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Fiscal News and Macroeconomic Volatilty

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Fiscal News and Macroeconomic Volatility*

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Abstract

This paper analyzes the contribution of anticipated capital and labor tax shocks to business cycle volatility in an estimated New Keynesian DSGE model. While fiscal policy accounts for 12 to 20 percent of output variance at business cycle frequencies, the anticipated component hardly matters for explaining fluctuations of real variables. Anticipated capital tax shocks do explain a sizable part of inflation and interest rate fluctuations, accounting for between 5 and 15 percent of total variance. In line with earlier studies, news shocks in total account for 20 percent of output variance. Further decomposing this news effect, we find that it is mostly driven by stationary TFP and non-stationary investment-specific technology.

JEL-Classification: E32, E62, C11
Keywords: Anticipated Tax Shocks; Sources of Aggregate Fluctuations; Bayesian Estimation.

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1 Introduction

The current paper analyzes the role of news about future fiscal policy ("fiscal news"), and in particular the anticipation of tax rate changes, for business cycle fluctuations. Recent macroeconomic research has increasingly shifted from explaining business cycle fluctuations through contemporaneous shocks to explaining them by anticipated, or news, shocks. Rational agents, anticipating future changes will already react today to these news (see e.g. Beaudry and Portier 2004, 2006, Jaimovich and Rebelo 2009, Schmitt-Grohé and Uribe 2010). However, most empirical studies on the effects of anticipated shocks on business cycles have focused on news about future productivity (see e.g. Forni et al. 2011, Fujiwara et al. 2011, Khan and Tsoukalas 2010).[1]

This is remarkable for two reasons. First, fiscal measures are usually publicly debated well in advance and often known before becoming effective, i.e. there are considerable decision and implementation lags. A tax bill typically takes about one year from the U.S. President's initial proposal to the law's enactment and another year until the tax change becomes effective (Mertens and Ravn 2011, Yang 2005). As a recent example, consider the *Patient Protection and Affordable Care Act* ("Obamacare"), whose core contents were debated for almost one year and whose financing provisions will only phase in gradually over time. Second, surprise fiscal policy shocks have long been discussed as a potential prominent driver of the business cycle (see e.g. Baxter and King 1993, Cardia et al. 2003, Jones 2002, McGrattan 1994). McGrattan (1994) for example attributes one third of the U.S. business cycle variance to distortionary taxation. [2] This potential importance of fiscal policy shocks, combined with the fact that many fiscal policy measures are known well in advance, makes fiscal news a natural candidate for explaining aggregate fluctuations.

We add upon the previous literature by explicitly analyzing the business cycle variance contribution of fiscal news. For this purpose, we employ a New Keynesian DSGE model featuring several real and nominal rigidities as well as various shocks identified as important drivers of the business cycle and augment it with a government sector financed through distortionary labor and capital taxes. Our main focus lies on the effects of fiscal news, but we also control for anticipation in technology, investment-specific productivity, and the wage markup. The model is estimated by full information (Bayesian) methods using quarterly U.S. data from 1955 to 2006. Model-based estimation allows us to circumvent the issue of non-invertibility typically encountered when estimating structural VARs in the presence of

[1] There is a prominent literature branch dealing with the importance of fiscal foresight. However, its focus has mostly been on analyzing single tax events (House and Shapiro 2006, Parker 1999, Poterba 1988) or tracing out the consequences for econometric analyses (Leeper et al. 2011, Yang 2005).

[2] Although Forni et al. (2009) find that unanticipated tax shocks contribute little to macroeconomic fluctuations of the Euro area, this could in principle be the result of ignoring fiscal foresight.

anticipation effects (Fernández-Villaverde et al. 2007, Hansen and Sargent 1991, Leeper et al. 2011).[3]

Computing forecast error variance decompositions, we find that while fiscal policy accounts for 12 to 20 percent of output variance at business cycle frequencies, fiscal news generally only plays a very limited role. Its contribution to output variance ranges around 3 percent.

With a variance share of 10 percent at the 5 year forecast horizon, government spending is the fiscal variable with the largest effect on output variance. However, this contribution only comes from surprise shocks, with anticipated spending shocks explaining virtually nothing. Contemporaneous and anticipated capital tax shocks each contribute $2-3$ percent to output fluctuations. However, they are considerably more important for explaining inflation and interest rate fluctuations. Depending on the forecast horizon, surprise capital tax shocks contribute roughly 30 percent to their variance. Anticipated capital tax shocks are responsible for 5 to 15 percent. The effect of contemporaneous and anticipated labor taxes, on the other hand, is negligible.

In line with previous studies that do not consider news shocks (e.g. Smets and Wouters 2007), we find that the main drivers of the output variance are preference and wage markup shocks. News shocks explain on average 20 percent of the variance of output, with the main effect coming from news about TFP and investment-specific productivity. This result conforms well with i) VAR evidence (Barsky and Sims forthcoming), ii) evidence coming from a factor model (Forni et al. 2011), and iii) other DSGE-based estimates of the importance of news shocks, who all find a similar fraction of output fluctuations explained by anticipated shocks.

The two papers most closely related to ours are recent contributions by Mertens and Ravn (forthcoming) and Schmitt-Grohé and Uribe (2010). The former use a VAR to analyze the business cycle contribution of narratively identified anticipated and unanticipated tax shocks.[4] They find that both types of tax shocks together explain 20 to 25 percent of output variance, with anticipation accounting for the majority. Schmitt-Grohé and Uribe (2010) evaluate the role of news about TFP, investment-specific technology, wage markup, and government spending shocks in an estimated RBC model with various real rigidities. In their setup, news shocks account for 41 percent of output fluctuations. But while they find government spending shocks to explain 10 percent, evenly distributed across surprise, one and two year anticipated shocks, they do not consider foresight about the financing side of the government budget

[3]Non-invertibility means that the DGSE-model has a VARMA representation that cannot be inverted to yield a finite-order VAR in the observables. Hence, the true innovations do not perfectly map into the VAR residuals, meaning that the structural shocks cannot be recovered using a VAR. For alternative ways to mitigate this problem, see e.g. Sims (2009), Giannone and Reichlin (2006), and Forni et al. (2011).

[4]Mertens and Ravn (forthcoming) classify the Romer and Romer (2010) tax shocks according to the time passed between the presidential signing of a bill and the tax changes becoming effective into anticipated and contemporaneous shocks.

constraint.

Our paper is also related to other DSGE-based papers focusing on the effects of anticipated technology shocks. Davis (2007), using a New Keynesian model, estimates news shocks to be responsible for 50 percent of output fluctuations. Fujiwara et al. (2011) extend the New Keynesian model of Smets and Wouters (2007) and Christiano et al. (2005) to include news about TFP. They estimate news shocks to explain 9 percent of output variance in the unconditional variance decomposition. The paper of Khan and Tsoukalas (2010) uses the same basic New-Keynesian model framework, but additionally allows for news about investment-specific technology growth. In their estimated model, both types of news shocks together account for less than 10 percent. Finally, Auray et al. (2009) estimate a New Keynesian model with an additional durables sector, featuring news about TFP in both sectors. They find that technology news in the non-durables sector explain 52% of output variance.

The outline of the paper is the following. Chapter 2 introduces the DSGE-model with fiscal foresight, while chapter 3 presents the estimation approach and results. In chapter 4, we compute variance decompositions and impulse responses. Chapter 5 concludes.

2 A DSGE-Model with Fiscal Foresight

We use a medium-scale DSGE-model featuring various real and nominal frictions as well as a variety of shocks that have been identified as important drivers of the business cycle (see e.g. Justiniano et al. 2010a, Smets and Wouters 2007). The model is an extended version of the basic model used in Born and Pfeifer (2011), where we incorporate both contemporaneous and anticipated elements into the shock processes as in Schmitt-Grohé and Uribe (2010) and allow for non-stationary shocks. We first discuss the information structure of the shock processes in the next section before describing the model in detail.

2.1 Shock Structure

Our model features 10 sources of stochastic fluctuations. On the government side, we include shocks to labor and capital tax rates τ_n and τ_k, a shock to government spending g, and a monetary policy shock ξ^R. The technology shocks considered are shocks to stationary neutral productivity z_t, non-stationary productivity X_t, stationary investment-specific productivity z_t^I, and non-stationary investment-specific productivity A_t. In addition, the model includes a preference shock ξ_t^{pref} and a wage markup shock μ_t^w.

The monetary policy shock and the preference shock are assumed to only contain a contemporaneous, unanticipated component. For the other shocks, we follow the framework proposed by Schmitt-Grohé and Uribe (2010) and allow for both contemporaneous shocks and shocks that are anticipated 4 and 8 periods in advance. Anticipation horizons of 4 and 8 quarters fulfill the aim of capturing longer anticipation horizons while keeping the state space at a manageable level. This is crucial as each additional anticipation horizon is an additional state variable. While specifically choosing 4 and 8 quarters of anticipation might be seen as arbitrary, this assumption can be rationalized by the workings of the political system. Four quarters of anticipation are close to the average length of a tax bill from the President's proposal announcement to enactment (Yang 2005). Eight quarters serves as a plausible upper bound for the anticipation of shocks to tax rates as Congressional elections take place every two years. We think this makes it very unlikely that people are able to correctly predict both the reigning majority and the tax laws being implemented by the next Congress. The same, of course, applies to spending bills. For reasons of symmetry, we then assume this anticipation structure for all shock processes.

The general structure for shock $\epsilon^i,\ i \in \left\{\tau^n, \tau^k, g, z, x, z^I, a, w\right\}$ is given by

$$\epsilon^i = \varepsilon^0_{i,t} + \varepsilon^4_{i,t-4} + \varepsilon^8_{i,t-8}\ , \tag{1}$$

where $\varepsilon^j_{i,t-j},\ j \in \{0,4,8\}$ denotes a shock to variable i that becomes known in period $t-j$ and hits the economy j periods later. For example, $\varepsilon^4_{\tau^n,t-4}$ denotes a four period anticipated shock to the labor tax rate that becomes known at time $t-4$ and becomes effective at time t. The shocks are assumed to have mean 0, standard deviation σ^j_i, to be serially uncorrelated, and to be uncorrelated across anticipation horizons, i.e. $E(\varepsilon^j_{i,t-j}) = 0$ and $E(\varepsilon^k_{i,t}\varepsilon^l_{i,t-j}) = (\sigma^k_i)^2$ for $j = 0,\ k = l$, and 0 otherwise. Moreover, they are uncorrelated across shock types $i_m, i_n \in i$, $E(\varepsilon^k_{i_m,t}\varepsilon^l_{i_n,t-j}) = 0\ \forall j, k, l$ and $i_m \neq i_n$, .

The assumed information structure implies that agents foresee future shocks to the extent of already known but not yet realized shocks $\varepsilon^m_{i,t-j},\ m > j$. The forward-looking behavior of rational optimizing agents results in them reacting to anticipated shocks even before they are realized. By imposing a structural model on the data, this anticipatory behavior enables the econometrician to achieve identification. However, it is exactly this foresight that makes identifying the shocks with a VAR impossible. The econometrician attempting to do this only uses current and past values of the observables and thus has a smaller information set than the agents. In particular, he is missing the anticipated but not yet realized shocks as states in his VAR.[5] To remedy this issue, structural estimation has been advocated (Blanchard et al.

[5]Sims (2009) shows that in some cases it may be possible to recover the shocks using a structural VAR. By including enough lags and forward-looking variables, it may be possible to move the non-invertible root(s) close enough to unity so that the discrepancy between true structural errors and the estimated ones becomes

2009). We will pursue this avenue in Section 3 by using Bayesian methods to estimate the proposed model.

2.2 Conceptualizing Tax Shocks

The tax shocks considered in the present work do not necessarily stem from actual changes in the labor and capital tax rates. Rather, they are interpreted as the probability weighted effect of tax actions under legislative debate or due to judicative decisions. They are the product of the likelihood of a tax change and the size of this effect, as perceived by rational agents forming expectations about the future path of taxes. Hence, our definition is wider than the one considered by Mertens and Ravn (forthcoming), who restrict their attention to the shocks directly deriving from the legislative process. Shocks deriving from e.g. the SEC suing against the legality of a tax shelter would be excluded from their definition but not from ours. Note that news shocks are distinct from pure uncertainty about future taxes. While the former are associated with an anticipated change in the mean of the tax rate, tax uncertainty shocks can be conceptualized as mean-preserving spreads.[6]

To fix ideas, consider the *Patient Protection and Affordable Care Act* of 2010 as an example. On June 9, 2009, a first draft of the health care bill was released. At that time, people at the latest could anticipate that taxes were going to rise in order to finance the bill, if it ever passed. However, both the size and the likelihood of such a change was largely unknown. The first point of uncertainty changed on July 13, 2009, when the Congressional Budget Office published official cost estimates: If passed, marginal income tax rates were going to increase by 22 percentage points for households between 100% and 400% of the poverty level. Taking these costs as given, households were experiencing tax shocks with changes in the likelihood of the passage of the bill. Intrade bets on the passage of the bill show that some people were constantly reevaluating this likelihood. Figure 1 presents the closing prices of an Intrade betting contract that paid 100, if a health care reform bill was passed into law before mid-2010 and 0 if a health care reform bill was not passed. Hence, the closing price is a direct measure of the likelihood of a bill becoming law. There is a large variance in the probability of passing the bill that varies with the ebb and flow of the political process. These changes potentially act like a huge sequence of tax shocks for households. If one considers only the change in the likelihood from the time directly after the Massachusetts Senate election in January to the final vote of the bill, this amounts in expectations to a tax shock of $0.7 \times 22\% = 15.4\%$

small.

[6]For an analysis of uncertainty about fiscal policy in the context of an estimated model, see Born and Pfeifer (2011).

during one quarter.[7]

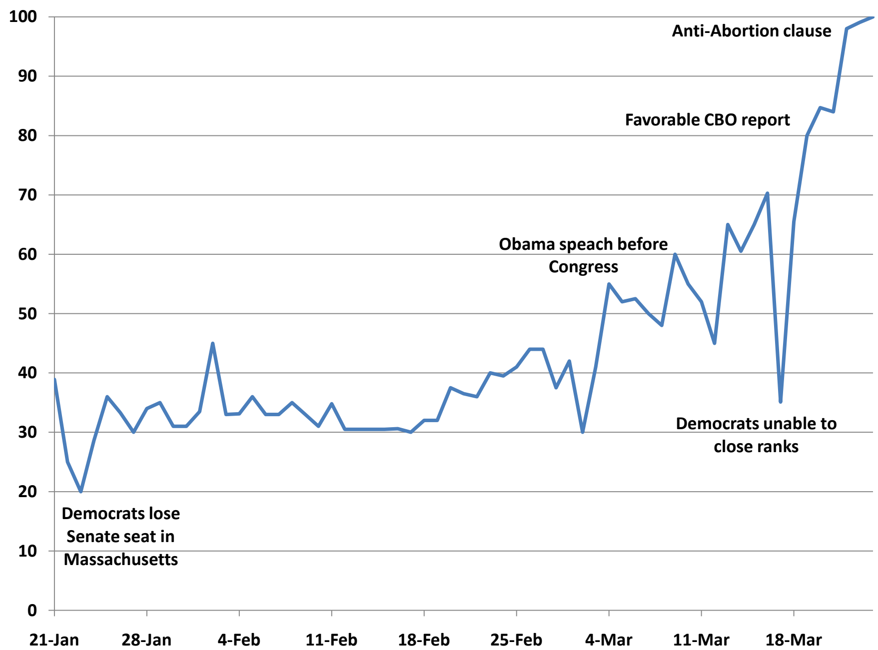

Figure 1: Intrade Daily Closing Prices:"Will 'Obamacare' health care reform become law in the United States?"
Note: This contract will settle (expire) at 100 ($10.00) if a health care reform bill is passed into law before midnight ET 30 Jun 2010. It will settle (expire) at 0 ($0.00) if a health care reform bill is not passed into law. *Source:* intrade^{TM}(`http://www.intrade.com/`)

2.3 The Model

The model economy includes five sectors: the household sector with a large representative household, the labor market featuring a continuum of monopolistically competitive unions selling differentiated labor services to intermediate firms, the firm sector including a continuum of intermediate goods firms producing intermediate goods and a final good firm bundling the intermediate goods, and the government sector responsible for fiscal and monetary policy.

2.3.1 Household Sector

The economy is populated by a large representative household with a continuum of members. Household preferences are defined over per capita consumption C_t and per capita labor effort L_t, where each member consumes the same amount and works the same number of hours.[8]

[7] Unfortunately, due to the non-availability of data for the relative price of investment, our sample does not cover this series of events.

[8] Due to the symmetric equilibrium, the decisions of the household members are identical. Hence, we suppress the subscript denoting individual members.

We follow Schmitt-Grohé and Uribe (2006) and assume that household members supply their labor uniformly to a continuum of unions $j \in [0,1]$. The unions are monopolistically competitive and supply differentiated labor services $l_t(j)$ to intermediate goods firms. Overall, total labor supply of the representative household is given by the integral over all labor markets j, i.e. $L_t = \int_0^1 l_t(j)dj$. We will discuss the labor market structure in detail below.

Following Jaimovich and Rebelo (2009), we assume a preference specification that allows to control the size of the wealth effect, but additionally assume habits in consumption:

$$U = E_0 \sum_{t=0}^{\infty} \beta^t \xi_t^{pref} \frac{\left(C_t - \phi_c C_{t-1} - \gamma \frac{L_t^{1+\sigma_l}}{1+\sigma_l} S_t \right)^{1-\sigma_c} - 1}{1-\sigma_c} \, . \tag{2}$$

Here, the parameter $\phi_c \in [0,1]$ measures the degree of internal habit persistence, $\sigma_c \geq 0$ governs the intertemporal elasticity of substitution, $\sigma_l \geq 0$ is related to the Frisch elasticity of labor supply, and $\gamma \geq 0$ measures the relative disutility of labor effort.[9] The term

$$S_t = (C_t - \phi_c C_{t-1})^{\sigma_s} S_{t-1}^{1-\sigma_s} \tag{3}$$

makes the preferences non-separable in both consumption and work effort. This preference specification introduces the parameter $\sigma_s \in (0,1]$ that allows to govern the magnitude of the wealth effect on the labor supply. As special cases, the specification nests the preference class discussed by King et al. (1988), i.e. $\sigma_s = 1$, and the preferences proposed by Greenwood et al. (1988), i.e. $\sigma_s = 0$, where the latter case implies a zero wealth elasticity of labor supply. We assume the preference shock ξ_t^{pref} to follow an $AR(1)$-process in logs:

$$\log \xi_t^{pref} = \rho_{pref} \log \xi_{t-1}^{pref} + \varepsilon_t^{pref} \, . \tag{4}$$

The household faces the budget constraint

$$\begin{aligned} C_t + z_t^I A_t I_t + \frac{B_{t+1}}{P_t} = &(1-\tau_t^n) \int_0^1 W_t(j) l_t(j) dj + \left(1-\tau_t^k\right) R_t^K u_t K_t + \Phi_t + T_t \\ &+ \left(1-\tau_t^k\right) \Xi_t + \left(1-\tau_t^k\right) (R_{t-1}-1) \frac{B_t}{P_t} + \frac{B_t}{P_t} \, . \end{aligned} \tag{5}$$

Besides labor income from supplying differentiated labor services $l_t(j)$ at the real wage $W_t(j)$, the household has capital income from renting out capital services $u_t K_t$ at the rental rate R_t^K, from receiving firm profits Ξ_t, and from investing in bonds B_{t+1}, which are in zero net

[9] In a recent paper, Nutahara (2010) shows that it is important to distinguish between internal and external habits in a model with news shocks. He finds that internal habits are able to generate news-driven business cycles, whereas external habits are not.

supply. Both forms of income are taxed at their respective tax rates τ_t^n and τ_t^k. Only net returns of bonds are taxed, such that the term $\left(1-\tau_t^k\right)(R_{t-1}-1)\frac{B_t}{P_t}+\frac{B_t}{P_t}$ is the after-tax return. In addition, the government pays lump sum transfers.

The household spends its income on consumption C_t and investment $z_t^I A_t I_t$, where I_t denotes gross investment at the price of capital goods. We assume that the relative price of investment in terms of the consumption good is subject to two shocks, a stationary investment-specific productivity shock z_t^I and non-stationary investment-specific technological progress A_t (see Greenwood et al. 1997, 2000). The relative price of investment is equal to the technical rate of transformation between investment and consumption goods. Changes in this price do not affect the productivity of already installed capital, but do affect newly installed capital and become embodied in it. For the non-stationary investment-specific technology process, we assume a random walk with drift in its logarithm

$$\log A_t = \log A_{t-1} + \log \mu_t^a \ . \tag{6}$$

The drift term μ_t^a is subject to contemporaneous and anticipated shocks according to

$$\log\left(\frac{\mu_t^a}{\mu^a}\right) = \rho_a \log\left(\frac{\mu_{t-1}^a}{\mu^a}\right) + \varepsilon_{a,t}^0 + \varepsilon_{a,t-4}^4 + \varepsilon_{a,t-8}^8 \ . \tag{7}$$

The stationary investment-specific technology shock z_t^I follows an $AR(1)$-process

$$\log z_t^I = \rho_{z^I} \log z_{t-1}^I + \varepsilon_{z^I,t}^0 + \varepsilon_{z^I,t-4}^4 + \varepsilon_{z^I,t-8}^8 \ . \tag{8}$$

Depreciation allowances are an important feature of the U.S. tax code, therefore, we also include them in our model. They are captured by the term Φ_t in equation (5) and have the form $\Phi_t = \tau_t^k \sum_{s=1}^{\infty} \delta_\tau (1-\delta_\tau)^{s-1} z_{t-s}^I A_{t-s} I_{t-s}$, where δ_τ is the depreciation rate for tax purposes.[10] Since depreciation allowances provide new investment with a tax shield at historical costs, they may be important in capturing the dynamics of investment following shocks (Christiano et al. 2007, Yang 2005).

The household members own the capital stock K_t, whose law of motion is given by

$$K_{t+1} = \left[1-\left(\delta_0 + \delta_1(u_t-1) + \frac{\delta_2}{2}(u_t-1)^2\right)\right] K_t + \left[1-\frac{\kappa}{2}\left(\frac{I_t}{I_{t-1}} - \mu^I\right)^2\right] I_t \ . \tag{9}$$

Household members do not simply rent out capital, but capital services $u_t K_t$, where u_t denotes

[10] Following Auerbach (1989), we allow the depreciation rate for tax purposes to differ from the physical rate.

capital utilization. Thus, they decide about the intensity with which the existing capital stock is used. However, using capital with an intensity that is higher than normal is not costless, but leads to higher depreciation of the capital stock. This is captured by the increasing and convex function $\delta(u_t) = \delta_0 + \delta_1 (u_t - 1) + \delta_2/2 (u_t - 1)^2$, with $\delta_0, \delta_1, \delta_2 > 0$. Without loss of generality, capital utilization in steady state is normalized to 1. Following Christiano et al. (2005), we assume the presence of investment adjustment costs $S(I_t/I_{t-1}) = \kappa/2 \left(I_t/I_{t-1} - \mu^I\right)^2$ to dampen the volatility of investment over the business cycle. $\kappa > 0$ is a parameter governing the curvature of the investment adjustment costs and μ^I is the steady state growth rate of investment, which is equal to the steady state growth rate of capital. This specification assures that the investment adjustment costs are minimized and equal to 0 along the balanced growth path, i.e. $S = S' = 0$ and $S'' > 0$, where the primes denote derivatives.

The household maximizes its utility, equation (2), by choosing $C_t,\ L_t,\ S_t,\ B_{t+1},\ K_{t+1},\ u_t$, and I_t, subject to the budget constraint (5), the law of motion for capital (9), and the resource constraint for aggregate labor given by (10) below.

2.3.2 Labor Market

The labor market is characterized by differentiated labor services and staggered wage setting. To model these features without letting idiosyncratic wage risk affect the household members, and thus making aggregation intractable, we assume a continuum of unions $j,\ j \in [0, 1]$. The household members supply their labor $l_t(j)$ equally to the unions, which are monopolistically competitive and supply differentiated labor $l_t(j)$ to intermediate firms at wage $W_t(j)$. Every period, a union j is able to re-optimize its wage with probability $(1 - \theta_w)$, $0 < \theta_w < 1$. A union j that is not able to re-optimize indexes its nominal wage to the price level according to $W_t(j) P_t = (\Pi_{t-1})^{\chi_w} \bar{\Pi}^{1-\chi_w} \mu_t^y W_{t-1}(j) P_{t-1}$, where the parameter $\chi_w \in [0, 1]$ measures the degree of indexing, $\bar{\Pi}$ is steady state gross inflation, and μ_t^y is the gross growth rate of output (see e.g. Smets and Wouters 2003). Thus, in the absence of price adjustment the wage still partly adapts to changes in productivity and inflation (Christiano et al. 2008), thereby assuring that no current wage contract will deviate arbitrarily far from the current optimal wage.

Household members supply the amount of labor services that is demanded at the current wage. Unions that can reset their wages choose the real wage that maximizes the expected utility of its members, taking into account the demand for its labor services $l_t(j) = (W_t(j)/W_t)^{-\eta_{w,t}} L_t^{comp}$, where L_t^{comp} is the aggregate demand for composite labor services, the respective resource constraint

$$L_t = L_t^{comp} \int_0^1 \left(\frac{W_t(j)}{W_t} \right)^{-\eta_{w,t}} dj \ , \tag{10}$$

and the aggregate wage level $W_t = \left(\int_0^1 W_t\,(j)^{1-\eta_{w,t}}\, dj \right)^{\frac{1}{1-\eta_{w,t}}}$. The time-varying substitution elasticity $\eta_{w,t}$ allows us to include a wage markup shock $\mu_t^w = (\eta_{w,t} - 1)^{-1}$ that follows

$$\log \left(\frac{\mu_t^w}{\mu^w} \right) = \rho_w \log \left(\frac{\mu_{t-1}^w}{\mu^w} \right) + \varepsilon_{w,t}^0 + \varepsilon_{w,t-4}^4 + \varepsilon_{w,t-8}^8 \ . \tag{11}$$

Including a wage markup shock is motivated by the finding that this shock is important for explaining output fluctuations (see e.g. Schmitt-Grohé and Uribe 2010, Smets and Wouters 2007).

2.3.3 Firm Sector

A continuum of monopolistically competitive intermediate goods firms i, $i \in [0,1]$, produces differentiated intermediate goods Y_{it} via a Cobb-Douglas production function, using capital services $u_{it}K_{it}$ and a composite labor bundle L_{it}^{comp}

$$Y_{it} = z_t \left(u_{it} K_{it} \right)^{\alpha} \left(X_t L_{it}^{comp} \right)^{1-\alpha} - \psi X_t^Y \ , \tag{12}$$

where α is the capital share, z_t is a stationary TFP shock, X_t is a non-stationary labor augmenting productivity process, and X_t^Y is the trend of output defined in Appendix B. The fixed cost of production ψ is set such that profits are 0 in steady state and there is no entry or exit (Christiano et al. 2005). The composite labor bundle is aggregated from differentiated labor inputs $L_{it}\,(j)$ with a Dixit-Stiglitz aggregator $l_{it}^{comp} = [\int_0^1 l_{it}(j)^{\frac{\eta_{w,t}-1}{\eta_{w,t}}} dj]^{\frac{\eta_{w,t}}{\eta_{w,t}-1}}$.

For the non-stationary labor augmenting productivity process X_t, we assume a random walk with drift in its logarithm

$$\log X_t = \log X_{t-1} + \log \mu_t^x. \tag{13}$$

The drift term μ_t^x is subject to contemporaneous and anticipated shocks according to

$$\log \left(\frac{\mu_t^x}{\mu^x} \right) = \rho_x \log \left(\frac{\mu_{t-1}^x}{\mu^x} \right) + \varepsilon_{x,t}^0 + \varepsilon_{x,t-4}^4 + \varepsilon_{x,t-8}^8. \tag{14}$$

Hence, in the deterministic steady state, the natural logarithm of the non-stationary component of the neutral technology shock grows with rate μ^x. The stationary technology shock z_t

follows an $AR(1)$-process with persistence ρ_z

$$\log z_t = \rho_z \log z_{t-1} + \varepsilon^0_{z,t} + \varepsilon^4_{z,t-4} + \varepsilon^8_{z,t-8}. \tag{15}$$

We assume staggered price setting a la Calvo (1983) and Yun (1996). Each period, an intermediate firm i can re-optimize its price with probability $(1-\theta_p)$, $0 < \theta_p < 1$. If a firm i cannot re-optimize the price, it is indexed to inflation $\Pi_t = \frac{P_t}{P_{t-1}}$ according to $P_{it+1} = (\Pi_t)^{\chi_p} (\bar{\Pi})^{1-\chi_p} P_{it}$, where $\chi_p \in [0,1]$ governs the degree of indexation. The intermediate firms maximize their discounted stream of profits subject to the demand from the final good producer, equation (17) below, applying the discount factor of their owners, the household members.

The intermediate goods are bundled by a competitive final good firm to a final good Y_t using a Dixit-Stiglitz aggregation technology with substitution elasticity η_p

$$Y_t = \left(\int_0^1 Y_{it}^{\frac{\eta_p - 1}{\eta_p}} di \right)^{\frac{\eta_p}{\eta_p - 1}} . \tag{16}$$

Expenditure minimization yields the optimal demand for intermediate good i as

$$Y_{it} = \left(\frac{P_{it}}{P_t} \right)^{-\eta_p} Y_t \quad \forall\, i \; . \tag{17}$$

2.3.4 Government Sector

Government expenditures are financed by taxing profits and the return to capital services at the rate τ^k_t and labor income at the rate τ^n_t. Following McGrattan (1994) and Mertens and Ravn (forthcoming), we model average tax rates as $AR(2)$-processes

$$\tau^n_t = (1-\rho^n_1-\rho^n_2)\,\tau^n + \rho^n_1 \tau^n_{t-1} + \rho^n_2 \tau^n_{t-2} + \varepsilon^0_{\tau^n,t} + \varepsilon^4_{\tau^n,t-4} + \varepsilon^8_{\tau^n,t-8} \tag{18}$$

$$\tau^k_t = \left(1-\rho^k_1-\rho^k_2\right) \tau^k + \rho^k_1 \tau^k_{t-1} + \rho^k_2 \tau^k_{t-2} + \varepsilon^0_{\tau^k,t} + \varepsilon^4_{\tau^k,t-4} + \varepsilon^8_{\tau^k,t-8} \; , \tag{19}$$

where $\tau^k, \tau^n \in [0,1)$ are parameters determining the unconditional mean. Using average effective tax rates may be a problem for labor income taxes, because usually the tax code is progressive. However, the clearly simplifying assumption can be justified on grounds that dynamics of marginal and average tax rates are very similar (Mendoza et al. 1994).

Government spending G_t, which may be thought of as entering the utility function additively separable, displays a stochastic trend X^G_t. Log deviations of government spending from its trend are assumed to follow an $AR(1)$-process

$$\log\left(\frac{g_t}{\bar{g}}\right) = \rho_g \log\left(\frac{g_{t-1}}{\bar{g}}\right) + \epsilon^0_{g,t} + \epsilon^4_{g,t-4} + \epsilon^8_{g,t-8} \ , \tag{20}$$

where $g_t = \frac{G_t}{X_t^G}$ denotes detrended government spending and ρ_g is the persistence parameter.

The stochastic trend in G_t is assumed to be cointegrated with the trend in output. This assures that the output share of government spending G_t/Y_t is stationary, while at the same time allowing the trend in G_t to be smoother than the one in Y_t. In particular,

$$X_t^G = \left(X_{t-1}^G\right)^{\rho_{xg}} \left(X_{t-1}^Y\right)^{1-\rho_{xg}}. \tag{21}$$

Lump sum transfers T_t are used to balance the budget. Thus, the government budget constraint is given by[11]

$$G_t + T_t = \tau_t^n W_t L_t^{comp} + \tau_t^k \left(R_t^K u_t K_t + \Xi_t\right) - \Phi_t. \tag{22}$$

We close the model by assuming that the central bank follows a Taylor rule that reacts to inflation and output growth:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\left(\frac{\Pi_t}{\bar{\Pi}}\right)^{\phi_{R_\Pi}} \left(\frac{Y_t}{Y_{t-1}}\frac{1}{\mu^y}\right)^{\phi_{R_Y}}\right)^{1-\rho_R} \exp\left(\xi_t^R\right), \tag{23}$$

where ρ_R is a smoothing parameter introduced to capture the empirical evidence of gradual movements in interest rates (see e.g. Clarida et al. 2000). The parameters ϕ_{R_Y} and ϕ_{R_Π} capture the responsiveness of the nominal interest rate to deviations of inflation and output growth from their steady state values. We assume that the central bank responds to changes in output rather than its level as this conforms better with empirical evidence and avoids the need to define a measure of trend growth that the central bank can observe (see Lubik and Schorfheide 2007). ξ_t^R is the i.i.d. monetary policy shock.

3 Model Estimation

We use a Bayesian approach as described in An and Schorfheide (2007) and Fernández-Villaverde (2010). Specifically, we use the Kalman filter to obtain the likelihood from the state-space representation of the model solution and the *Tailored Randomized Block Metropolis-Hastings (TaRB-MH)* algorithm (Chib and Ramamurthy 2010) to maximize the posterior

[11] Note that private bonds are in zero net supply.

Table 1: Parameters fixed prior to estimation

Parameter	Value	Target/Motivation (matched to quarterly data)
σ_c	2	Common in RBC models
γ	0.0216	Set labor effort in steady state to 20%
β	0.99	Common in RBC models
δ_0	0.025	Annual physical depreciation of 10%
δ_1	0.0486	Set capacity utilization $u = 1$ in steady state
δ_τ	0.05	Twice the rate of physical depreciation δ_0 (Auerbach 1989)
α	0.2935	Match capital share in output
ψ	0.0432	Set profits to zero
η_p	10	Set price markup to 11% in steady state
η_w	10	Set wage markup to 11% in steady state
μ^y	1.0045	Match average sample growth rate of per capita output
μ^a	0.9957	Match average sample growth rate of relative price of investment
τ^n	0.1984	Match average sample labor tax rate
τ^k	0.3880	Match average sample capital tax rate
G/Y	0.2031	Match average sample mean
$\bar{\Pi}$	1.0089	Match average sample mean

likelihood.[12]

3.1 Data

We use quarterly U.S. data from 1955:Q1 until 2006:Q4 and include twelve observable time series: the growth rates of per capita GDP, consumption, investment, wages and government expenditure, all in real terms, the logarithm of the level of per capita hours worked, the growth rates of the relative price of investment and of total factor productivity, the log difference of the GDP deflator, and the federal funds rate. Since our main objective are the effects of tax shocks, we also include capital and labor tax rates.[13]

3.2 Fixed Parameters

Prior to estimation, we fix a number of parameters to match sample means (see Table 1). The curvature of the utility function σ_c is set to 2. This value is consistent with most DSGE models. The discount factor β is fixed at 0.99. We set the parameter that governs the

[12]We used a t-distribution with 10 degrees of freedom as proposal density. The posterior distribution was computed from a 10,000 draw Monte Carlo Markov Chain, where the first 2,500 draws were discarded as burn-in draws.

[13]Detailed data sources and the observation equation that describes how the empirical time series are matched to the corresponding model variables can be found in Appendices D and C.

disutility of labor effort γ such that labor effort in steady state is 20%. We assume an annual physical depreciation rate of 10%, which corresponds to a δ_0 of 0.025 per quarter. Following Auerbach (1989) and Mertens and Ravn (2011), we set the depreciation rate for tax purposes δ_τ to twice the rate of physical depreciation, i.e. 0.05. The depreciation parameter δ_1 is fixed to set the steady state capacity utilization to 1 (Christiano et al. 2005). The parameter α is 0.2935, which matches the capital share in output over our sample, and the fixed cost parameter ψ is set to ensure zero profits in steady state. We assume a steady state price and wage markup of 11% and thus set η_p and η_w to 10.

The steady state gross growth rates of per capita output μ^y and of the relative price of investment μ^a are set to their sample means of $1 + 0.45\%$ and $1 - 0.43\%$. The parameters τ^k and τ^n, which determine the unconditional mean of the tax rates, equal the post-war sample means of 0.388 and 0.1984. We set the steady state ratio of government spending to output G/Y to 0.2031, which also corresponds to the sample mean. The steady state inflation rate corresponds to the average sample mean of 1.0089, i.e. annual inflation of 3.6%

3.3 Priors

Tables 2 and 3 present the prior distributions. Where available, we use prior values that are standard in the literature (e.g. Smets and Wouters 2007) and independent of the underlying data. The autoregressive parameters of the tax processes, $\rho_1^n,\ \rho_2^n,\ \rho_1^k,\ \rho_2^k$, are essentially left unrestricted, but we impose stability of the $AR(2)$-processes.[14] The other autoregressive parameters, $\rho_i,\ i \in \left\{pref, g, z, x, z^I, a, w\right\}$, are assumed to follow a beta distribution with mean 0.5 and standard deviation 0.2. We assume the standard deviations of the shocks to follow inverse-gamma distributions with prior means 0.1 and standard deviations 2. For the parameters of the Taylor-rule, ϕ_{R_Π} and ϕ_{R_Y}, we impose gamma distributions with a prior mean of 1.5 and 0.5, respectively, while the interest rate smoothing parameter ρ_R has the same prior distribution as the persistence parameters of the shock processes. The habit parameter ϕ_c is assumed to be beta distributed with a prior mean of 0.7, which is standard in the literature. Following Justiniano et al. (2010b), the parameter determining the Frisch elasticity of labor supply σ_l is assumed to follow a gamma distribution with a prior mean of 2 and a standard deviation of 0.75. The prior distribution for the parameter governing the wealth elasticity of labor supply σ_s is a beta distribution with mean 0.5 and standard deviation 0.2. We impose an inverse-gamma distribution with prior mean of 0.5 and standard deviation of 0.15 for δ_2/δ_1, the elasticity of marginal depreciation with respect to capacity

[14]Specifically, we impose a uniform prior for each of the corresponding autoregressive roots over the stability region $(-1, +1)$. Let ξ_1 and ξ_2 be the roots of such an $AR(2)$-process. The autoregressive parameters corresponding to these roots can be recovered from: $\rho_1 = \xi_1 + \xi_2$ and $\rho_2 = -\xi_1\xi_2$.

utilization. The parameters governing the indexation of prices and wages, χ_p and χ_w, each are beta distributed with mean 0.5 and standard deviation 0.2. For the Calvo parameters θ_w and θ_p we assume a beta distribution with a prior mean of 0.5, which corresponds to price and wage contracts having an average length of half a year (Smets and Wouters 2007). Finally, we follow the literature (e.g. Justiniano et al. 2010a, Smets and Wouters 2007) and impose a gamma prior with mean 4 for the parameter controlling investment adjustment costs κ.

3.4 Posterior Distribution

The last four columns of Tables 2 and 3 display the mean, the standard deviation and the 90%-posterior intervals for each of the estimated parameters. Most estimated parameters and shock processes are in line with previous studies on the determinants of business cycle fluctuations, both with those using only contemporaneous shocks (e.g. Justiniano et al. 2010a, Smets and Wouters 2007) as well as those including contemporaneous and anticipated shocks (Fujiwara et al. 2011, Khan and Tsoukalas 2010, Schmitt-Grohé and Uribe 2010).

However, some estimates deserve further comment. We find a considerable degree of internal habits with $\phi_c = 0.86$, which is right between the estimates obtained by Smets and Wouters (2007) and Schmitt-Grohé and Uribe (2010). The posterior mean of the parameter governing the wealth elasticity ($\sigma_s = 0.1$) implies a very low wealth elasticity of labor supply and, thus, preferences that are close to the ones proposed by Greenwood et al. (1988). Schmitt-Grohé and Uribe (2010) find an even lower wealth elasticity that is almost zero. Khan and Tsoukalas (2010), on the other hand, estimate the wealth elasticity of labor to be quite high at 0.85. A possible explanation for these differing estimates is the inclusion of government spending as an observable. Increases in government spending may entail positive consumption responses (Blanchard and Perotti 2002, Galí et al. 2007),[15] a behavior which can be explained by a New-Keynesian model with a low wealth elasticity (Monacelli and Perotti 2008). Thus, including government spending as an observable, as Schmitt-Grohé and Uribe (2010) and we do, restricts the parameter governing the wealth elasticity to a low value in order to account for this effect. On the other hand, without the observable government spending as in Khan and Tsoukalas (2010), this parameter remains mostly unrestricted with regard to the effects of government spending on consumption.[16]

Turning to the nominal rigidities in our model, we find that prices are on average adjusted about every three quarters, while the Calvo parameter for wages implies a high degree of wage stickiness. The degree of price indexation is low ($\chi_p = 0.06$) and in a similar range as

[15]For a dissenting view, see Ramey (2011).

[16]A small wealth effect also helps in explaining the empirical behavior of labor market variables (Galí et al. 2011).

in Justiniano et al. (2011). Wages, on the other hand, are indexed to inflation with a higher proportion than prices ($\chi_w = 0.6$), which corresponds well with the estimates in Smets and Wouters (2007).

The parameters of the Taylor rule are in line with previous estimates (e.g. Clarida et al. 2000). They imply a high degree of interest rate smoothing ($\rho_R = 0.86$), a strong response to inflation ($\phi_{R_\Pi} = 2.96$), and a moderate value for the standard deviation of the monetary policy shock ($\sigma_R = 0.251\%$).

With the exception of the non-stationary technology shock, all shocks are estimated to be highly persistent, with $AR(1)$-coefficients ranging from 0.94 for the government spending shock to 0.99 for the preference, the stationary technology, and the non-stationary investment-specific technology shock. The non-stationary productivity component has a relatively low serial correlation of 0.34, a value commonly found in the literature (e.g. Justiniano et al. 2011).

The contemporaneous shock as well as the 4 quarter anticipated non-stationary technology shock have relatively low standard deviations of 0.04% and 0.03%, respectively, whereas the two year anticipated shock is the most important one with a standard deviation of 0.6%. A similar pattern emerges for the stationary technology shock. In this case, however, the standard deviation of the unanticipated component has a similar size as the 8 quarter anticipated component, 0.74% and 0.73%, whereas the 4 quarter anticipated shock is less important with a standard deviation of 0.18%.

Examining investment-specific technology shows that investment-specific growth displays the same pattern as neutral technology growth. The shock with the longest anticipation horizon is the most important one, having the highest standard deviation ($\sigma_a^8 = 0.14\%$), albeit in this case it is only slightly higher than the one for the contemporaneous shock ($\sigma_a^0 = 0.11$). The 4 quarter anticipated shock, on the other hand, is negligible ($\sigma_a^4 = 0.04\%$). In contrast, for stationary investment-specific technology anticipation does not play a role, the standard deviations are less than 0.05%, while the unanticipated stationary shock component has a higher standard deviation than the unanticipated non-stationary investment-specific technology shock ($\sigma_{z^I}^0 = 0.31\%$).

Another shock, where the anticipated shock components are negligible, is the wage markup shock. While the standard deviation of the unanticipated shock is relatively high, the anticipated shocks have very low standard deviations that are below 0.04%. In contrast, the surprise wage markup shock has a high standard deviation of almost 46%, which is consistent with evidence from Smets and Wouters (2007) and Galí et al. (2011), who showed this shock to be the most important driver of business cycles.[17]

[17] Note that the shock applies to the net markup so a 46% shock increases the markup from 11% to about

Next, we direct our focus to the fiscal policy shock processes. Both tax processes show a very high persistence, with the roots of the autoregressive processes implying autoregressive parameters of $\rho_1^n = 0.770$, $\rho_2^n = 0.228$, $\rho_1^k = 1.604$, and $\rho_2^k = -0.605$, respectively.[18] The posterior estimates suggest that for government spending and labor taxes fiscal foresight is rather limited. The unanticipated government spending shock has a volatility of 3%, a value also found by Leeper et al. (2010). The volatilities of the anticipated shock components, on the other hand, are rather small, $\sigma_g^4 = 0.03\%$ and $\sigma_g^8 = 0.04\%$. A similar pattern emerges for the labor tax process τ_t^n. The shock with the largest volatility is the unanticipated component $\varepsilon^0_{\tau^n,t}$ with 0.48%, while the anticipated components have a similar size as the anticipated government spending shocks. Only for the capital tax rate, news shocks display a higher standard deviation. Particularly, compared to the shocks to the labor tax process, the shocks $\varepsilon^i_{\tau^k,t-i}$ to the capital tax process τ_t^k display a much higher volatility. The unanticipated component $\varepsilon^0_{\tau^k,t}$ has the highest standard deviation of 0.92%, while the anticipated components have smaller, but still sizeable standard deviation, $\sigma^4_{\tau^k} = 0.46\%$ and $\sigma^8_{\tau^k} = 0.65\%$.

4 Business Cycle Effects of Fiscal News

We are now in a position to analyze the dynamic effects of fiscal news. Given the estimated deep parameters of the model, we compute forecast error variance decompositions to trace out the shocks' contributions to business cycle volatility. To better understand the dynamic effects of news shocks, we then analyze their transmission into the economy in Section 4.2.

4.1 Variance Decomposition

4.1.1 Results

We use our estimated model to analyze the quantitative importance of the different anticipated and surprise shocks for explaining business cycles. To this end, we compute conditional and unconditional forecast error variance decompositions for the growth rates of output, consumption, investment, hours, wages, the Federal funds rate, and inflation (see Table 4).[19]

Overall, we find that news shocks on average explain between 10 and 30 percent of the

16%. Chari et al. (2009) point out that wage markup shocks cannot be distinguished from labor supply shocks. For policy makers this distinction matters, since both shocks entail different policy implications (Galí et al. 2011). However, as we are not interested in optimal policy, it is not important to identify the two shocks separately.

[18]The high persistence of the labor tax rate has, for example, been documented in Cardia et al. (2003).

[19]For ease of exposition we have combined the two anticipated shock components into one and left out three anticipated shocks (stationary investment-specific, wage markup, and government spending) that each contributed less than 0.01 percent to the variance of the variables.

variance of the variables considered. However, fiscal foresight only plays a very limited role. Of the three types of fiscal foresight we consider, only the anticipated capital tax shock has a sizeable variance contribution. While news about future capital taxes contribute only 2 percent to output growth variance, they matter for inflation and interest rate variability, explaining more than 10 percent of the variability of inflation and interest rates at forecast horizons longer than three years. This makes them the third largest source of inflation and interest rate volatility, only behind preference and unanticipated capital tax shocks. Together, surprise and anticipated capital tax shocks explain around 40 to 50 percent of inflation and interest rate fluctuations. In contrast, news about labor tax and government spending shocks explain at most 0.01 percent of the variance of any of the seven variables considered.

More important than fiscal foresight are the surprise components of the fiscal variables. As already noted, besides the preference shock, the surprise capital tax shock is the most important factor for the variance of the Federal funds rate and inflation. Moreover, it accounts for 2 to 3 percent of output fluctuations. While the surprise government spending shock ε_g^0 accounts for almost 10 percent of the output growth variance at the five year horizon and even more at shorter horizons, it hardly contributes anything to the other variables' fluctuations.

Whereas fiscal foresight seems to be of only minor importance for the fluctuations of output, consumption, and investment, other news shocks contribute significantly to their variance. The news shocks that matter most are news about stationary technology, which account for 8 to 12 percent of the variance of output and consumption. News about non-stationary technology mostly affects the volatility of wages, predominantly at long horizons. At the five year horizon, it is the single most important factor affecting wage volatility. News about non-stationary investment-specific technology explain around 8 percent of the variance of investment at all horizons and about the same amount of the variance of hours (at the five year horizon). In contrast, the news components of stationary investment-specific technology and the wage markup shock account for at most 0.01 percent of the variance of any variable we consider.

In general, the importance of news shocks increases at longer forecast horizons. E.g., anticipated shocks account for a larger share of output volatility at the five year horizon (21%) than at the one year horizon (11%).

Turning to the surprise shocks, we find the most important drivers of business cycles to be wage markup, preference, and unanticipated technology shocks. At business cycle frequencies, these shocks combined explain about 60 to 70 percent of the fluctuations of real variables. E.g., at the 20 period forecast horizon, these three shocks account for 31, 21, and 16 percent of output volatility, respectively. Inflation and interest rate variability are mostly explained by preference and capital tax shocks, whereas wage fluctuations are mainly driven by technology shocks, especially anticipated non-stationary technology shocks. Lastly, the monetary policy shock plays a minor role in accounting for macroeconomic fluctuations, a result similar to Smets and Wouters (2007). It explains around 15 percent of the Federal funds rate volatility, but only at the short term, i.e. horizons of about one year, and has much smaller contributions for the other variables.

4.1.2 Discussion

Using a DSGE-based estimation approach to determine the importance of news about fiscal policy, we find that fiscal foresight only plays a minor role in explaining business cycle fluctuations. Specifically, using full information Bayesian estimation and accounting for different kinds of shocks, we find tax shocks and, in particular, news about taxes to explain about 5 percent of output growth fluctuations. This compares to about 25 percent in the VAR study of Mertens and Ravn (forthcoming), indicating that the rigid anticipation structure and the strict exogeneity assumption in the latter paper may be problematic (see also Leeper et al. 2011).

Our estimates also attribute less than one third of output fluctuations to surprise tax shocks, which was found by McGrattan (1994). However, her paper only featured TFP, government spending, and tax rate shocks. In contrast, our analysis features a richer set of shocks commonly thought to be essential for explaining business cycles (Chari et al. 2007, Smets and Wouters 2007).

Regarding the evidence on the effects of news shocks on the business cycles, our result of 10 to 30 percent of the variance of output growth being attributable to anticipated shocks squares well with the evidence found by Forni et al. (2011) and Barsky and Sims (forthcoming). Using a factor model, Forni et al. (2011) find that around 20 percent of output volatility is explained by technology and 10 percent by news about technology, while Barsky and Sims (forthcoming), in a VAR, attribute 10 to 40 percent to news shocks.

Fujiwara et al. (2011) and Khan and Tsoukalas (2010), using an estimated DSGE model with nominal rigidities, find a technology news contribution to output variance of 8.5 and 1.6 percent, respectively, which is lower than our own estimates. On the other hand, Schmitt-Grohé and Uribe (2010) find that news about technology account for as much as 41 percent of output variance. Part of this higher number can be attributed to the absence of nominal rigidities in their model (Khan and Tsoukalas 2010). Overall and consistent with these studies, news shocks contribute a higher share to the unconditional variance of nominal variables (wages, inflation, interest rate) than to the variance of real variables (output, consumption, investment, hours). However, allowing anticipation not only for TFP but also for other shocks, leads to a higher relative contribution of news shocks. Whereas the contribution of anticipated shocks in the study by Fujiwara et al. (2011) ranges from 4 percent (to the variance of investment) to 15 percent (to inflation volatility), we find contributions of anticipated shocks (combining all shocks) between 19 percent (investment and consumption volatility) and 52 percent (variance of wages).

Turning to the role of unanticipated shocks, we see that while the investment-specific technology shock has been identified as an important driver of business cycles by previous studies (Davis 2007, Fisher 2006, Justiniano et al. 2010a), it is of lesser importance in our case and contributes a smaller fraction to fluctuations than TFP shocks. The contributions of non-stationary investment-specific productivity vary between 5 and 15 percent, whereas stationary investment-specific technology explains hardly 1 percent. The difference to the previous studies finding the high contribution of investment-specific technology stems from our decision to include the relative price of investment as an observable. Recent studies including the relative price of investment as an observable find similarly small contributions of investment-specific technology (Justiniano et al. 2011, Schmitt-Grohé and Uribe 2010).[20] However, we have to stress that both the stationary as well as the non-stationary investment-specific productivity shock pertain to the relative price of investment and are accordingly mapped to this observable.[21] Thus, our stationary investment-specific technology shock is not directly comparable to the stationary investment-specific technology shock in Schmitt-Grohé and Uribe (2010). This could explain the starkly differing results regarding the effects of this particular shock for output and investment fluctuations, 30 to 60 percent in their case vs. less than 1 percent in our case.

4.2 Impulse Responses

In order to better understand what drives the results of the previous section, we analyze the impulse responses to stationary TFP shocks and to capital tax rate shocks. We choose to focus on these shocks as they are the technology and fiscal policy shock, respectively, where the anticipated component contributes most to business cycle variance.[22]

Figure 2 shows the impulse responses to an unanticipated (solid line) and an eight period anticipated (dashed line) one percentage point cut of the capital tax rate.[23] The top left

[20] Models that do not use the relative price of investment as an observable variable usually imply wrong moments for this series (Justiniano et al. 2011). When this problem is eliminated, the variance contribution of investment-specific technology shocks tends to disappear.

[21] The observation equation in appendix (C) shows the exact mapping.

[22] Although we find the preference and wage markup shocks to be the most important drivers of business cycles, we omit analyzing their impulse responses as their importance and behavior is already well understood (see e.g. Galí et al. 2011, Smets and Wouters 2007).

[23] For the surprise shock, this roughly corresponds to a one standard deviation shock as $\sigma^0_{\tau^k} = 0.923\%$. For the eight period anticipated shock, $\sigma^8_{\tau^k} = 0.645\%$, so that we have re-scaled the size of this shock to make

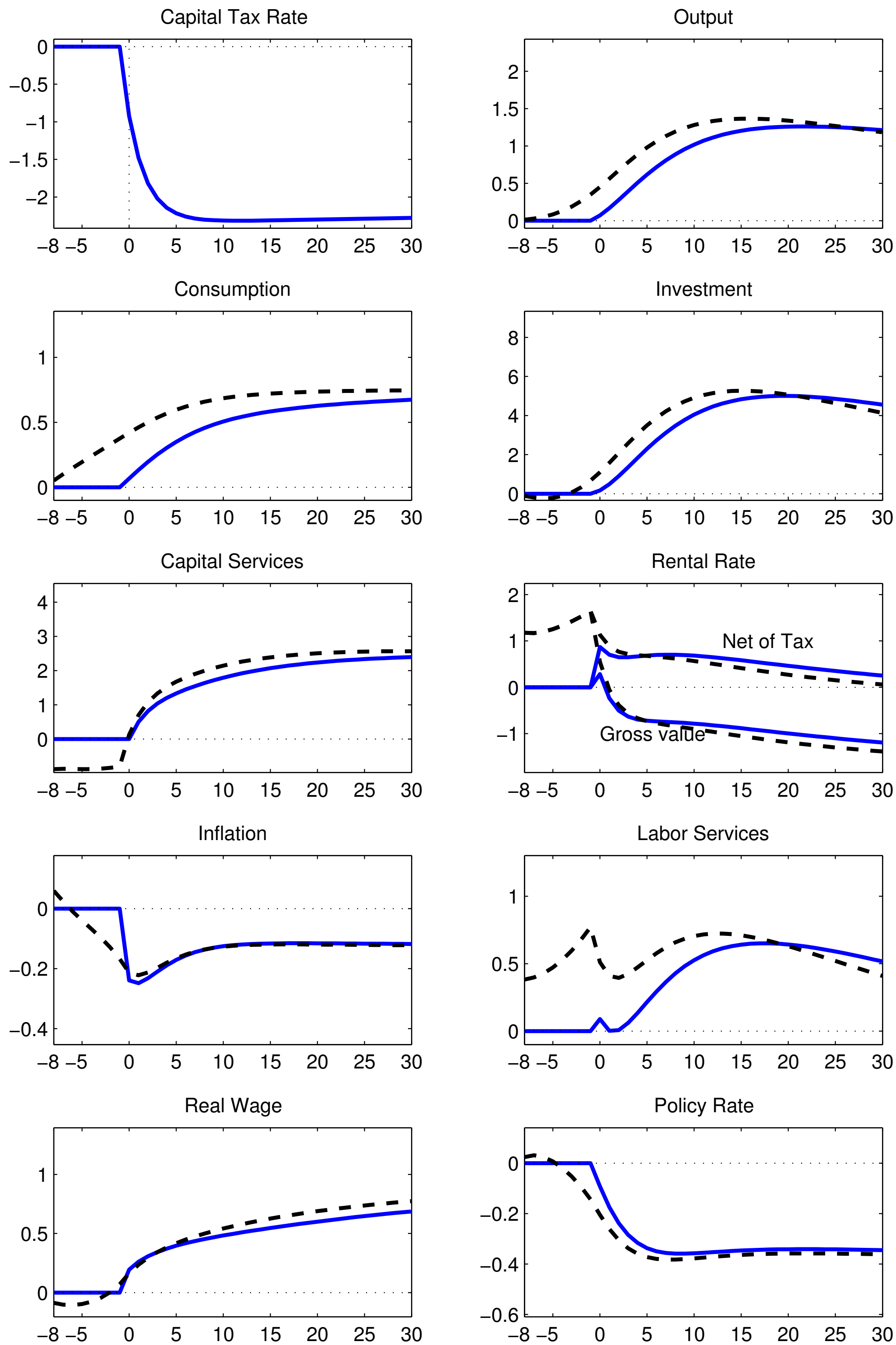

Figure 2: Impulse responses to unanticipated and anticipated capital tax shocks.
Notes: solid line: impulse responses to an unanticipated 1 percentage point cut of the capital tax rate τ^k; dashed line: impulse responses to an eight period anticipated 1 percentage point cut of the capital tax rate τ^k that becomes known at $t = -8$ and effective at $t = 0$. All impulse responses are semi-elasticities and measured in percent. Inflation and the policy rate are measured as gross rates so that the responses can be interpreted as percentage point changes.

panel shows the impulse response for the capital tax rate that is shocked. The actual response of the exogenous capital tax rate is the same after the surprise and anticipated tax shock, because the only difference between the two cases is the time at which the tax change that happens at $t = 0$ is known. But the other variables react differently, because with anticipation the future realization of the tax rate is already known at $t = -8$ and agents immediately start to optimally respond to this information.

First, consider the solid line representing the impulse responses to a surprise 1 percentage point decrease in the capital tax rate. This tax cut acts expansionary and leads to an increase in output, investment, and consumption on impact. The effect is quite large due to the strong estimated persistence of the shock process. Consistent with the evidence of high multipliers for tax rates (Mountford and Uhlig 2009, Romer and Romer 2010), an initial 1 percentage point decrease in the capital tax rate leads to a peak output response of 1.25 percent. Labor and capital services increase in a hump shaped manner after the realization. For capital services, this is driven by the higher after-tax rental rate that can be earned after the tax cut. Note that the gross value of the rental rate decreases, reflecting the decreased tax wedge. The increase in capital services also raises the marginal product of labor, leading to an initial jump in the real wage as a fraction of unions is able to reset wages in the current period and to a further rise over time when additional unions are able to reset their nominal wages. The initial increase of the real wage is amplified by an overshooting of the nominal wage, which is indexed to past inflation, due to a drop in inflation. Current inflation falls due to the positive supply side effect of the tax decrease. This positive effect on inflation is also the reason why the policy rate falls considerably, accommodating the expansion and further fueling investment and consumption.

Although the impulse responses for the eight period anticipated tax shock look very similar, there are two major differences. First, agents have more time to adjust and already react during the anticipation phase. Hence, the impulse responses are now more drawn out. Reacting immediately to an anticipated tax shock is optimal for the agents, because the estimated degrees of consumption habits, capital adjustment costs, capital utilization, and nominal rigidities imply that large abrupt changes in important choice variables are welfare reducing and must be avoided. As a result of these more gradual and hence more resource-saving responses, the peak responses of all variables are now higher than for the case of a comparable surprise tax cut and generally occur earlier relative to the shock realization at t=0. Note that relative to the announcement of the shocks, i.e. the point in time where the horizon for the forecast error variance decomposition starts,[24] the peak responses generally

both shocks comparable. Note that the impulse responses are semi-elasticities, i.e. they are measured in percent of the steady state values of the corresponding variables.

[24] I.e. t=-8 for the anticipated shock and t=0 for the surprise shock.

occur later for the news shocks. This peak response at later horizons for news shocks explains why their importance in the forecast error variance decomposition tends to be larger at later horizons.

Second, in contrast to the unanticipated shock, agents now substitute labor services for capital services, leading to an immediate increase in the former and a decrease in the latter. Only when the tax shock realizes, there is a jump in capital services. The higher production resulting from the increase in labor services and the resources saved through the initially lower depreciation resulting from the weaker capital use allows to increase consumption during the anticipation phase. The net result of this substitution of labor for capital services with the simultaneous increase in consumption and investment expenditures is a slight inflationary pressure in the first period. As a response, the central bank somewhat tightens its policy. However, the negative supply side effect of the input substitution subsides with the subsequent further increase in labor supply. This increase is driven by the household's desire to increase the physical capital stock through investment while also keeping up consumption. As a result, inflationary pressures abate and give room to an accommodating policy stance.

Note that physical investment in the capital stock slightly decreases initially. This behavior is due to the depreciation allowances, whose present value for new investment decreases with the future tax bill from which it is deducted. But, in contrast to the results of Mertens and Ravn (2011), this incentive to disinvest is rather mild. Hence, in our estimated model, the announcement of a tax cut is insufficient to generate the investment-driven slump during the anticipation phase of a tax cut found in their model. This difference can be explained by the different estimation procedures used. Mertens and Ravn (2011) rely on an impulse response matching technique, where the empirical impulse responses were derived from a VAR using a narrative identification scheme. The impulse responses to be matched by the model were only the ones to anticipated and unanticipated labor and capital tax shocks. In contrast, our estimation uses full information techniques and thus tries to match all moments given the full set of exogenous driving forces of the model.

Figure 3 displays the impulse responses to one standard deviation surprise (solid line) and anticipated (dashed line) stationary TFP shocks.[25] The result of a surprise increase in total factor productivity is a prolonged boom driven by both consumption and investment. Consistent with a typical supply side shock, inflation decreases considerably with the central bank lowering the policy rate by 20 basis points in response. This in turn leads to an increase in the real wage and a subsequent increase in the labor services used.

For the eight period anticipated increase in technology, we observe an immediate increase in output, investment, and consumption during the anticipation phase due to the entailed

[25]We scaled the news shock by 1.03 to have exactly the same standard deviation as the surprise shock.

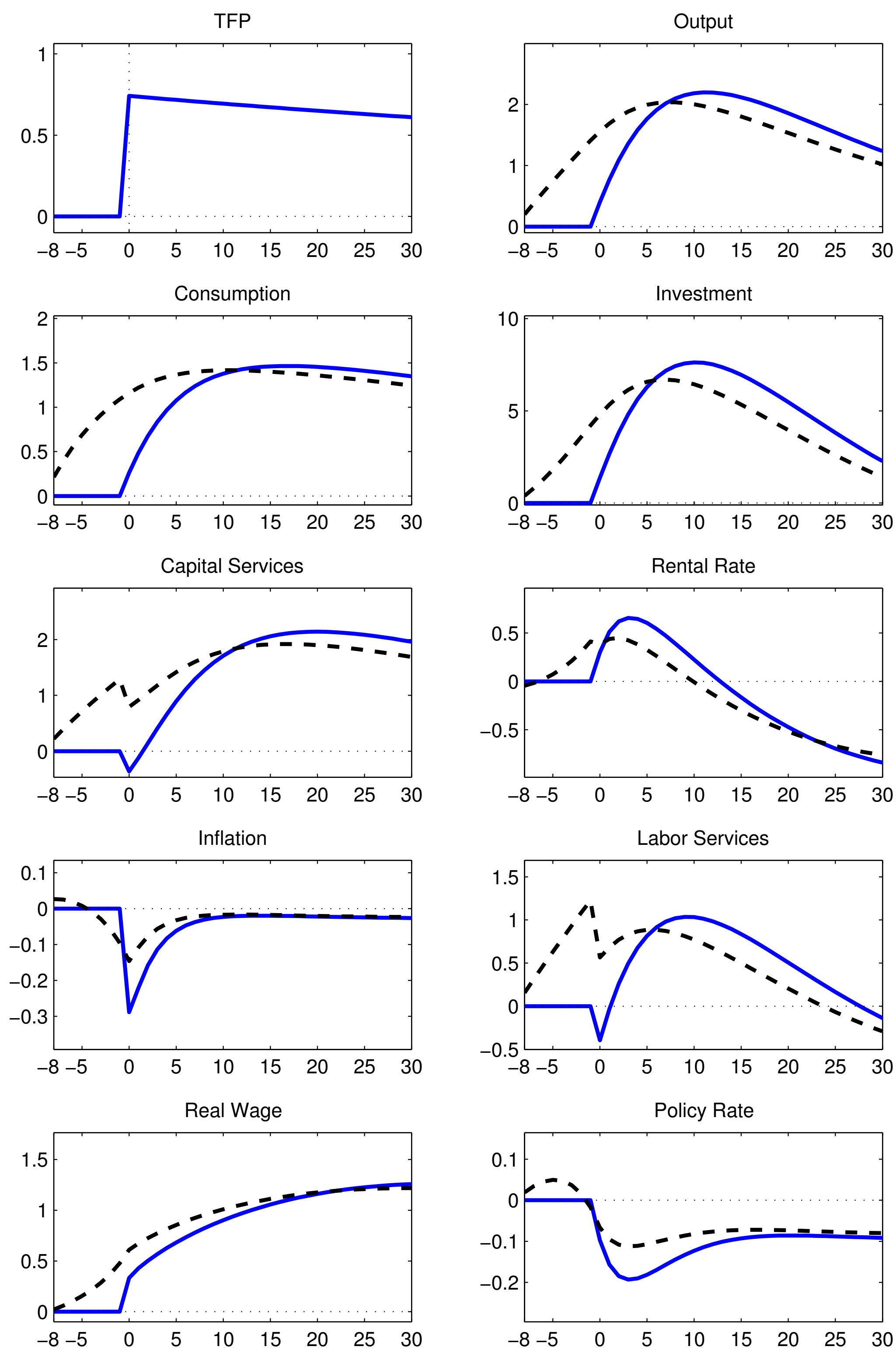

Figure 3: Impulse responses to unanticipated and anticipated stationary TFP shocks.
Notes: solid line: impulse responses to an unanticipated one standard deviation increase in stationary TFP z; dashed line: impulse responses to an eight period anticipated one standard deviation increase in stationary TFP z that becomes known at $t = -8$ and effective at $t = 0$. All impulse responses are semi-elasticities and measured in percent. Inflation and the policy rate are measured as gross rates so that the responses can be interpreted as percentage point changes.

wealth effect. This boom occurs already before the technology has actually increased and is fueled by a rise in both capital and labor services.[26] In this regard, the response differs from the response to an anticipated capital tax shock, where a substitution of capital services for labor services is observed. The reason for the difference is that, for the anticipated TFP shock, agents have a stronger incentive to increase investment during the anticipation phase. In contrast, for the anticipated capital tax shock, investment falls slightly on announcement due to the decrease in the present value of the depreciation allowances.

Lastly, to better understand the contribution of capital tax and stationary TFP shocks to business cycle variance, it is worth comparing the relative size and persistence of the impulse responses of output, inflation, and the nominal interest rate to these shocks. As can be seen from the the upper right panels of Figures 2 and 3, the peak response of output to an average TFP shock is about 80% higher than to an average capital tax shock, although the latter is somewhat more persistent.[27] This difference in the size of the output responses explains why stationary TFP shocks are more important for the volatility of output than capital tax shocks. In contrast, both the inflation and the policy rate responses to capital tax shocks have higher peaks and show more persistence. In particular, the average surprise TFP shock leads to a peak reduction in the nominal interest rate of -0.2%, while the average surprise tax shock leads to a drop of -0.4%. As this larger response is also more persistent, the difference in response sizes explains why capital taxes are rather important for the variance of inflation and the nominal interest rate, while they are less important for explaining output variance.

5 Conclusion

In this paper, we analyzed the contribution of fiscal foresight about labor and capital tax rates and government spending to business cycle volatility in an estimated New Keynesian DSGE model. Computing forecast error variance decompositions, we found that fiscal foresight only plays a limited role for business cycle fluctuations. Its variance contribution was mostly confined to inflation and interest rate fluctuations, where anticipated capital tax shocks were responsible for between 5 and 15 percent of the total variance.

Our results show that accounting for fiscal foresight does not qualitatively alter the importance of traditional business cycle factors like technology, wage markup, and preference shocks (see e.g. Smets and Wouters 2007).

[26] This observation is consistent with Jaimovich and Rebelo (2009), who show theoretically that a low estimated wealth elasticity of labor supply facilitates positive comovement of output, consumption, and hours in response to TFP news.

[27] Note also that the average anticipated capital tax shock is roughly 40% smaller than the one depicted due to re-scaling.

Structural estimation always runs the risk of misspecifying the underlying model structure. Hence, future work should test whether the results obtained here are robust against the specification of different fiscal rules where taxes respond to debt and possibly output as in Leeper et al. (2010) or Forni et al. (2009). Moreover, the role of the information structure assumed in the present work should be further scrutinized as the particular choice of information structures may matter (Leeper and Walker 2011).

A Tables

Table 2: Prior and Posterior Distributions of Preference and Technology Parameters

Parameter	Prior distribution			Posterior distribution			
	Distribution	Mean	Std. Dev.	Mean	Std. Dev.	5 Percent	95 Percent
ϕ_c	Beta	0.7	0.1	0.858	0.014	0.834	0.880
σ_l	Gamma	2	0.75	3.410	0.452	2.704	4.132
σ_s	Beta	0.5	0.2	0.101	0.023	0.069	0.137
κ	Gamma	4	1.5	4.860	0.425	4.128	5.526
δ_2/δ_1	Inverse-Gamma	0.5	0.15	0.280	0.023	0.243	0.316
χ_w	Beta	0.5	0.2	0.590	0.069	0.486	0.704
χ_p	Beta	0.5	0.2	0.059	0.024	0.022	0.098
θ_w	Beta	0.5	0.2	0.938	0.006	0.927	0.948
θ_p	Beta	0.5	0.2	0.662	0.009	0.646	0.676

Table 3: Prior and Posterior Distributions of the Shock Processes

Parameter	Prior distribution			Posterior distribution			
	Distribution	Mean	Std. Dev.	Mean	Std. Dev.	5 Percent	95 Percent
			Preference Shock				
ρ_{pref}	Beta	0.5	0.2	0.991	0.003	0.987	0.996
σ_{pref}	Inverse-Gamma	0.1	2	40.383	11.382	22.511	57.325
			Wage Markup Shock				
ρ_w	Beta	0.5	0.2	0.976	0.006	0.967	0.986
σ_w^0	Inverse-Gamma	0.1	2	45.692	7.160	34.538	58.147
σ_w^4	Inverse-Gamma	0.1	2	0.037	0.018	0.020	0.058
σ_w^8	Inverse-Gamma	0.1	2	0.032	0.017	0.023	0.045
			Stationary Technology Shock				
ρ_z	Beta	0.5	0.2	0.994	0.004	0.989	0.999
σ_z^0	Inverse-Gamma	0.1	2	0.738	0.043	0.663	0.806
σ_z^4	Inverse-Gamma	0.1	2	0.178	0.161	0.024	0.394
σ_z^8	Inverse-Gamma	0.1	2	0.730	0.047	0.648	0.804

Table 3: Prior and Posterior Distributions of the Shock Processes - Continued

Parameter	Prior distribution			Posterior distribution			
	Distribution	Mean	Std. Dev.	Mean	Std. Dev.	5 Percent	95 Percent
	Non-stationary Technology Shock						
ρ_x	Beta	0.5	0.2	0.336	0.059	0.245	0.438
σ_x^0	Inverse-Gamma	0.1	2	0.040	0.024	0.024	0.061
σ_x^4	Inverse-Gamma	0.1	2	0.034	0.015	0.021	0.047
σ_x^8	Inverse-Gamma	0.1	2	0.601	0.028	0.554	0.645
	Stationary Investment-Specific Productivity Shock						
ρ_{z^I}	Beta	0.5	0.2	0.968	0.019	0.942	0.992
$\sigma_{z^I}^0$	Inverse-Gamma	0.1	2	0.313	0.021	0.274	0.342
$\sigma_{z^I}^4$	Inverse-Gamma	0.1	2	0.034	0.015	0.025	0.053
$\sigma_{z^I}^8$	Inverse-Gamma	0.1	2	0.037	0.017	0.023	0.053
	Non-stationary Investment-Specific Productivity Shock						
ρ_a	Beta	0.5	0.2	0.986	0.0062	0.9766	0.996
σ_a^0	Inverse-Gamma	0.1	2	0.114	0.011	0.095	0.130
σ_a^4	Inverse-Gamma	0.1	2	0.036	0.013	0.020	0.056
σ_a^8	Inverse-Gamma	0.1	2	0.139	0.013	0.117	0.160
	Taylor Rule and Monetary Policy Shock						
ρ_R	Beta	0.5	0.2	0.865	0.009	0.851	0.879
ϕ_{R_Π}	Gamma	1.5	3	2.958	0.107	2.779	3.126
ϕ_{R_Y}	Gamma	0.5	3	0.314	0.050	0.235	0.402
σ_R	Inverse-Gamma	0.1	2	0.251	0.011	0.234	0.268
	Government Spending Shock						
ρ_g	Beta	0.5	0.2	0.940	0.017	0.912	0.968
ρ_{xg}	Beta	0.5	0.2	0.912	0.102	0.864	0.984
σ_g^0	Inverse-Gamma	0.1	2	3.024	0.124	2.815	3.217
σ_g^4	Inverse-Gamma	0.1	2	0.033	0.012	0.025	0.044
σ_g^8	Inverse-Gamma	0.1	2	0.038	0.023	0.025	0.058

Table 3: Prior and Posterior Distributions of the Shock Processes - Continued

Parameter	Prior distribution			Posterior distribution			
	Distribution	Mean	Std. Dev.	Mean	Std. Dev.	5 Percent	95 Percent
				Labor Tax Shock			
ξ_{n1}	Uniform	0	0.577	-0.228	0.046	-0.313	-0.164
ξ_{n2}	Uniform	0	0.577	0.998	0.001	0.997	0.999
$\sigma^0_{\tau^n}$	Inverse-Gamma	0.1	2	0.476	0.019	0.441	0.503
$\sigma^4_{\tau^n}$	Inverse-Gamma	0.1	2	0.037	0.018	0.024	0.051
$\sigma^8_{\tau^n}$	Inverse-Gamma	0.1	2	0.032	0.015	0.023	0.044
				Capital Tax Shock			
ξ_{k1}	Uniform	0	0.577	0.605	0.147	0.574	0.999
ξ_{k2}	Uniform	0	0.577	0.999	0.144	0.634	0.999
$\sigma^0_{\tau^k}$	Inverse-Gamma	0.1	2	0.923	0.045	0.856	0.997
$\sigma^4_{\tau^k}$	Inverse-Gamma	0.1	2	0.460	0.044	0.386	0.531
$\sigma^8_{\tau^k}$	Inverse-Gamma	0.1	2	0.645	0.046	0.571	0.721

Table 4: Variance Decomposition of Shocks (in %):

	Pref./Wage Markup		Technology							Policy					
	ξ^{pref}	ε_w^0	ε_z^0	$\varepsilon_z^{4,8}$	ε_x^0	$\varepsilon_x^{4,8}$	$\varepsilon_{z^I}^0$	ε_a^0	$\varepsilon_a^{4,8}$	ξ^R	ε_g^0	$\varepsilon_{\tau^n}^0$	$\varepsilon_{\tau^n}^{4,8}$	$\varepsilon_{\tau^k}^0$	$\varepsilon_{\tau^k}^{4,8}$
4 Periods															
GDP	5.00	35.26	24.03	7.98	0.01	0.65	0.27	1.96	2.09	1.48	18.43	0.46	0.00	2.11	0.25
Cons.	18.93	44.73	16.30	11.58	0.02	2.99	0.07	0.87	0.84	0.31	0.05	1.06	0.01	1.49	0.76
Invest.	37.59	17.99	20.53	3.63	0.00	0.00	0.41	7.75	7.91	2.08	0.04	0.09	0.00	1.86	0.12
Hours	3.29	48.73	4.29	7.96	0.03	0.84	0.07	9.48	5.61	4.11	8.91	0.66	0.00	0.13	5.89
Wages	7.39	2.65	50.01	3.35	0.65	0.09	0.12	8.72	5.51	1.71	0.18	0.05	0.00	17.58	1.99
FFR	16.46	2.39	17.85	1.10	0.00	0.20	0.01	5.62	9.99	15.01	0.75	0.00	0.00	29.51	1.11
Infl.	19.15	6.82	25.09	0.53	0.00	0.08	0.03	4.24	8.05	2.04	0.17	0.03	0.00	31.75	2.02
8 Periods															
GDP	11.18	35.13	20.52	9.54	0.01	0.68	0.26	1.83	2.75	1.04	12.76	0.44	0.00	2.96	0.90
Cons.	15.94	46.39	16.20	12.43	0.02	3.16	0.08	0.79	0.74	0.26	0.04	1.10	0.01	1.76	1.08
Invest.	41.33	18.32	15.61	5.40	0.00	0.03	0.35	6.19	7.88	1.29	0.02	0.09	0.00	2.76	0.72
Hours	8.78	52.59	6.56	9.78	0.01	0.98	0.13	6.64	5.49	1.78	2.87	0.68	0.00	0.61	3.09
Wages	6.53	2.41	44.66	11.78	0.53	0.52	0.12	7.65	4.77	1.52	0.16	0.05	0.00	15.14	4.15
FFR	21.19	3.23	12.88	0.86	0.00	0.22	0.01	4.50	10.55	5.54	0.42	0.00	0.00	35.54	5.06
Infl.	22.27	7.10	17.80	1.90	0.00	0.07	0.02	3.01	6.82	1.39	0.15	0.03	0.00	31.29	8.14
20 Periods															
GDP	21.15	30.89	16.43	9.13	0.01	0.98	0.21	1.58	3.44	0.87	9.89	0.39	0.00	2.89	2.12
Cons.	19.72	44.09	14.88	11.98	0.02	3.14	0.08	0.72	0.84	0.23	0.04	1.06	0.01	1.80	1.37
Invest.	45.16	16.75	12.51	5.79	0.00	0.17	0.28	5.04	8.13	1.07	0.03	0.09	0.00	2.73	2.24
Hours	22.63	50.14	4.20	4.30	0.00	0.25	0.12	5.14	8.29	0.49	0.71	0.67	0.01	1.52	1.52
Wages	6.16	2.26	18.65	8.87	0.20	48.45	0.06	3.00	2.22	0.64	0.06	0.02	0.00	6.08	3.31
FFR	31.49	4.15	5.45	1.94	0.00	0.12	0.00	1.64	5.08	1.53	0.17	0.00	0.00	30.96	17.48
Infl.	31.97	6.27	9.91	3.44	0.00	0.04	0.01	1.74	3.85	0.76	0.10	0.02	0.00	25.83	16.06
Uncond. Variance															
GDP	23.57	26.88	12.88	7.67	0.01	0.73	0.19	5.61	11.02	0.66	6.83	0.28	0.00	2.09	1.58
Cons.	24.27	37.52	12.06	9.74	0.01	2.45	0.07	3.75	6.54	0.20	0.04	0.83	0.00	1.43	1.08
Invest.	44.46	15.95	9.61	5.26	0.00	0.14	0.22	7.14	12.98	0.73	0.02	0.07	0.00	1.85	1.56
Hours	46.58	16.62	2.83	2.68	0.00	0.09	0.06	9.97	18.68	0.11	0.15	0.96	0.01	0.67	0.59
Wages	19.01	4.34	13.37	6.78	0.14	32.83	0.05	6.53	9.74	0.45	0.05	0.02	0.00	4.26	2.42
FFR	31.89	1.64	0.42	0.27	0.00	0.01	0.00	1.46	2.76	0.06	0.01	0.01	0.00	35.25	26.22
Infl.	31.43	1.69	1.00	0.43	0.00	0.00	0.00	1.34	2.53	0.07	0.01	0.01	0.00	35.33	26.16

Notes: Variance decompositions are performed at the posterior mean. ε_i^0 represents contemporaneous shock components; $\varepsilon_i^{4,8}$ represents the sum of the 4 and 8 quarter anticipated shock components. For ease of exposition, we leave out anticipated stationary investment-specific, wage-markup, and government spending shocks, since these shocks contribute less then 0.01% to the variances of the variables.

B Stationary Equilibrium

In order to derive a state-space representation of the model, the model presented in the main text is solved by using a first-order perturbation method. However, due to the two integrated processes A_t and X_t, which grow with rates

$$\mu_t^a = \frac{A_t}{A_{t-1}}, \quad \mu_t^x = \frac{X_t}{X_{t-1}}, \tag{24}$$

the model has to be detrended first in order to induce stationarity and to have a well-defined steady state. Y_t, C_t and W_t inherit the trend $X_t^Y = A^{\frac{\alpha}{\alpha-1}} X_t$, which corresponds to a growth rate of

$$\mu_t^y = (\mu_t^a)^{\frac{\alpha}{\alpha-1}} \mu_t^x. \tag{25}$$

K_t and I_t inherit the trend $X_t^K = A^{\frac{1}{\alpha-1}} X_t$ and thus grow with

$$\mu_t^k = \mu_t^I = (\mu_t^a)^{\frac{1}{\alpha-1}} \mu_t^x. \tag{26}$$

G_t inherits $X_t^G = \left(X_{t-1}^G\right)^{\rho_{xg}} \left(X_{t-1}^Y\right)^{1-\rho_{xg}}$ due to the assumed cointegrated trend with output. It hence grows with rate

$$x_t^g = \frac{(x_{t-1}^g)^{\rho_{xg}}}{\mu_t^y}. \tag{27}$$

The detrending is performed by dividing the trending model variables by their respective trend. For the estimation of our structural model, these stationary model variables are matched to the data presented in Appendix D.

C Observation Equation

The observation equation describes how the empirical times series are matched to the corresponding model variables:[28]

$$OBS_t = \begin{bmatrix} \Delta\log(Y_t) \\ \Delta\log(C_t) \\ \Delta\log\left(z_t^I A_t I_t\right) \\ \log(L_t) \\ \Delta\log(G_t) \\ \Delta\log\left(z_t^I A_t\right) \\ \Delta\log\left(\tau_t^k\right) \\ \Delta\log(\tau_t^n) \\ \Delta\log(TFP_t) \\ \Delta\log(W_t) \\ \Delta\log(R_t) \\ \Delta\log(\Pi_t) \end{bmatrix} \times 100 = - \begin{bmatrix} \log(\mu^y) \\ \log(\mu^y) \\ \log(\mu^y) \\ \log\left(\bar{L}\right) \\ \log(\mu^y) \\ \log(\mu^a) \\ \log\left(\tau^k\right) \\ \log(\tau^n) \\ (1-\alpha)\log(\mu^x) \\ \log(\mu^y) \\ \log(R) \\ \log\left(\bar{\Pi}\right) \end{bmatrix} + \begin{bmatrix} \hat{y}_t - \hat{y}_{t-1} + \hat{\mu}_t^y \\ \hat{c}_t - \hat{c}_{t-1} + \hat{\mu}_t^y \\ \hat{i}_t - \hat{i}_{t-1} + \hat{z}_t^I - \hat{z}_{t-1}^I + \hat{\mu}_t^y \\ \hat{L}_t \\ \hat{g}_t - \hat{g}_{t-1} + \hat{x}_t^g - \hat{x}_{t-1}^g + \hat{\mu}_t^y \\ \hat{\mu}_t^a + \hat{z}_t^I - \hat{z}_{t-1}^I \\ \hat{\tau}_t^k \\ \hat{\tau}_t^n \\ \hat{z}_t - \hat{z}_{t-1} + (1-\alpha)\hat{\mu}_t^x \\ \hat{w}_t + \hat{w}_{t-1} + \hat{\mu}^y \\ \hat{R}_t \\ \hat{\Pi}_t \end{bmatrix},$$

where Δ denotes the temporal difference operator, $\bar{L}$ denotes the steady state of hours worked, μ^y is the steady state growth rate of output[29], μ^a is the steady state growth rate of the relative price of investment, τ^k and τ^n are the steady state tax rates, $TFP_t = z_t X_t^{1-\alpha}$ is total factor productivity, and R is the steady state interest rate. The hats above the variables denote log deviations from steady state.

D Data construction

Unless otherwise noted, all data are from the Bureau of Economic Analysis (BEA)'s NIPA Tables and available in quarterly frequency from 1955Q1 until 2006Q4.

Capital and labor tax rates. Our approach to calculate average tax rates closely

[28]The equation for L_t follows from

$$\log L_t = \log\left(L_t \frac{\bar{L}}{\bar{L}}\right) \approx \hat{L}_t + \log \bar{L}\ .$$

The equation for government spending follows from

$$\log\frac{G_t}{G_{t-1}} = \log\frac{g_t X_t^g}{g_{t-1} X_{t-1}^g} = \log\frac{g_t x_t^g X_t^Y}{g_{t-1} x_{t-1}^g X_{t-1}^Y} = \log\frac{g_t x_t^g}{g_{t-1} x_{t-1}^g}\mu_t^y\ .$$

[29]This is also the growth rate of the individual components of GDP along the balanced growth path.

follows Mendoza et al. (1994), Jones (2002), and Leeper et al. (2010). 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), W is wage and salary accruals (Table 1.12 line 3), PRI is proprietor's income (Table 1.12 line 9), and $CI \equiv PRI/2 + RI + CP + NI$ is capital income. Here, RI is rental income (Table 1.12 line 12), CP is corporate profits (Table 1.12 line 13), and NI denotes the net interest income (Table 1.12 line 18).

The average labor and capital income tax rates can then be computed as

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

where CSI denotes contributions for government social insurance (Table 3.1 line 7), and EC is compensation of employees (Table 1.12 line 2), and

$$\tau^k = \frac{\tau^p CI + CT + PT}{CI + PT} \ ,$$

where CT is taxes on corporate income (Table 3.1 line 5), and PT is property taxes (Table 3.3 line 8).

Government spending. Government spending is the sum of government consumption (Table 3.1 line 16) and government investment (Table 3.1 line 35) divided by the GDP deflator (Table 1.1.4 line 1) and the civilian noninstitutional population (BLS, Series LNU00000000Q).

Total factor productivity (TFP). The construction of TFP closely follows Beaudry and Lucke (2010), i.e.

$$TFP_t = \frac{Y_t}{K^\alpha H^{1-\alpha}} \ .$$

To construct K, we use data on capital services for the private non-farm business sector (Bureau of Labor Statistics (BLS), Historical Multifactor Productivity Tables),[30] multiply it by the total capacity utilization rate (Federal Reserve System, Statistical Release G.17 - Industrial Production and Capacity Utilization), and divide it by the civilian noninstitutional population above 16 years of age (BLS, Series LNU00000000Q). Real GDP per capita Y is nominal GDP (Table 1.1.5 line 1) divided by the GDP deflator (line 1 in Table 1.1.4) and the population, and per capita hours H are non-farm business hours worked (BLS, Series PRS85006033) divided by the population. The capital share α is set at 0.2935, the mean over the sample compiled by the BLS (Bureau of Labor Statistics (BLS), Historical Multifactor

[30] Quarterly data is interpolated from the annual series using cubic spline interpolation.

Productivity Tables).

Relative price of investment. The relative price of investment is taken from Schmitt-Grohé and Uribe (2011). They base their calculations on Fisher (2006).

Output. Nominal GDP (Table 1.1.5 line 1) divided by the GDP deflator (Table 1.1.4 line 1) and the civilian noninstitutional population (BLS, Series LNU00000000Q).

Investment. Sum of Residential fixed investment (Table 1.1.5 line 12) and nonresidential fixed investment (Table 1.1.5 line 9) divided by the GDP deflator (Table 1.1.4 line 1) and the civilian noninstitutional population (BLS, Series LNU00000000Q).

Consumption. Sum of personal consumption expenditures for nondurable goods (Table 1.1.5 line 5) and services (Table 1.1.5 line 6) divided by the GDP deflator (Table 1.1.4 line 1) and the civilian noninstitutional population (BLS, Series LNU00000000Q).

Real wage. Hourly compensation in the nonfarm business sector (BLS, Series PRS85006103) divided by the GDP deflator (Table 1.1.4 line 1).

Inflation. Computed as the log-difference of the GDP deflator (Table 1.1.4 line 1).

Nominal interest rate. Geometric mean of the effective Federal Funds Rate (St.Louis FED - FRED Database, Series FEDFUNDS).

Hours worked. Nonfarm business hours worked (BLS, Series PRS85006033) divided by the civilian noninstitutional population (BLS, Series LNU00000000Q)

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