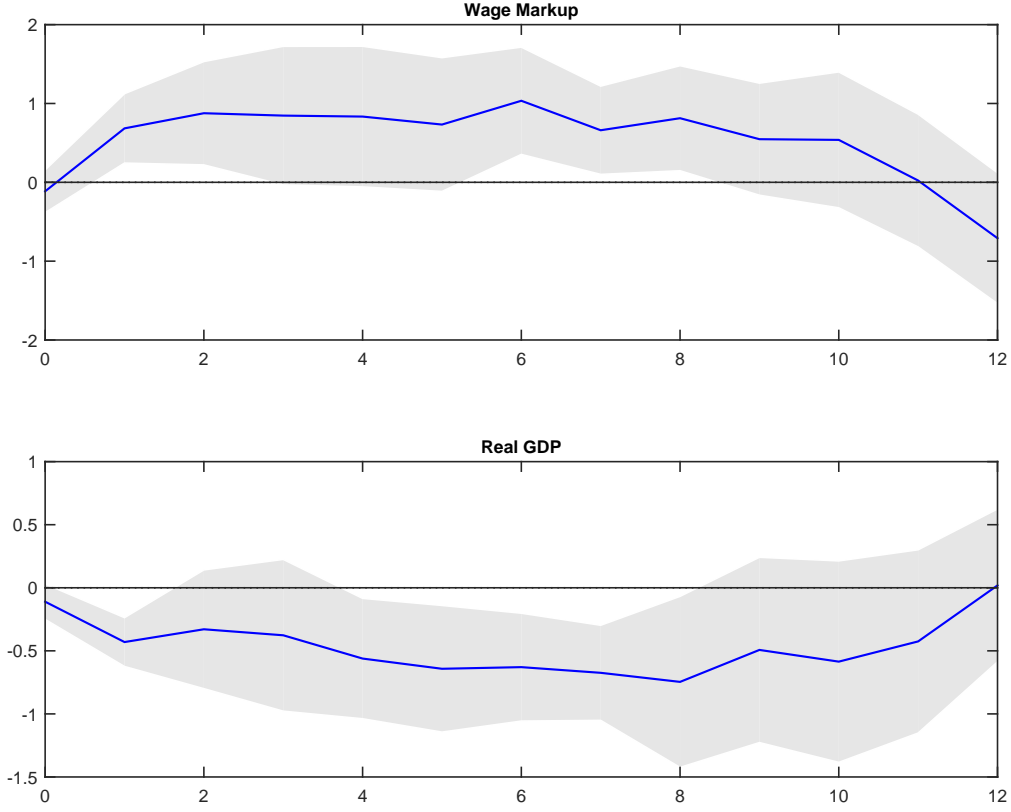


Figure 9: Wage markup response to volatility shock from the two-step approach.

### Bloom (2009) VAR - Uncertainty ordered second

We also consider the original 9-variable VAR from Bloom (2009) where uncertainty, measured by stock market volatility, is ordered second. Uncertainty shocks again are identified recursively and we add our markup measure as a tenth variable. Results from the mixed-frequency estimation are shown in Figure 10. They are very similar to the baseline results, indicating that the ordering of the uncertainty measure is not crucial for our results.

### Stock market volatility as uncertainty proxy in the 11-variable VAR

As Bloom (2009) uses stock market volatility (and specifically the VXO) to measure uncertainty, we also include the VXO instead of the Jurado et al. (2015)-macro uncertainty measure in our baseline VAR (see Figure 11). Results are robust.

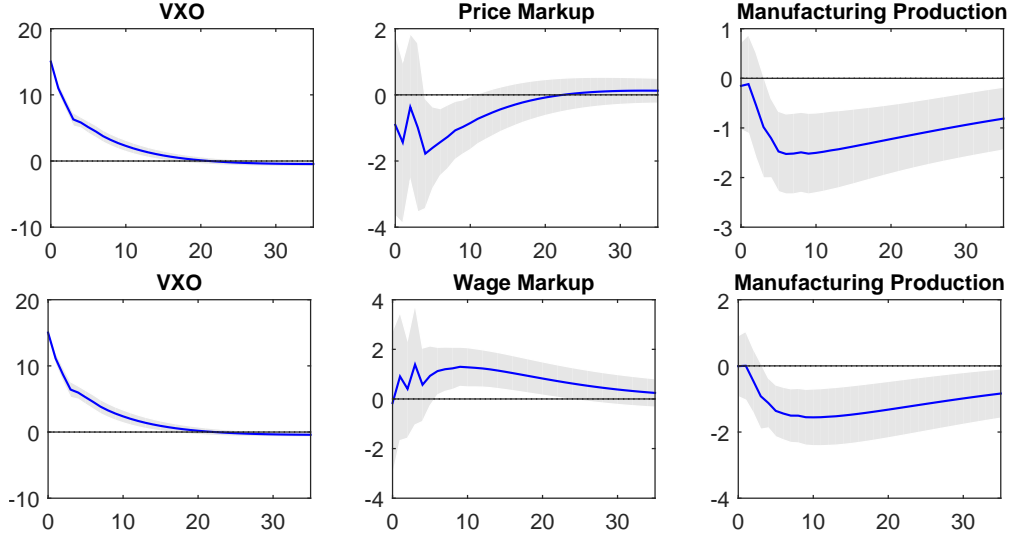


Figure 10: Dynamic responses to uncertainty shocks in the mixed-frequency VAR. Included variables as in Bloom (2009) plus markup measure. Horizontal axis measures months. Bands are pointwise 90% HPDIs.

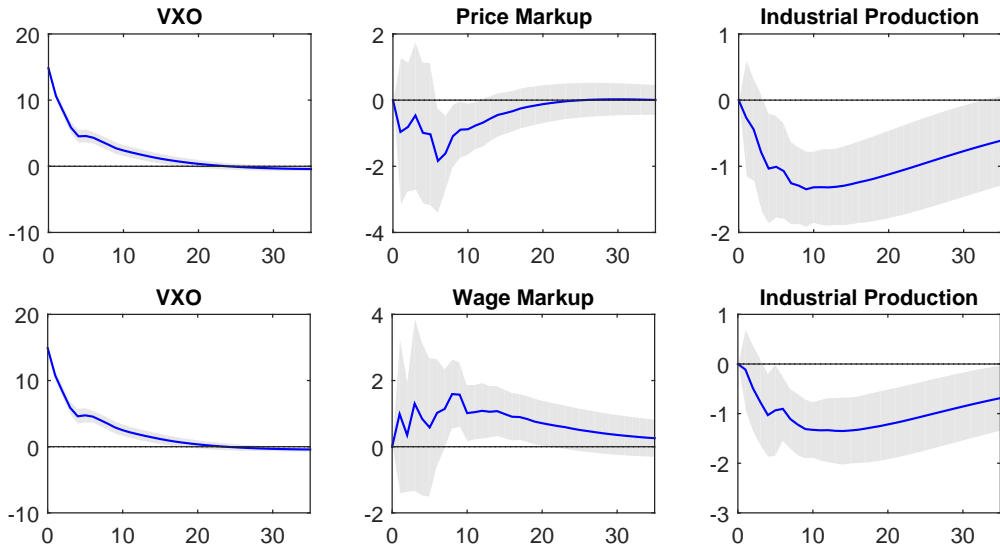


Figure 11: Dynamic responses to uncertainty shocks in the mixed-frequency VAR. Uncertainty measured via the VXO. Horizontal axis measures months. Bands are pointwise 90% HPDIs.

### Alternative markup measurements

In our baseline price markup measure, we employ the utilization-adjusted TFP measure of Fernald (2012). According to Nekarda and Ramey (2013) this is key to obtain an acyclical price markup. In this robustness check, we instead use a utilization-unadjusted TFP measure. This results in a strongly countercyclical price markup (see Figure 12), which, as Nekarda and Ramey (2013) note, is similar to the one constructed in Galí

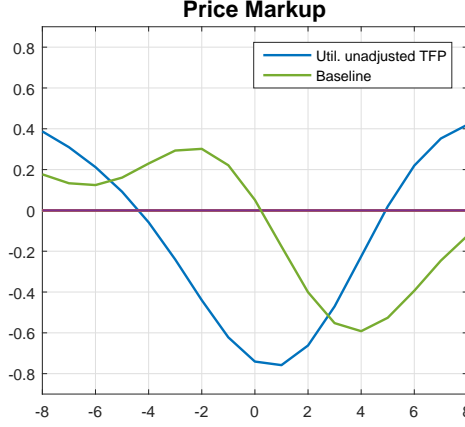


Figure 12: Correlograms of price markups constructed with utilization-adjusted (green line) and unadjusted (blue line) TFP measures.

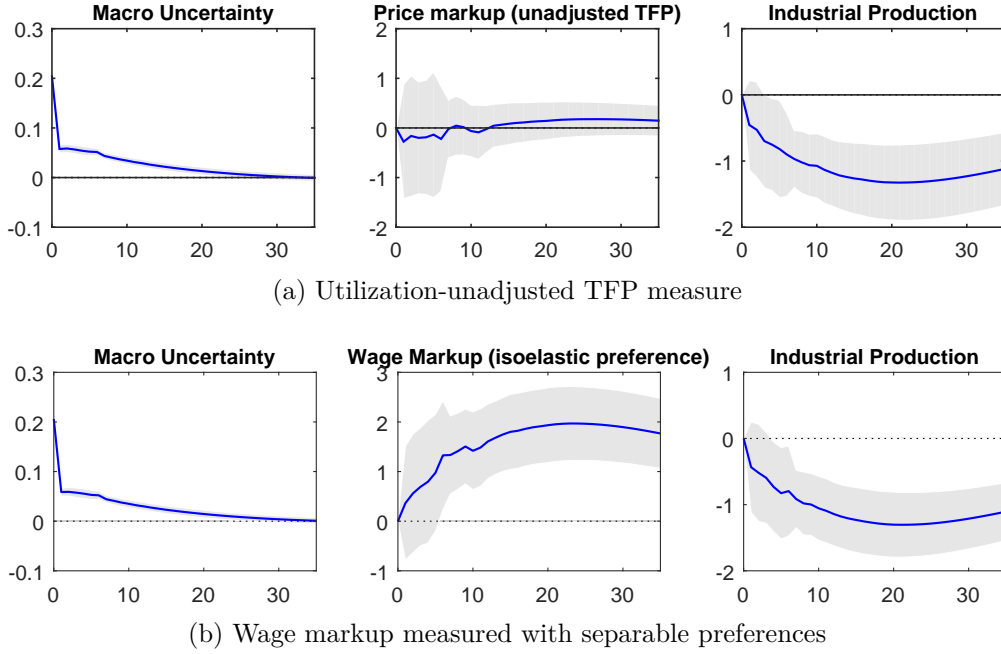


Figure 13: Dynamic responses to uncertainty shocks in the mixed-frequency VAR. Horizontal axis measures months. Bands are pointwise 90% HPDIs.

et al. (2007). Estimating our mixed-frequency with the alternative price markup measure included yields the IRFs reported in Panel (a) of Figure 13. The drop in the price markup is less pronounced than in the baseline but there is still no evidence for an increase.

We also change the preference specification of our setup and construct the wage markup using separable preferences. The results shown in panel (b) of Figure 13 show a somewhat stronger increase in the wage markup, but are otherwise similar to the baseline.

## 6 Conclusion

The question of the markup channel as a viable transmission mechanism of uncertainty shocks into the macroeconomy is highly relevant for the policy debate given that the supposedly negative influence of policy uncertainty has become a recurring theme in the political discourse. With much of the model-based evidence featuring this supposed transmission mechanism it is of paramount importance to subject it to a rigorous empirical assessment. We construct a DSGE model to measure markups and generate theoretical markup responses following uncertainty shocks. We then provide empirical evidence on conditional response of markups to uncertainty shocks. Contrary to the model's prediction, price markups tend to fall. However, wage markups increase after uncertainty shocks, suggesting that future studies should focus on the role of sticky wages instead of sticky prices.

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## A FOCs

The first order conditions of the model after imposing a symmetric equilibrium are given by:

Production function

$$Y_t = Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}} - \Phi. \quad (\text{A.1})$$

Firm FOC for renting  $N_t$

$$\frac{W_t}{P_t} = \Xi_t MPL_t \quad (\text{A.2})$$

where

$$MPL_t = Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}-1} \frac{(1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi}{N_t - N^o} \quad (\text{A.3})$$

which, in the presence of no overhead labor and fixed costs, simplifies to

$$MPL_t = (1 - \alpha) \left( e^{Z_t} \right)^\psi \left( \frac{Y_t}{N_t} \right)^{-\psi}$$

Firm FOC for renting  $K_t$

$$R_t^K = \Xi_t MPK_t \quad (\text{A.4})$$

where

$$MPK_t = Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}-1} \frac{\alpha K_t^\psi}{K_t} \quad (\text{A.5})$$

which, in the presence of no fixed costs, simplifies to

$$MPK_t = \alpha \left( \frac{Y_t}{K_t} \right)^{1-\psi}$$

Firm FOC for  $P_t$

$$\begin{aligned} \phi_p \left[ \Pi^{-1} \frac{P_t}{P_{t-1}} - 1 \right] \Pi^{-1} \frac{P_t}{P_{t-1}} &= (1 - \theta_p) + \theta_p \Xi_t \\ &+ \phi_p \mathbb{E}_t \left\{ M_{t+1} \frac{Y_{t+1}}{Y_t} \left[ \Pi^{-1} \frac{P_{t+1}}{P_t} - 1 \right] \left[ \Pi^{-1} \frac{P_{t+1}}{P_t} \right] \right\} \end{aligned} \quad (\text{A.6})$$

where  $M_t$  is the stochastic discount factor defined below. Firm FOC for capital

$$\begin{aligned} q_t = \mathbb{E}_t \left\{ M_{t+1} \left( R_{t+1}^K + q_{t+1} \left( 1 - \delta - \frac{\phi_K}{2} \left( \frac{I_{t+1}}{K_{t+1}} - \delta \right)^2 \right. \right. \right. \\ \left. \left. \left. + \phi_K \left( \frac{I_{t+1}}{K_{t+1}} - \delta \right) \frac{I_{t+1}}{K_{t+1}} \right) \right) \right\} \end{aligned} \quad (\text{A.7})$$

Firm FOC for investment

$$\frac{1}{q_t} = 1 - \phi_K \left( \frac{I_t}{K_t} - \delta \right) \quad (\text{A.8})$$

Definition value function<sup>20</sup>

$$V_t = \left[ e^{\xi_t^{pref}} V^{norm} \left( C_t^\eta (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} + \beta \left( \mathbb{E}_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{1-\sigma}} \quad (\text{A.9})$$

Definition marginal utility of wealth

$$\lambda_t(1 + \tau_t^c) = V_{C,t}, \quad (\text{A.10})$$

where  $V_{C,t}$  is the first derivative of the value function:

$$V_{C,t} = V_t^{1-\frac{1-\sigma}{\theta_V}} \eta \xi_t^{pref} V^{norm} \frac{1}{C_t} \left( C_t^\eta (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} \quad (\text{A.11})$$

FOC with respect to W

$$\begin{aligned} 0 = & \left[ \xi_t^{pref} V^{norm} \left( C_t^\eta (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} + \beta \left( \mathbb{E}_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_V}} \right]^{\frac{\theta_V}{1-\sigma}-1} \\ & \times \xi_t^{pref} V^{norm} \left( C_t^\eta (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_V}} \frac{1 - \eta}{(1 - N_t)} \theta_w N_t \\ & + \lambda_t \left[ (1 - \theta_w)(1 - \tau_t^l) N_t \frac{W_t}{P_t} - \phi_w \left( \Pi^{-1} \frac{W_t}{W_{t-1}} - 1 \right) \frac{W_t}{\Pi W_{t-1}} Y_t \right] \\ & + \beta \lambda_{t+1} \left[ \phi_w \left( \Pi^{-1} \frac{W_{t+1}}{W_t} - 1 \right) \Pi^{-1} \frac{W_{t+1}}{W_t} Y_{t+1} \right] \end{aligned} \quad (\text{A.12})$$

Definition stochastic discount factor (see Appendix B)

$$M_{t+1} \equiv \frac{\frac{\partial V_t}{\partial C_{t+1}}}{\frac{\partial V}{\partial C_t}} \frac{1 + \tau_t^c}{1 + \tau_{t+1}^c} = \beta \frac{\xi_{t+1}^{pref}}{\xi_t^{pref}} \frac{1 + \tau_t^c}{1 + \tau_{t+1}^c} \left( \frac{C_{t+1}^\eta (1 - N_{t+1})^{1-\eta}}{C_t^\eta (1 - N_t)^{1-\eta}} \right)^{\frac{1-\sigma}{\theta_V}} \left( \frac{C_t}{C_{t+1}} \right) \left( \frac{V_{t+1}^{1-\sigma}}{\mathbb{E}_t [V_{t+1}^{1-\sigma}]} \right)^{1-\frac{1}{\sigma_V}} \quad (\text{A.13})$$

Euler Equation

$$1 = R_t \mathbb{E}_t \left\{ \left( \beta \frac{\xi_{t+1}^{pref}}{\xi_t^{pref}} \frac{1 + \tau_t^c}{1 + \tau_{t+1}^c} \right) \left( \frac{C_{t+1}^\eta (1 - N_{t+1})^{1-\eta}}{C_t^\eta (1 - N_t)^{1-\eta}} \right)^{1-\frac{1}{\sigma_V}} \left( \frac{C_t}{C_{t+1}} \right) \left( \frac{V_{t+1}^{1-\sigma}}{\mathbb{E}_t [V_{t+1}^{1-\sigma}]} \right)^{1-\frac{1}{\sigma_V}} \Pi_{t+1}^{-1} \right\} \quad (\text{A.14})$$

Taylor Rule

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\rho_R} \left( \left( \frac{\Pi_t}{\Pi} \right)^{\phi_{R\pi}} \left( \frac{Y_t}{Y_t^{HP}} \right)^{\phi_{Ry}} \right)^{1-\rho_R}. \quad (\text{A.15})$$

Law of motion for capital

$$K_{t+1} = \left( 1 - \delta - \frac{\phi_K}{2} \left( \frac{I_t}{K_t} - \delta \right)^2 \right) K_t + I_t \quad (\text{A.16})$$

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<sup>20</sup>The implementation of recursive utility in Dynare (Adjemian et al., 2011) requires the introduction of an additional auxiliary variable  $X_t = E_t(V_{t+1})$ .

Definition output gap

$$\begin{aligned}
& Y_t^{HP}(1 + 6 \times 1600) + Y_{t-1}^{HP}(-4 \times 1600) + E_t Y_{t+1}^{HP}(-4 \times 1600) + Y_{t-2}^{HP} \times 1600 + E_t Y_{t+2}^{HP} 1600 \\
& = Y_t(6 \times 1600) + Y_{t-1}(-4 \times 1600) + E_t Y_{t+1}(-4 \times 1600) + Y_{t-1} 1600 + E_t Y_{t+1} 1600
\end{aligned} \tag{A.17}$$

Budget constraint household after imposing that  $B_t/P_t = 0 \forall t$

$$(1 + \tau_t^c)C_t = (1 - \tau_t^l)\frac{W_t}{P_t}N_t + \Xi_t - \frac{\phi_w}{2} \left( \Pi^{-1} \frac{W_t}{W_{t-1}} - 1 \right)^2 Y_t + T_t \tag{A.18}$$

Budget constraint government:

$$\tau_t^c C_t + \tau_t^l \frac{W_t}{P_t} N_t = T_t \tag{A.19}$$

These 19 equations define the evolution of the following 17 variables:  $C_t, I_t, K_t, \lambda_t, M_t, MPL_t, MPK_t, N_t, \Pi_t, q_t, R_t, R_t^K, T_t, V_t, V_{C,t}, \frac{W_t}{P_t}, \Xi_t, Y_t, Y_t^{HP}$

Finally, the exogenous processes for  $Z_t, \sigma_t^z, \xi_t^{pref}$ , and  $\sigma_t^{pref}$  are given by

$$Z_t = \rho_z Z_{t-1} + e^{\sigma_t^z} \varepsilon_t^z \tag{A.20}$$

$$\sigma_t^z = (1 - \rho_{\sigma^z}) \bar{\sigma}^z + \rho_{\sigma^z} \sigma_{t-1}^z + \sigma^{\sigma^z} \varepsilon_t^{\sigma^z} \tag{A.21}$$

$$\xi_t^{pref} = \rho_{pref} \xi_{t-1}^{pref} + e^{\sigma_t^{pref}} \varepsilon_t^{pref} \tag{A.22}$$

$$\sigma_t^{pref} = (1 - \rho_{\sigma^{pref}}) \bar{\sigma}^{pref} + \rho_{\sigma^{pref}} \sigma_{t-1}^{pref} + \sigma^{\sigma^{pref}} \varepsilon_t^{\sigma^{pref}}, \tag{A.23}$$

## B Deriving the Stochastic Discount Factor

The stochastic discount factor is given by

$$M_{t+1} \equiv \frac{\partial V_t / \partial C_{t+1}}{\partial V_t / \partial C_t} \frac{1 + \tau_t^c}{1 + \tau_{t+1}^c} \tag{B.1}$$

where

$$\frac{\partial V}{\partial C_t} = \frac{1}{1 + \tau_t^c} V_t^{1 - \frac{1-\sigma}{\theta_v}} \eta \xi_t^{pref} V^{norm} \frac{\left( C_t^\eta (1 - N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}}}{C_t} \tag{B.2}$$

and, using the envelope theorem,

$$\begin{aligned}
\frac{\partial V_t}{\partial C_{t+1}} &= \frac{\theta_v}{1-\sigma} \left( \xi_t^{pref} V^{norm} \left( C_t^\eta (1-N_t)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}} + \beta \left( E_t V_{t+1}^{1-\sigma} \right)_t^{\frac{1}{\theta_v}} \right)^{\frac{\theta_v}{1-\sigma}-1} \beta \frac{1}{\theta_v} \left( E_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_v}-1} \\
&\quad \times E_t \left( (1-\sigma) V_{t+1}^{-\sigma} \frac{\partial V_{t+1}}{\partial C_{t+1}} \right) \\
&\stackrel{(B.2)}{=} V_t^{1-\frac{1-\sigma}{\theta_v}} \beta \left( E_t V_{t+1}^{1-\sigma} \right)^{\frac{1}{\theta_v}-1} E_t \left( V_{t+1}^{-\sigma} V_{t+1}^{1-\frac{1-\sigma}{\theta_v}} \eta \xi_{t+1}^{pref} V^{norm} \frac{\left( C_{t+1}^\eta (1-N_{t+1})^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}}}{C_{t+1}} \right)
\end{aligned} \tag{B.3}$$

Thus,

$$M \equiv \frac{\frac{\partial V_t}{\partial C_{t+1}}}{\frac{\partial V}{\partial C_t}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} = \beta E_t \frac{\xi_{t+1}^{pref}}{\xi_t^{pref}} \frac{1+\tau_t^c}{1+\tau_{t+1}^c} \left( \frac{C_{t+1}^\eta (1-N_{t+1})^{1-\eta}}{C_t^\eta (1-N_t)^{1-\eta}} \right)^{\frac{1-\sigma}{\theta_v}} \frac{C_t}{C_{t+1}} \left( \frac{V_{t+1}^{1-\sigma}}{E_t V_{t+1}^{1-\sigma}} \right)^{1-\frac{1}{\theta_v}} \tag{B.4}$$

## C Calibration

### C.1 Frisch Elasticity

This section shows how to compute the Frisch elasticity of labor supply for our model. The resulting expression will be used in steady state computations to determine the weight of leisure in the Cobb-Douglas felicity function, i.e. when determining  $\eta$ . As shown in e.g. Domeij and Floden (2006), the Frisch elasticity  $\eta^\lambda$  can be computed from:

$$\eta^\lambda = \frac{U_N(C, N)}{\left( U_{NN}(C, N) - \frac{U_{CN}^2(C, N)}{U_{CC}}(C, N) \right)} \frac{1}{N} \tag{C.1}$$

For the felicity function

$$U(C, N) = \frac{\left( C^\eta (1-N)^{1-\eta} \right)^{\frac{1-\sigma}{\theta}}}{1-\sigma} = \frac{C^{\eta(1-\sigma)} (1-N)^{(1-\eta)\frac{(1-\sigma)}{\theta}}}{1-\sigma}, \tag{C.2}$$

where we suppress the subscript on  $\theta_V$ , we get

$$U_N = -\frac{(1-\eta)}{\theta} (C^\eta)^{1-\sigma} (1-N)^{(1-\eta)\frac{(1-\sigma)}{\theta}-1} = -\frac{(1-\eta)}{\theta} (1-\sigma) \frac{U(C, N)}{(1-N)} \quad (\text{C.3})$$

$$U_{NN} = (1-\eta) \frac{(1-\sigma)}{\theta} \left( (1-\eta) \frac{(1-\sigma)}{\theta} - 1 \right) \frac{U(C, N)}{(1-N)^2} \quad (\text{C.4})$$

$$U_C = \frac{\eta}{\theta} C^{\eta\frac{(1-\sigma)}{\theta}-1} (1-N)^{(1-\eta)(1-\sigma)} = \eta \frac{(1-\sigma)}{\theta} \frac{U(C, N)}{C} \quad (\text{C.5})$$

$$U_{CC} = \eta \left( \eta \frac{(1-\sigma)}{\theta} - 1 \right) \frac{(1-\sigma)}{\theta} \frac{U(C, N)}{C^2} \quad (\text{C.6})$$

$$\begin{aligned} U_{CN} &= -\eta \frac{(1-\eta)}{\theta} \frac{(1-\sigma)}{\theta} C^{\eta\frac{(1-\sigma)}{\theta}-1} (1-N)^{(1-\eta)\frac{(1-\sigma)}{\theta}-1} \\ &= -\eta (1-\eta) \frac{(1-\sigma)}{\theta} \frac{(1-\sigma)}{\theta} \frac{U(C, N)}{C(1-N)} \end{aligned} \quad (\text{C.7})$$

After a lot of tedious algebra, we get that

$$\eta^\lambda = \frac{U_N(C, N)}{\left( U_{NN}(C, N) - \frac{U_{CN}^2(C, N)}{U_{CC}}(C, N) \right)} \frac{1}{N} = \frac{1 - \eta \frac{(1-\sigma)}{\theta}}{1 - \frac{(1-\sigma)}{\theta}} \frac{1-N}{N} \quad (\text{C.8})$$

## D Investment Adjustment Costs

The FOC for investment implies

$$\frac{1}{q_t} = 1 - \phi_K \left( \frac{I_t}{K_t} - \delta \right), \quad (\text{D.1})$$

which can be written as

$$\log \left( \frac{I_t}{K_t} \right) = \log \left( \frac{1}{\phi_K} - \frac{1}{\phi_K} e^{-\log q_t} + \delta \right) \quad (\text{D.2})$$

The elasticity of the investment to capital-ratio with respect to Tobin's  $q$  is then given by

$$\frac{\partial \log \left( \frac{I_t}{K_t} \right)}{\partial \log q_t} = \frac{1}{\frac{1}{\phi_K} - \frac{1}{\phi_K} e^{-\log q_t} + \delta} \left( -\frac{1}{\phi_K} e^{-\log q_t} (-1) \right) \quad (\text{D.3})$$

In steady state, this evaluates to:

$$\frac{\partial \log \left( \frac{I}{K} \right)}{\partial \log q} = \frac{1}{\delta} \frac{1}{\phi_K} \quad (\text{D.4})$$

## E Steady State

The stochastic discount factor, equation (A.13) in steady state evaluates to

$$M = \beta, \quad (\text{E.1})$$

while the first order condition for investment, equation (A.8), gives Tobin's marginal  $q$ :

$$q = 1 \quad (\text{E.2})$$

Plugging this into (A.7) implies

$$R_K = \frac{1}{\beta} - (1 - \delta) \quad (\text{E.3})$$

and the pricing FOC, (A.6) in steady state implies that

$$\Xi = \frac{\theta_p - 1}{\theta_p} \quad (\text{E.4})$$

The wage setting FOC, (A.12) implies

$$\begin{aligned} & \left[ V^{norm} \left( C^\eta (1 - N)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}} + \beta \left( V^{1-\sigma} \right)^{\frac{1}{\theta_v}} \right]^{\frac{\theta_v}{1-\sigma}-1} V^{norm} \left( C^\eta (1 - N)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}} \frac{1-\eta}{1-N} \theta_w N \\ &= \frac{V_C}{1 + \tau^c} \left[ (\theta_w - 1) (1 - \tau_t^l) \frac{W}{P} N \right] \end{aligned} \quad (\text{E.5})$$

Using the definition of marginal utility, (A.11),

$$V_C = V^{1-\frac{1-\sigma}{\theta_v}} \eta V^{norm} \frac{\left( C^\eta (1 - N)^{1-\eta} \right)^{\frac{1-\sigma}{\theta_v}}}{C} \quad (\text{E.6})$$

equation (E.5) reduces to

$$\frac{1-\eta}{1-N} \theta_w = \frac{\eta}{1 + \tau^c} \frac{1}{C} \left[ (\theta_w - 1) (1 - \tau^l) \frac{W}{P} \right] \quad (\text{E.7})$$

With net output normalized to 1 by appropriately setting  $Y^{norm}$ , which is determined later, and the labor and capital share given by  $\aleph$  and  $1 - \aleph$ , respectively, we have

$$\aleph = \frac{\frac{W}{P} N}{Y} = \frac{\frac{W}{P} N}{1} \Rightarrow W/P = \frac{\aleph}{N} \quad (\text{E.8})$$

and similarly

$$K = \frac{1 - \aleph}{R^K} \quad (\text{E.9})$$

Equation (E.9) can be used with equation (E.3) to directly compute  $K$  and via the law of motion for capital, equation (A.16), also investment  $I$ :

$$I = \delta K \quad (\text{E.10})$$

Next, substituting for real wage in (E.7) from (E.8) one obtains

$$\frac{1-\eta}{\eta} \frac{C}{1-N} = \frac{\theta_w - 1}{\theta_w} \frac{1 - \tau^l}{1 + \tau^c} \frac{\aleph}{N} \quad (\text{E.11})$$

Solving this equation for consumption yields

$$C = \frac{\theta_w - 1}{\theta_w} \frac{1 - \tau^l}{1 + \tau^c} \aleph \frac{1 - N}{N} \frac{\eta}{1 - \eta} \quad (\text{E.12})$$

Consolidating the household and government budget constraints, equations (A.18) and (A.19), and using equation (E.10) yields:

$$C + \delta K = Y = 1 \quad (\text{E.13})$$

Plugging in from (E.12) for consumption yields

$$\frac{\theta_w - 1}{\theta_w} \frac{1 - \tau^l}{1 + \tau^c} \aleph \frac{1 - N}{N} \frac{1 - \eta}{\eta} + \delta K = 1, \quad (\text{E.14})$$

where K is already known from (E.9).

The Frisch elasticity  $\eta^\lambda$  is calibrated to 1. From (C.8) then follows that

$$\eta = \frac{\theta}{1 - \sigma} \left[ 1 - \left( 1 - \frac{1 - \sigma}{\theta} \right) \frac{N}{1 - N} \right] \quad (\text{E.15})$$

Plugging in from (E.15) into (E.14), one obtains a nonlinear equation for  $N$ :

$$0 = \frac{\theta_w - 1}{\theta_w} \frac{1 - \tau^l}{1 + \tau^c} \aleph \frac{1 - N}{N} \frac{1 - \frac{\theta}{1 - \sigma} \left( 1 - \left( 1 - \frac{1 - \sigma}{\theta} \right) \frac{N}{1 - N} \right)}{\frac{\theta}{1 - \sigma} \left( 1 - \left( 1 - \frac{1 - \sigma}{\theta} \right) \frac{N}{1 - N} \right)} + \delta K - 1 \quad (\text{E.16})$$

This equation is solved for hours worked  $N$ . Consumption immediately follows from (E.12),  $\eta$  from (E.15), the real wage from (E.8). For numerical reasons,  $V$  in equation (A.9) is normalized to 1 by setting

$$V^{norm} = \frac{1 - \beta}{(C^\eta (1 - N)^{1 - \eta})^{\frac{1 - \sigma}{\theta_V}}} \quad (\text{E.17})$$

Up to this point, we have assumed that output is normalized to 1. We are now in a position to compute the variables and parameters of the production side of our model, including the normalizing technology factor  $Y^{norm}$  that allowed working with  $Y = 1$ .

Fixed costs  $\Phi$  are set equal to steady state profits, which are the difference between output and factor payments:

$$\Phi = Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} - K R^K - W N \quad (\text{E.18})$$

With technology being in steady state, i.e.  $Z=0$ , the firm FOCs, equations (3.8)-(A.5),



imply:

$$R^K = \Xi Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi} - 1} \alpha K^{\psi - 1} \quad (\text{E.19})$$

$$\frac{W}{P} = \Xi Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi} - 1} (1 - \alpha) (N - N^o)^\psi \frac{1}{N - N^o} \quad (\text{E.20})$$

so that (E.18) with  $N^o = \phi_o N$  becomes

$$\begin{aligned} \Phi &= Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} \\ &\quad - \Xi Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi} - 1} \alpha K^\psi \\ &\quad - \Xi Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi} - 1} (1 - \alpha) (N - N^o)^\psi \frac{N}{N - N^o} \\ &= Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} \left( 1 - \Xi \frac{\alpha K_t^\psi + (1 - \alpha) (N - N^o)^\psi \frac{1}{(1 - \phi_o)}}{\alpha K_t^\psi + (1 - \alpha) (N_t - N^o)^\psi} \right) \end{aligned} \quad (\text{E.18'})$$

In the absence of overhead labor, this reduces to

$$\Phi = (1 - \Xi) Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}}$$

Net output  $Y$  is given by production minus fixed costs:

$$\begin{aligned} Y &= Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} - \Phi \\ &\stackrel{\text{E.18'}}{=} Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} \Xi \frac{\alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \frac{1}{(1 - \phi_o)}}{\alpha K^\psi + (1 - \alpha) (N - N^o)^\psi}, \end{aligned} \quad (\text{E.21})$$

which in the absence of overhead labor reduces to

$$Y = Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}}.$$

Equation (E.21) implies that the normalizing technology factor  $Y^{norm}$  is given by

$$Y^{norm} = \left[ \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} \Xi \frac{\left( \alpha K_t^\psi + (1 - \alpha) (N - N^o)^\psi \frac{1}{(1 - \phi_o)} \right)}{\left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)} \right]^{-1} \quad (\text{E.22})$$

All the previous equations require knowledge of the labor share parameter  $\alpha$ , which is not a true structural parameter in the sense that it depends on the units of the model variables (see Cantore and Levine, 2012, for details). It can be computed from the actual labor share  $\aleph$  using

$$\begin{aligned}
1 - \aleph &= \frac{KR^K}{Y} = \frac{\Xi Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi} - 1} \alpha K^{\psi - 1}}{Y^{norm} \left( \alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \right)^{\frac{1}{\psi}} \Xi \frac{\alpha K^\psi + (1 - \alpha) (N - N^o)^\psi \frac{1}{1 - \phi_o}}{\alpha K^\psi + (1 - \alpha) (N - N^o)^\psi}} \\
&= \frac{\alpha K^\psi}{\alpha K^\psi + (1 - \alpha) \left( N - \bar{N}^o \right)^\psi \frac{1}{1 - \phi_o}} \tag{E.23}
\end{aligned}$$

Solving for  $\alpha$  yields

$$\alpha = \frac{\aleph (N - N^o)^\psi \frac{1}{1 - \phi_o}}{(1 - \aleph) K^\psi + \aleph (N - N^o)^\psi \frac{1}{1 - \phi_o}} , \tag{E.24}$$

allowing us to compute the normalizing technology factor  $Y^{norm}$  from (E.22) and the fixed costs  $\Phi$  from (E.18').

We also need to compute the steady states of our auxiliary variables in the model. The steady state price markup is given by

$$\mu = \frac{P}{MC} = \frac{1}{\Xi} = \frac{\theta_p}{\theta_p - 1} \tag{E.25}$$

This markup is equal to the inverse of the firm labor wedge between the marginal product of labor and real wage, as can be immediately seen from

$$W = (1 - \alpha) \Xi A N^{-\alpha} K^\alpha = \Xi M P N \tag{E.26}$$

The wage markup between marginal rate of substitution, which is

$$MRS = \frac{1 - \eta}{\eta} \frac{C}{1 - N} , \tag{E.27}$$

and the real wage is given by

$$\tau^f = \frac{\theta_w}{\theta_w - 1} . \tag{E.28}$$

## F Wage Phillips Curve

### F.1 The Calvo Problem

The household chooses the optimal wage  $W_t^*$  to solve the following generic program

$$\begin{aligned}
&\max_{W_t^*} E_t \sum_{k=0}^{\infty} (\beta \theta_w)^k U \left( C_{t+k|t}, N_{t+k|t} \right) \\
&s.t. \\
&N_{t+k|t} = \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \\
&(1 + \tau_{t+k}^c) P_{t+k} C_{t+k|t} = (1 - \tau_{t+k}^l) W_t^* N_{t+k|t}
\end{aligned}$$

where e.g.  $N_{t+k|t}$  denotes the labor supply in period  $t+k$  conditional on having reset the wage the last time at time  $t$  and all terms not related to consumption, the wage and labor supply have been omitted. The Lagrangian is then given by

$$L = \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left[ U \left( C_{t+k|t}, \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \right) - \lambda_{t+k|t} \left\{ (1 + \tau_{t+k}^c) P_{t+k} C_{t+k|t} - (1 - \tau_{t+k}^l) W_t^* \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \right\} \right] \quad (\text{F.1})$$

The FOC for consumption is given by

$$(1 + \tau_{t+k}^c) \lambda_{t+k|t} P_{t+k} = U_{C,t+k|t} \quad (\text{F.2})$$

while the FOC for  $W_t^*$  is given by

$$0 = \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left[ U_N \left( C_{t+k|t}, \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \right) (-\varepsilon_w) \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} \frac{N_{t+k}}{W_t^*} + \lambda_{t+k|t} \left\{ (1 - \varepsilon_w) (1 - \tau_{t+k}^l) \left( \frac{W_t^*}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \right\} \right] \quad (\text{F.3})$$

This can be rewritten as

$$0 = \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left[ N_{t+k} \left( \frac{\varepsilon_w}{\varepsilon_w - 1} (1 + \tau_{t+k}^c) \frac{U_{N,t+k}}{U_{C,t+k}} + (1 - \tau_{t+k}^l) \frac{W_t^*}{P_{t+k}} \right) \right] \quad (\text{F.4})$$

Defining the marginal rate of substitution

$$MRS_t = - \frac{U_{N,t}}{U_{C,t}} \quad (\text{F.5})$$

this is equal to

$$0 = \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left[ N_{t+k} \frac{\varepsilon_w}{\varepsilon_w - 1} (1 + \tau_{t+k}^c) MRS_{t+k|t} - N_{t+k} (1 - \tau_{t+k}^l) \frac{W_t^*}{P_{t+k}} \right] \quad (\text{F.6})$$

Performing a log-linearization around the deterministic steady state and suppressing tax deviations from steady state yields

$$0 = \sum_{k=0}^{\infty} (\beta\theta_w)^k E_t \left[ N \frac{\varepsilon_w}{\varepsilon_w - 1} (1 + \tau^c) MRS \left( \hat{N}_{t+k} + \widehat{MRS}_{t+k|t} \right) - N (1 - \tau^l) \frac{W^*}{P} \left( \hat{N}_{t+k|t} + \hat{W}_t^* - \hat{P}_{t+k} \right) \right] \quad (\text{F.7})$$

or

$$\hat{W}_t^* = (1 - \beta\theta_w) \sum_{k=0}^{\infty} (\beta\theta)^k E_t [\widehat{MRS}_{t+k|t} + \hat{P}_{t+k}] \quad (\text{F.8})$$

In order to derive the New Keynesian Wage Phillips Curve, one needs to write the previous equation recursively. To do this,  $\widehat{MRS}_{t+k|t}$  needs to be replaced by an expression not depending on the initial period. The marginal rate of substitution in our model is given by

$$MRS_t = \frac{1 - \eta}{\eta} \frac{C_t}{1 - N_t} \quad (\text{F.9})$$

so that

$$\widehat{MRS}_{t+k|t} = \hat{C}_{t+k|t} + \frac{N}{1 - N} \hat{N}_{t+k|t} \quad (\text{F.10})$$

Using the average rate of marginal substitution in the economy,

$$\widehat{MRS}_{t+k} = \hat{C}_{t+k} + \frac{N}{1 - N} \hat{N}_{t+k} \quad (\text{F.11})$$

equation (F.10) can be written as

$$\widehat{MRS}_{t+k|t} = \hat{C}_{t+k} + \frac{N}{1 - N} \hat{N}_{t+k} + \frac{N}{1 - N} (\hat{N}_{t+k|t} - \hat{N}_{t+k}) \quad (\text{F.12})$$

Note that this is the step where generally the presence of complete markets is required in order for consumption to not be idiosyncratic. Using the demand function for labor of variety  $j$

$$\hat{N}_{t+k|t} = -\varepsilon_w (\hat{W}_t^* - \hat{W}_{t+k}) + \hat{N}_{t+k} \quad (\text{F.13})$$

This can be written as

$$\widehat{MRS}_{t+k|t} = \widehat{MRS}_{t+k} - \varepsilon_w \frac{N}{1 - N} (\hat{W}_t^* - \hat{W}_{t+k}) \quad (\text{F.14})$$

This can be substituted into equation (F.8) to yield

$$\hat{W}_t^* = (1 - \beta\theta_w) \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left[ \widehat{MRS}_{t+k} - \varepsilon_w \frac{N}{1 - N} (\hat{W}_t^* - \hat{W}_{t+k}) + \hat{P}_{t+k} \right] \quad (\text{F.15})$$

which implies

$$\hat{W}_t^* = \frac{(1 - \beta\theta_w)}{1 + \varepsilon_w \frac{N}{1 - N}} \sum_{k=0}^{\infty} (\beta\theta)^k E_t \left[ \widehat{MRS}_{t+k} + \varepsilon_w \frac{N}{1 - N} \hat{W}_{t+k} + \hat{P}_{t+k} \right] \quad (\text{F.16})$$

This can be written recursively as

$$\hat{W}_t^* = (1 - \beta\theta_w) \left( \hat{W}_t + \frac{1}{1 + \varepsilon_w \frac{N}{1 - N}} (\widehat{MRS}_t - (\hat{W}_t - \hat{P}_t)) \right) + \beta\theta_w E_t \hat{W}_{t+1}^* \quad (\text{F.17})$$

Defining

$$\hat{\mu}_t^W \equiv (\hat{W}_t - \hat{P}_t) - \widehat{MRS}_t \quad (\text{F.18})$$

In the Calvo case, the evolution of the price level is given by

$$W_t = \left[ (1 - \theta_w) (W_t^*)^{1-\varepsilon_w} + \theta_w W_{t-1}^{\varepsilon_w} \right]^{\frac{1}{1-\varepsilon_w}} \quad (\text{F.19})$$

or in linearized form

$$\hat{W}_t^* = \frac{1}{1 - \theta_w} \hat{W}_t - \frac{\theta_w}{1 - \theta_w} \hat{W}_{t-1} \quad (\text{F.20})$$

After plugging (F.20) into (F.17),

$$\frac{1}{1 - \theta_w} \hat{W}_t - \frac{\theta_w}{1 - \theta_w} \hat{W}_{t-1} = (1 - \beta\theta_w) \left( \hat{W}_t - \frac{1}{1 + \varepsilon_W \frac{N}{1-N}} \hat{\mu}_t^W \right) + \beta\theta_w E_t \left( \frac{1}{1 - \theta_w} \hat{W}_{t+1} - \frac{\theta_w}{1 - \theta_w} \hat{W}_t \right) \quad (\text{F.21})$$

After some tedious algebra and defining  $\hat{\Pi}_t^w = \frac{W_t}{W_{t-1}}$ , the New Keynesian Wage Phillips Curve follows as

$$\hat{\Pi}_t^w = \beta E_t \hat{\Pi}_{t+1}^w - \frac{(1 - \theta_w)(1 - \beta\theta_w)}{\theta_w \left( 1 + \varepsilon_W \frac{N}{1-N} \right)} \hat{\mu}_t^W \quad (\text{F.22})$$

## F.2 Rotemberg Problem

The Rotemberg firm problem is given by the following program

$$\begin{aligned} & \max_{W_t} E_t \sum_{k=0}^{\infty} (\beta\theta_w)^k U(C_{t+k}, N_{t+k}|t) \\ & s.t. \\ & N_{t+k}(j) = \left( \frac{W_{t+k}(j)}{W_{t+k}} \right)^{-\varepsilon_w} N_{t+k} \\ & (1 + \tau_{t+k}^c) P_{t+k} C_{t+k} = (1 - \tau_{t+k}^l) W_{t+k}(j) N_{t+k}(j) - \frac{\phi_w}{2} \left( \frac{W_{t+k}(j)}{W_{t+k-1}(j)} - 1 \right)^2 P_{t+k} Y_{t+k} \end{aligned}$$

The corresponding first order condition for the optimal wage is given by

$$\begin{aligned} 0 = & U_N \left( C_t, \left( \frac{W_t(j)}{W_t} \right)^{-\varepsilon_w} N_t \right) (-\varepsilon_w) \left( \frac{W_t(j)}{W_t} \right)^{-\varepsilon_w} \frac{N_t}{W_t(j)} \\ & + \lambda_t \left\{ (1 - \varepsilon_w) (1 - \tau_t^l) \left( \frac{W_t(j)}{W_t} \right)^{-\varepsilon_w} N_t - \phi_w \left( \frac{W_t(j)}{W_{t-1}(j)} - 1 \right) P_t \frac{Y_t}{W_{t-1}(j)} \right\} \\ & - E_t \lambda_{t+1} \left\{ \phi_w \left( \frac{W_{t+1}(j)}{W_t(j)} - 1 \right) (-1) \frac{W_{t+1}(j)}{(W_t(j))^2} P_{t+1} Y_{t+1} \right\} \end{aligned} \quad (\text{F.23})$$

this can be written was

$$0 = \frac{U_N(C_t, N_t)}{U_C(C_t, N_t)} (1 + \tau_t^c) (-\varepsilon_w) N_t + \frac{W_t}{P_t} \left\{ (1 - \varepsilon_w) (1 - \tau_t^l) N_t - \phi_w \left( \frac{W_t}{W_{t-1}} - 1 \right) P_t \frac{Y_t}{W_{t-1}} \right\} \\ + E_t \beta \frac{U_C(C_{t+1}, N_{t+1})}{U_C(C_t, N_t)} \frac{(1 + \tau_t^c)}{(1 + \tau_{t+1}^c)} \left\{ \phi_w \left( \frac{W_{t+1}}{W_t} - 1 \right) \frac{W_{t+1}}{W_t} Y_{t+1} \right\} \quad (\text{F.24})$$

or

$$0 = \varepsilon_w \frac{MRS_t}{\frac{W_t}{P_t}} (1 + \tau_t^c) + \left\{ (1 - \varepsilon_w) (1 - \tau_t^l) - \phi_w (\Pi_{w,t} - 1) \Pi_t \frac{1}{N_t} \frac{Y_t}{\frac{W_{t-1}}{P_{t-1}}} \right\} \\ + E_t \beta \frac{U_C(C_{t+1}, N_{t+1})}{U_C(C_t, N_t)} \frac{(1 + \tau_t^c)}{(1 + \tau_{t+1}^c)} \frac{1}{N_t} \frac{1}{\frac{W_t}{P_t}} \{ \phi_w (\Pi_{w,t+1} - 1) \Pi_{w,t+1} Y_{t+1} \} \quad (\text{F.25})$$

Linearizing around the steady state yields

$$0 = \varepsilon_w \underbrace{\frac{MRS}{\frac{W}{P}}}_{\frac{\varepsilon_w - 1}{\varepsilon_w} \frac{1 - \tau_l}{1 + \tau_c}} (1 + \tau_t^c) \widehat{MRS}_t \\ - \phi_w \underbrace{(\Pi_w - 1)}_0 \Pi \frac{1}{N} \frac{Y}{\frac{W}{P}} \left( \hat{\Pi}_t - \hat{N}_t + \hat{Y}_t - \frac{\hat{W}_t}{P_t} \right) \\ - \phi_w \Pi \frac{1}{N} \frac{Y}{\frac{W}{P}} \Pi_w (\hat{\Pi}_{w,t}) \\ + E_t \beta \frac{1}{N} \frac{1}{\frac{W}{P}} \phi_w \underbrace{(\Pi_w - 1)}_0 \Pi_w Y \left( \hat{U}_C(C_{t+1}, N_{t+1}) - \hat{U}_C(C_t, N_t) - \hat{N}_t - \frac{\hat{W}_t}{P_t} + \hat{Y}_{t+1} \right) \\ + E_t \beta \frac{1}{N} \frac{1}{\frac{W}{P}} \phi_w Y \left( 2\Pi_w^2 \hat{\Pi}_{w,t+1} - \Pi_w \hat{\Pi}_{w,t+1} \right) \quad (\text{F.26})$$

Simplifying yields

$$0 = \varepsilon_w \frac{\varepsilon_w - 1}{\varepsilon_w} (1 - \tau^l) \widehat{MRS}_t - \phi_w \underbrace{\frac{Y}{N \frac{W}{P}}}_{\frac{1}{\aleph}} \hat{\Pi}_{w,t} + E_t \beta \frac{Y}{N \frac{W}{P}} \phi_w \hat{\Pi}_{w,t+1} \quad (\text{F.27})$$

and thus

$$\hat{\Pi}_{w,t} = \frac{(\varepsilon_w - 1) (1 - \tau^l) \aleph}{\phi_w} \widehat{MRS}_t + E_t \beta \hat{\Pi}_{w,t+1} \quad (\text{F.28})$$

where the labor share  $\aleph$  collapses to the familiar  $(1 - \alpha)$  if there are no pure profits.

### F.3 Comparison

Comparing the slopes of the two Wage Phillips Curves, equations (F.22) and (F.28), yields

$$\frac{(1 - \theta_w)(1 - \beta\theta_w)}{\theta_w \left(1 + \varepsilon_W \frac{N}{1-N}\right)} = \frac{(\varepsilon_w - 1)(1 - \tau^l) \left(\frac{N^W}{Y}\right)}{\phi_w} \quad (\text{F.29})$$

so that

$$\phi_w = \frac{(\varepsilon_w - 1)(1 - \tau^l) \left(\frac{N^W}{Y}\right)}{(1 - \theta_w)(1 - \beta\theta_w)} \theta_w \left(1 + \varepsilon_W \frac{N}{1-N}\right). \quad (\text{F.30})$$

## G Marginal Product of Labor

For convenience, we repeat here

$$MPL_t = Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}-1} \frac{(1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi}{N_t - N^o}. \quad (4.5)$$

This is equal to

$$MPL_t = \left( Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}} \right)^{1-\psi} (Y^{norm})^\psi \frac{(1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi}{N_t - N^o}. \quad (\text{G.1})$$

Using (A.1), we have that

$$Y_t + \Phi = Y^{norm} \left[ \alpha K_t^\psi + (1 - \alpha) \left( e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}} \quad (\text{G.2})$$

so that

$$MPL_t = (1 - \alpha) (Y^{norm})^\psi \left( e^{Z_t} \right)^\psi \left( \frac{Y_t + \Phi}{N_t - N^o} \right)^{1-\psi}. \quad (\text{G.3})$$

In case of no fixed costs and no overhead labor, this reduces to the familiar

$$MPL_t = (1 - \alpha) (Y^{norm})^\psi \left( e^{Z_t} \right)^\psi \left( \frac{Y_t}{N_t} \right)^{1-\psi}. \quad (\text{G.4})$$

In logs, we have from (G.3)

$$\log(MPL_t) = \log \left( (1 - \alpha) (Y^{norm})^\psi \right) + \psi \log \left( e^{Z_t} \right) + (1 - \psi) \log \left( \frac{Y_t + \Phi}{N_t - N^o} \right), \quad (4.6)$$

where the first term is constant that depends on the units of measurement.

## G.1 Computing labor-augmenting technology growth

Technology movements are approximated using the Fernald (2012) utilization adjusted TFP measure. This TFP measure, based on growth accounting, originally assumes a unit elasticity of output with respect to technology, which would correspond to Hicks-neutral technology growth. Starting from a general production function

$$Y = Y(K, L, TFP) \quad (\text{G.5})$$

the contribution of TFP to output growth is effectively computed via the total differential as part of output growth not accounted for by utilization adjusted factor growth:

$$\frac{dTFP_t}{TFP_t} = \frac{dY_t}{Y_t} - \varepsilon_{K,t} \frac{dK_t}{K_t} - \varepsilon_{N,t} \frac{dN_t}{N_t}, \quad (\text{G.6})$$

where  $\varepsilon$  denotes the respective output elasticities and  $\varepsilon_{TFP,t} = 1$ . Thus, we need to transform this TFP measure to correspond to our measure of labor-augmenting (Kaldor-neutral) technology  $A_t = e^{Z_t}$  as

$$\frac{dTFP_t}{TFP_t} = \varepsilon_{A,t} \frac{dA_t}{A_t} \Rightarrow \log A_t = \frac{1}{\varepsilon_{A,t}} \log TFP_t, \quad (\text{G.7})$$

where the integration constant has been set to 0. Thus, when knowing the elasticity  $\varepsilon_{A,t}$ , the Fernald (2012) measure can be transformed into our required technology measure. As  $\varepsilon_{A,t}$  is invariant to multiplicative transformations of output, we first normalize output by steady state/balanced growth path output  $Y$  to get gross deviations from steady state:<sup>21</sup>

$$\hat{Y} \equiv \frac{Y_t}{Y} = \frac{\left[ \alpha K_t^\psi + (1 - \alpha) \left( A e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}} - \Phi}{\left[ \alpha K^\psi + (1 - \alpha) (A (N - N^o))^\psi \right]^{\frac{1}{\psi}} - \Phi} \quad (\text{G.8})$$

where  $A$  is a constant capturing the unknown level of labour augmenting technology and all other normalizations, e.g. the one introduced by using an index for output.

Noting that in steady state

$$Y = \frac{1}{(1 + \phi_{fix})} \left[ \alpha K^\psi + (1 - \alpha) (A (N - N^o))^\psi \right]^{\frac{1}{\psi}} \quad (\text{G.9})$$

$$\Phi = \frac{\phi_{fix}}{(1 + \phi_{fix})} \left[ \alpha K^\psi + (1 - \alpha) (A (N - N^o))^\psi \right]^{\frac{1}{\psi}} \quad (\text{G.10})$$

equation (G.8) can be rewritten as

$$\hat{Y} = \frac{(1 + \phi_{fix}) \left[ \alpha K_t^\psi + (1 - \alpha) \left( A e^{Z_t} (N_t - N^o) \right)^\psi \right]^{\frac{1}{\psi}}}{\left[ \alpha K^\psi + (1 - \alpha) (A (N - N^o))^\psi \right]^{\frac{1}{\psi}}} - \phi_{fix} \quad (\text{G.11})$$

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<sup>21</sup>We suppress the assumed deterministic loglinear trend in  $A$  for simplicity.



Using the corresponding firm first order conditions

$$\frac{W_t}{P_t} = \Xi \left[ \frac{(1 - \alpha) (A e^{Z_t} (N_t - N^o))^\psi}{\alpha K_t^\psi + (1 - \alpha) (A e^{Z_t} (N_t - N^o))^\psi} \right] \frac{Y_t + \Phi}{N_t - N^o} \quad (\text{G.12})$$

and

$$R_t^K = \Xi \left[ \frac{\alpha K_t^\psi}{\alpha K_t^\psi + (1 - \alpha) (A e^{Z_t} (N_t - N^o))^\psi} \right] \frac{Y_t + \Phi}{K_t} \quad (\text{G.13})$$

equation (G.11) becomes

$$\begin{aligned} \hat{Y} &= (1 + \phi_{fix}) \left[ \frac{\alpha K_t^\psi}{\alpha K_t^\psi + (1 - \alpha) (A (N - N^o))^\psi} + \frac{(1 - \alpha) (A e^{Z_t} (N_t - N^o))^\psi}{\alpha K_t^\psi + (1 - \alpha) (A (N - N^o))^\psi} \right]^{\frac{1}{\psi}} - \phi_{fix} \\ &= (1 + \phi_{fix}) \left[ \frac{1}{\Xi} \frac{R^K K}{(Y + \Phi)} \left( \frac{K_t}{K} \right)^\psi + \frac{1}{\Xi} \frac{W}{P} \frac{(N - N^o)}{(Y + \Phi)} \left( \frac{A e^{Z_t} (N_t - N^o)}{A (N - N^o)} \right)^\psi \right]^{\frac{1}{\psi}} - \phi_{fix} \end{aligned} \quad (\text{G.14})$$

Defining the share of non-overhead labor compensation in output as

$$\aleph^o \equiv \frac{\frac{W}{P} (N - N^o)}{Y} = \frac{\frac{W}{P} N}{Y} \frac{N - N^o}{N} = \aleph (1 - \phi^o) \quad (\text{G.15})$$

and noting that the prefactors before capital and labor sum up to 1, equation (G.11) can be rewritten as

$$\hat{Y}_t = (1 + \phi_{fix}) \left[ \left( 1 - \frac{\aleph^o}{\Xi (1 + \phi_{fix})} \right) \hat{K}_t^\psi + \frac{\aleph^o}{\Xi (1 + \phi_{fix})} (e^{Z_t} \hat{N}_t)^\psi \right]^{\frac{1}{\psi}} - \phi_{fix} \quad (\text{G.16})$$

Differentiating this with respect to  $Z_t$ , the elasticity of output with respect to technology  $A_t$  can be computed from

$$\begin{aligned} \varepsilon_{A,t} &= \frac{\partial(\hat{Y}_t - 1)}{\partial Z_t} \\ &= (1 + \phi_{fix}) \left[ \left( 1 - \frac{\aleph^o}{\Xi (1 + \phi_{fix})} \right) \hat{K}_t^\psi + \frac{\aleph^o}{\Xi (1 + \phi_{fix})} (e^{Z_t} \hat{N}_t)^\psi \right]^{\frac{1}{\psi} - 1} \frac{1}{\Xi (1 + \phi_{fix})} \aleph^o (e^{Z_t} \hat{N}_t)^\psi \\ &\stackrel{(\text{G.16})}{=} \left[ \frac{\hat{Y}_t + \phi_{fix}}{1 + \phi_{fix}} \right]^{1 - \psi} \frac{1}{\Xi} \aleph^o (e^{Z_t} \hat{N}_t)^\psi \end{aligned} \quad (\text{G.17})$$

In the Cobb-Douglas case in steady state, this simplifies to the well-known

$$\varepsilon_{A,t} = \frac{1}{\Xi} \aleph \quad (\text{G.18})$$

To operationalize the aforementioned, we first need to detrend output with the rate of labor-augmenting technology growth

## H Data

### H.1 Household Wedge

For the household wedge, i.e. the wedge between the marginal rate of substitution and the real wage, we focus on an encompassing measure of hours. Recall the equation for computing the household wedge

$$\tau_t^h = \log \left( \frac{1 - \tau_t^l}{1 + \tau_t^c} \right) + \log \left( \frac{W_t N_t}{P_t Y_t} \right) + \log \left( \frac{Y_t}{C_t} \right) - \log \left( \frac{1 - \eta}{\eta} \right) + \log \left( \frac{1 - N_t}{N_t} \right) . \quad (4.4)$$

Demeaning yields:

$$\begin{aligned} \tau_t^h - \tau^h = & \left[ \log \left( \frac{W_t N_t}{P_t Y_t} \right) - \log \left( \frac{W N}{P Y} \right) \right] + \left[ \log \left( \frac{Y_t}{C_t} \right) - \log \left( \frac{Y}{C} \right) \right] \\ & + \left[ \log \left( \frac{1 - N_t}{N_t} \right) - \log \left( \frac{1 - N}{N} \right) \right] \\ & + \log \left( \frac{1 - \tau_t^l}{1 + \tau_t^c} \right) - \log \left( \frac{1 - \tau^l}{1 + \tau^c} \right) \end{aligned} \quad (H.1)$$

where the first term on the right hand side is the labor share. Expanding the fractions to get the wedge in terms of the labor share and the consumption to output ratio has the advantage of avoiding problems with different trends that may be contained in different data sources.<sup>22</sup>

- $\frac{W_t N_t}{P_t Y_t}$ : to compute the labor share, we take the share of employees' compensation *Compensation of Employees, Paid* (FRED: COE) in net national income (NNI), where net national income is compute as *National Income* (FRED: NICUR) minus net indirect taxes, computed as the difference between taxes on production and imports (FRED: GDITAXES) and subsidies (FRED: GDISUBS). To this we add part of the ambiguous proprietor's income (PI). The share of proprietor's income assigned to labor this is as the share of unambiguous labor income in total unambiguous income (employees' compensation)/(net national income - proprietor's income), which implies that  $\frac{WN}{PY} = \frac{COE}{NNI-PI}$
- $P_t$ : *Gross Domestic Product: Implicit Price Deflator* (FRED: GDPDEF)

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<sup>22</sup>For example, the trend in NIPA GDP and *Average hourly earnings of production and nonsupervisory workers in the private sector* differs, although theory says they should be the same.

- $Y_t$ : *Gross Domestic Product* (FRED: GDP), deflated by the GDP deflator and divided by *Civilian non-institutional population*
- $C_t$ : real private consumption is computed as the sum of *Personal Consumption Expenditures: Nondurable Goods* (FRED: PCND) and *Personal Consumption Expenditures: Services* (FRED: PCESV), each deflated by the GDP deflator and divided by *Civilian non-institutional population*<sup>23</sup>
- Population: *Civilian non-institutional population* (FRED: CNP16OV), smoothed with an HP-filter with  $\lambda = 10,000$  to solve the best levels problem (Edge et al., 2013).
- $N_t$ : We use a total hours measure following Cociuba et al. (2012). For this purpose, we extend their measure to include more recent periods by downloading ?
- $1 - N_t$ : Following (Karabarbounis, 2014), who in turn is motivated by Aguiar et al. (2013), we normalize discretionary time available to 92 hours per week per person.
- Labor tax rate  $\tau_t^l$ : The average labor income tax rates is computed as the sum of taxes on labor income,  $\tau^{LI}$ , plus the “tax rate” on social insurance contributions,  $\tau^{SI}$ ,

$$\tau^n = \tau^{LI} + \tau^{SI} .$$

We closely follow Mendoza et al. (1994), Jones (2002), and Leeper et al. (2010) and compute the tax rate from the national accounts by dividing the tax revenue by the respective tax base. For labor income tax rates, we need to compute the portion of personal income tax revenue that can be assigned to labor income. We first compute the average personal income tax rate

$$\tau^p = \frac{IT}{W + PRI/2 + CI} ,$$

where  $IT$  is personal current tax revenues (Table 3.1 line 3, FRED: A074RC1Q027SBEA + W071RC1Q027SBEA),  $W$  is wage and salary accruals (Table 1.12 line 3, FRED: WASCUR),  $PRI$  is proprietor’s income (Table 1.12 line 9, FRED: PROPINC), and  $CI$  is capital income. It is computed as

$$CI \equiv PRI/2 + RI + CP + NI ,$$

where  $RI$  is rental income (Table 1.12 line 12, FRED: RENTIN),  $CP$  is corporate profits (Table 1.12 line 13, FRED: CPROFIT), and  $NI$  denotes the net interest income (Table 1.12 line 18, FRED: W255RC1Q027SBEA). In doing so, the ambiguous

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<sup>23</sup>Due to chain-weighting, this separate deflating is required to preserve additivity.

proprietor's income is assigned in equal parts to capital and labor income. The labor income tax can then be computed as

$$\tau^{LI} = \frac{\tau^p(W + PRI/2)}{EC + PRI/2} ,$$

where  $EC$  is compensation of employees (Table 1.12 line 2, FRED: COE), which, in addition to wages, includes contributions to social insurance and untaxed benefits. The social insurance “tax rate” is given by

$$\tau^{SI} = \frac{CSI}{EC + PRI/2} ,$$

where  $CSI$  denotes contributions to government social insurance (Table 3.1 line 7, FRED: W782RC1Q027SBEA)

- Consumption tax rate  $\tau_t^c$ : The tax revenue from consumption taxes,  $CT$ , requires apportioning the indirect tax revenue to investment and consumption.<sup>24</sup> We do this as:

$$CT = \frac{PC}{PC + I} IND T ,$$

3 where  $PC$  is personal consumption expenditure (FRED: PCE),  $I$  is investment (FRED: GPDI), and  $IND T$  is net indirect taxes, computed as the difference between taxes on production and imports (FRED: GDITAXES) and subsidies (FRED: GDISUBS).<sup>25</sup> The consumption tax rate is then computed as

$$\tau^c = \frac{CT}{PC - CT} .$$

## H.2 Firm Wedge

For the firm wedge, i.e. the wedge between the real wage and the marginal product of labor, we focus on the private business sector. Recall the equation for computing the firm wedge:

$$\tau_t^f = \log \left( (1 - \alpha) (Y^{norm})^\psi \right) + \psi \log \left( e^{Z_t} \right) + (1 - \psi) \log \left( \frac{Y_t + \Phi}{N_t - N^o} \right) - \log \left( \frac{W_t}{P_t} \right) . \quad (4.7)$$

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<sup>24</sup>We opt to not attribute sales tax revenues to government purchases due to the different tax-exemption status of local, state, and federal purchases in different states. For example, government entities are sales tax-exempt in New York, but are tax-liable in California.

<sup>25</sup>The use of net indirect taxes follows Karabarbounis (2014) and differs from e.g. Mendoza et al. (1994) who use gross indirect taxes.

Demeaning this expression yields:

$$\begin{aligned} \tau_t^f - \tau^f = & \psi \log(e^{Z_t}) + (1 - \psi) \left[ \log\left(\frac{Y_t + \Phi}{N_t - N^o}\right) - \log\left(\frac{Y + \Phi}{N - N^o}\right) \right] \\ & - \left[ \log\left(\frac{W_t}{P_t}\right) - \log\left(\frac{W}{P}\right) \right] \end{aligned} \quad (\text{H.2})$$

where

$$e^{z_t} = \frac{1}{\varepsilon_{A,t}} \log TFP_t \quad (\text{H.3})$$

$$\varepsilon_{A,t} = \left[ \frac{\hat{Y}_t + \phi_{fix}}{1 + \phi_{fix}} \right]^{1-\psi} \frac{1}{\Xi} \aleph^o(e^{Z_t} \hat{N}_t)^\psi \quad (\text{G.17})$$

- $W_t$ : following the approach in Nekarda and Ramey (2013), we use the *Average hourly earnings of production and nonsupervisory workers in the private sector* (BLS: CES0500000008).<sup>26</sup>
- $P_t$ : *Gross Domestic Product: Implicit Price Deflator* (FRED: GDPDEF)
- $N_t - N^o$ : *Average weekly hours of production and nonsupervisory employees, private business* (BLS: CES0500000006) multiplied by *Production and nonsupervisory employees, private business* (CES: CES0500000006), divided by *Civilian non-institutional population*
- $Y_t$ : *Current dollar output, private business* (BLS: PRS84006053), deflated using the GDP deflator and divided by *Civilian non-institutional population*.
- $\Phi$ : Consistent with our model, we assume additional fixed costs of 2.96% of steady state output per capita, which we approximate using the average detrended log output per capita.
- $C_t$ : real private consumption is computed as the sum of *Personal Consumption Expenditures: Nondurable Goods* (FRED: PCND) and *Personal Consumption Expenditures: Services* (FRED: PCESV), each deflated by the GDP deflator and divided by *Civilian non-institutional population*
- Population: *Civilian non-institutional population* (FRED: CNP16OV), smoothed with an HP-filter with  $\lambda = 10,000$  to solve the best levels problem (Edge et al., 2013).
- $1 - N_t$ : Following (Karabarbounis, 2014), who in turn is motivated by , we normalize discretionary time available to 92 hours per week per person.

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<sup>26</sup>This implicitly assumes that all nonproduction and supervisory workers are overhead labor, which probably is an upper bound (see Ramey, 1991).

- $TFP_t$ : cumulated sum of the utilization adjusted TFP growth rates of Fernald (2012) (`dtfp_util`, starting value initialized to 1), log-linearly detrended
- $\aleph^o$ : The labor share not accounting for overhead labor,  $\aleph$  is computed as 1 minus “Capital’s share of income” from Fernald (2012).<sup>27</sup> This series is “Based primarily on NIPA data for the corporate sector”. To derive the share of non-overhead labor  $\aleph^o$ , we use equation (G.15) with  $\phi^o = 0.11$  as discussed in the calibration section.

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<sup>27</sup>This series substitutes for *Business Sector: Labor Share*, (FRED: PRS84006173), which is unfortunately only available in index form.