News Shocks, Price Levels, and Monetary Policy[*]

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March 21, 2011

Abstract

This paper presents a model in which improvement in the future TFP is, on impact, associated with increases in consumption, stock prices, and real wages, and decreases in GDP, investment, hours worked, and inflation. These predictions are consistent with empirical findings of Barsky and Sims. The model features research and development, sticky nominal wages, and the monetary authority responding to inflation and consumption growth. Empirically, the proposed policy rule fits the actual Federal Funds rate as closely as an alternative policy rule responding to inflation and GDP growth. Theoretically, it nicely reduces distortion due to the nominal wage stickiness.

JEL Classification: E00, E30, E52; Key Words: news shock, R&D, inflation, sticky wages, monetary policy

1 Introduction

What are the macroeconomic implications of a change in expectations about future technology? This classic question received renewed interest in the last decade. Paul Beaudry and Franck Portier (2006), which I discuss later, report empirical evidence suggesting that a favorable news about

future technology generates positive comovement among output, consumption, investment, and hours worked, as Arthur Pigou (1927) hypothesized. A large literature follows, trying to replicate this comovement in a theoretical model (e.g., Paul Beaudry and Franck Portier (2004), Wouter J. den Haan and Georg Kaltenbrunner (2009), and Nir Jaimovich and Sergio Rebelo (2010)). But recently, an empirical study of Robert B. Barsky and Eric R. Sims (2010) develops an arguably more fitting identification technique, and finds that the data favor the basic neo-classical growth model's original predictions, i.e., a favorable news is, on impact, associated with an increase in consumption, and decreases in output, investment, and hours worked, suggesting that there may be no need to "fix" the basic neo-classical growth model for explaining impacts of news shocks.[1]

But unfortunately, this is not the case, since their empirical findings on price levels are hard to square with standard macroeconomic models. For example, they report that favorable news is associated with a stock market boom, but the standard neo-classical framework predicts that asset prices should decline when investment is weak (e.g., Fumio Hayashi (1982)).[2] Barsky and Sims also report that favorable news is associated with deflation, but in the standard new Keynesian sticky price model, it is strongly inflationary (see Robert B. Barsky and Eric R. Sims (2009)). So the question arises, "What kind of a model, if any, accounts for Barsky and Sims's empirical findings on both quantities and prices together?" This paper offers such a model.

The model is a slightly extended version of my previous work, Ryo Jinnai (2010), which focuses on asset pricing implications of news shocks. Unlike most papers in the literature, my model does not have exogenous future productivity improvement, but instead, I introduce private research and development (R&D) activities, aimed at inventing new intermediate varieties. The private R&D can be collectively productive or collectively unproductive, due to exogenous disturbances, and this stationary fluctuation in aggregate research productivity very much looks like a news shock, because it affects the measured total factor productivity (TFP) only gradually, as product innovations materialized and accumulated. In a simple model, however, the stock market value collapses when the research productivity improves, because under the usual assumption of constant

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[1] Deokwoo Nam and Jian Wang (2010) apply the method for studying exchange rate dynamics.

[2] See also Lawrence Christiano, Cosmin Ilut, Roberto Motto and Massimo Rostagno (2008) for more general discussion about difficulty in generating a stock market boom preceding a technology improvement.

elasticity of substitution between every pair of intermediate products, expectation of the massive introduction of new products lowers the values of existing products. But in my model, the idea of an existing product is used not only for manufacturing the product, but also for inventing new products, and because the latter value—as a seed of new products—rises, the stock market value appreciates when the aggregate research productivity improves and hence people expect future TFP improvement.

This paper introduces sticky nominal wages to the framework. This nominal friction is a common ingredient in new Keynesian models (e.g., Christopher J. Erceg, Dale W. Henderson and Andrew T. Levin (2000)), and its empirical evidence is documented by Alessandro Barattieri, Susanto Basu and Peter Gottschalk (2010), among others. I assume that the monetary authority sets the nominal interest rate according to a feedback rule responding to both inflation rate and consumption growth. In this model, the price level declines when aggregate research productivity improves. The reasoning goes as follows. Because of the wealth effect, households immediately raise consumption levels. The monetary authority, reading it as a sign of a heated economy, raises the target interest rate, but this move makes fixed-income bond abnormally attractive, given that the inflation expectation is anchored by the Taylor principle, and the capital productivity is little impacted by the "news shock." For market clearings, something has to persuade the monetary authority to refrain from extreme tightening. That is deflation. The deflation pushes down the target interest rate back to the point at which the fixed-income bond becomes as attractive as the other assets. Therefore, the price level declines when people expect future TFP improvement.

The monetary policy rule is worth a discussion. In the empirical literature, output is a conventional target, partly because pioneering work by John B. Taylor (1993) demonstrates an impressive fit to the actual Federal Funds rate with a simple feedback rule responding to inflation and output. But I find that my proposed monetary policy rule also fits the actual Federal Funds rate as closely as its output targeting counterpart. In the theoretical literature, consumption and output are often identical because investment is not modeled. But with investment, the distinction in the policy targets is potentially very important, and this paper is a striking example. That is, I demonstrate that if the assumed target variable is changed from consumption growth to GDP

growth, the model is no longer able to replicate Barsky and Sims's empirical findings. In addition, I argue that the consumption targeting monetary policy has an advantage in the normative sense. The reasoning goes as follows. Other things equal, an increase in consumption should raise real wages, since it raises the marginal rate of substitution of consumption for leisure. The nominal wage stickiness, however, is an impediment to this adjustment. But the consumption targeting monetary policy can mitigate the problem by affecting the general price level, at the right time, in the right direction. The welfare gain of choosing the right policy target can be significant; in my benchmark model, it is equivalent to about half a percentage point of average consumption.

Barsky and Sims (2009) also present a model in which a news shock is disinflationary. They propose two modifications to a standard new Keynesian sticky price model: real wage rigidity and misperception of the output gap by the monetary authority, the latter leading to more contractionary monetary policy than otherwise would be for a number of periods after a news shock. Their model, however, does not have investment, and hence, cannot account for joint dynamics among important macroeconomic aggregates. In addition, a surprise technology shock reduces hours worked in the sticky price model, but this is inconsistent with their empirical finding.

Now I discuss related empirical studies. Beaudry and Portier (2006), Paul Beaudry, Martial Dupaigne and Franck Portier (2008), and Paul Beaudry and Bernd Lucke (2010) identify news shock by artfully combining short-run and long-run zero restrictions. Their methods, however, require many auxiliary assumptions as the number of variables increases. Barsky and Sims (2010) overcome this problem by identifying news shock with an application of principal component analysis. This method can be applied to a VAR system of any size with only a minimal (and ubiquitous) assumption that a limited number of shocks lead to movements in aggregate technology. It does not have to make explicit assumptions on the common trend either, and in fact, results are robust to specifications. In contrast, Beaudry and Lucke's results are sensitive to assumption on the number of common trends (see Jonas Fisher (2010)).

The remainder of the paper is organized as follows. Section 2 lays out the model. Section 3 discusses parameter values. Section 4 presents predictions of the benchmark model. Section 5 discusses implications of different monetary policy targets. Section 6 concludes.

2 Model

The economy consists of a final good firm, multi-product intermediate goods firms, continuum of households with a unit measure, and the monetary authority. The final good firm competitively assembles intermediates goods. The intermediate goods firms manufacture products, and invent new varieties by conducting R&D. The households provide production factors and make consumption and investment decisions. The monetary authority sets the nominal interest rate.

I present the model as if the number of intermediate goods firms is fixed, but this is not restricting because allowing firm entry and exit by introducing the property rights market does not alter the aggregate allocation, as long as the key assumption—there are always more than two intermediate goods firms—is met. See Jinnai (2010) for discussion.

2.1 Final good firm

The production function in period t is

$$Z_t = \left[\int_{\omega \in \Omega_t} z_t(\omega)^{\frac{\theta_p - 1}{\theta_p}} d\omega \right]^{\frac{\theta_p}{\theta_p - 1}} \tag{1}$$

where Z_t is the final good production, Ω_t is the set of available products in period t, $z_t(\omega)$ is the input of the intermediate good of index ω, and $\theta_p > 1$ is the elasticity of substitution between every pair of intermediate products. At the beginning of each period, intermediate goods firms post prices of products they can supply. After observing them, the final good firm purchases each product from the lowest price offering firm. If firms tie for the lowest price, I assume that the final good firm purchases the equal amount from each of them. Solving the cost minimization problem leads to the usual demand function of a product, $(p_t^*(\omega)/P_t)^{-\theta_p} Z_t$ where $p_t^*(\omega)$ is the lowest price posted for product ω in period t and P_t is the aggregate price index, $P_t \equiv \left[\int_{\omega \in \Omega_t} p_t^*(\omega)^{1-\theta_p} d\omega \right]^{\frac{1}{1-\theta_p}}$.

2.2 Intermediate goods firms

The underlying manufacturing technology is a Cobb-Douglas combination of capital k_t and homogenous labor h_t, i.e., $A_t k_t^\alpha h_t^{1-\alpha}$, where A_t is goods producing productivity, which is common

across products, and $\alpha \in [0,1]$ is the capital elasticity. The intermediate products, however, are categorized into two groups, depending on which firms can manufacture it. One is called innovative. The innovative product is relatively new after its invention, and only the inventing firm can manufacture it. But an innovative product stochastically switches to the other type called maturing, and after the maturation, it can be manufactured by any intermediate goods firm. The maturation is exogenous, idiosyncratic, and independent from aggregate shocks.

Therefore, in any given period, an intermediate goods firm monopolistically supplies innovative products it invents, and competitively supplies maturing products. I assume that each product is individually managed. An innovative product's manager, as a monopolist, makes the real profit

$$d_t \equiv \frac{1}{\theta_p - 1} \left(\frac{\theta_p}{\theta_p - 1} \right)^{-\theta_p} \left(\frac{MC_t}{P_t} \right)^{1-\theta_p} Z_t$$

where MC_t is nominal marginal cost:

$$MC_t = \frac{1}{A_t} \left(\frac{R_{K,t}}{\alpha} \right)^{\alpha} \left(\frac{W_t}{1 - \alpha} \right)^{1-\alpha}$$

where $R_{K,t}$ is nominal rental price of capital, and W_t is nominal wage rate of homogenous labor. A maturing product manager engages in the Bertrand competition, and therefore makes zero profit.

An intermediate goods firm makes R&D decision to maximize the firm value. If firm j devotes X_t^j of final good in R&D in period t, it acquires measure $S_t \left(N_{I,t-1}^j \right)^{1-\nu} \left(X_t^j \right)^{\nu}$ of new innovative products at the end of the period, where $N_{I,t-1}^j$ is the measure of firm j's innovative products in period t, S_t is research productivity in period t, which is common across intermediate goods firms, and $\nu \in [0,1]$ is the research elasticity. At the end of each period, a share δ_N of both innovative and maturing products become obsolete, i.e., becoming permanently unavailable from the economy, and a share $(1 - \delta_N)\sigma$ of innovative products become maturing products. Therefore, the law of motion of firm j's innovative products is

$$N_{I,t}^j = (1 - \delta_N)(1 - \sigma) N_{I,t-1}^j + S_t \left(N_{I,t-1}^j \right)^{1-\nu} \left(X_t^j \right)^{\nu} \tag{2}$$

The real firm value at the beginning of period t is

$$E_t \left[\sum_{\tau=0}^{\infty} Q_{t,t+\tau} \frac{P_{t+\tau}}{P_t} \left(N^j_{I,t-1+\tau} d_{t+\tau} - X^j_{t+\tau} \right) \right] \tag{3}$$

where $Q_{t,t+\tau}$ is the stochastic discount factor, which is defined later. The first order conditions for the optimal R&D sequence are

$$v_t \left[\nu S_t \left(\frac{N^j_{I,t-1}}{X^j_t} \right)^{1-\nu} \right] = 1 \tag{4}$$

$$v_t = E_t \left[Q_{t,t+1} \frac{P_{t+1}}{P_t} \left(d_{t+1} + v_{t+1} \left((1-\delta_N)(1-\sigma) + (1-\nu) S_{t+1} \left(\frac{X^j_{t+1}}{N^j_{I,t}} \right)^{\nu} \right) \right) \right] \tag{5}$$

where v_t is the Lagrange multiplier on (2). Equation (4) says that a firm with more innovative products spends more resource in R&D because such a firm is more productive in R&D. Equation (5) says that the shadow price of an innovative product reflects not only the real profit earned in the goods market, but also its marginal contribution in R&D. Combining (4) and (5) and substituting forward, we find that the real firm value at the end of the period (i.e., the ex-dividend real firm value) is equal to the shadow price of an innovative product multiplied by the end-of-the-period innovative products, $v_t N^j_{I,t}$.

Let $N_{I,t-1} \equiv \sum_j N^j_{I,t-1}$ denote the measure of the aggregate innovative products in period t. Let $X_t \equiv \sum_j X^j_t$ denote the aggregate R&D spending in period t. Because the ratio $X^j_t / N^j_{I,t-1}$ is identical across firms, the law of motion of the aggregate innovative products is

$$N_{I,t} = (1-\delta_N)(1-\sigma) N_{I,t-1} + S_t (N_{I,t-1})^{1-\nu} (X_t)^{\nu} \tag{6}$$

Let $N_{M,t-1}$ denote the measure of the maturing products in period t. Its law of motion is

$$N_{M,t} = (1-\delta_N) N_{M,t-1} + (1-\delta_N) \sigma N_{I,t-1} \tag{7}$$

Let $N_{t-1} \equiv N_{M,t-1} + N_{I,t-1}$ denote the measure of the total intermediate products in period t. Its

law of motion is

$$N_t = (1 - \delta_N) N_{t-1} + S_t (N_{I,t-1})^{1-\nu} (X_t)^{\nu}$$

Following the national income accounting convention, I define GDP as $Y_t \equiv Z_t - X_t$.

2.3 Households

The expected lifetime utility of household $\iota \in [0, 1]$ is

$$E_t \left[\sum_{\tau=0}^{\infty} \beta^{\tau} \left(\log [c_{t+\tau} (\iota)] - \chi_0 \frac{l_{t+\tau} (\iota)^{1+\chi}}{1 + \chi} \right) \right] \tag{8}$$

where $c_t (\iota)$ denotes consumption of household ι in period t and $l_t (\iota)$ denotes labor service of household ι in period t. The flow budget constraint is

$$P_t (c_t (\iota) + i_t (\iota)) + E_t [Q_{t,t+1} B_{t+1} (\iota)] = w_t (\iota) l_t (\iota) + R_{K,t} k_{t-1} (\iota) + B_t (\iota) + \Gamma_t (\iota) \tag{9}$$

where $i_t (\iota)$ denotes investment of household ι in period t, $w_t (\iota)$ is the wage rate for its labor service in period t, $k_{t-1} (\iota)$ is capital holding of household ι at the beginning of period t, $B_t (\iota)$ is the value of the household ι's portfolio at the beginning of period t, and $\Gamma_t (\iota)$ is an aliquot share of the aggregate profits, i.e., $\Gamma_t (\iota) = P_t (N_{I,t-1} d_t - X_t)$. The capital evolves according to

$$k_t (\iota) = (1 - \delta_K) k_{t-1} (\iota) + i_t (\iota)$$

where $\delta_K \in [0, 1]$ is the physical capital depreciation rate. I assume that the state contingent claims markets are complete, and the initial wealth is identical across households. Therefore, consumption and investment are identical across households in every period, i.e., $c_t (\iota) = \int c_t (\iota) d\iota \equiv C_t$, $i_t (\iota) = \int i_t (\iota) d\iota \equiv I_t$, and $k_t (\iota) = \int k_t (\iota) d\iota \equiv K_t$. The first order conditions are

$$Q_{t,t+1} = \beta \frac{C_t}{C_{t+1}} \frac{P_t}{P_{t+1}} \tag{10}$$

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$$1 = E_t \left[\beta \frac{C_t}{C_{t+1}} \left(\frac{R_{K,t+1}}{P_{t+1}} + 1 - \delta_K \right) \right] \tag{11}$$

and the aggregate capital stock evolves according to

$$K_t = (1 - \delta_K) K_{t-1} + I_t \tag{12}$$

Each household supplies a differentiated labor service to the production sector. It is convenient to assume a representative labor aggregator who competitively combines households' labor hours. The labor index H_t has the Dixit-Stiglitz form

$$H_t \equiv \left[\int_0^1 l_t(\iota)^{\frac{\theta_w - 1}{\theta_w}} d\iota \right]^{\frac{\theta_w}{\theta_w - 1}}$$

where $\theta_w > 1$ is the elasticity of substitution between every pair of differentiated labor services. Zero profit condition implies $W_t = \left[\int_0^1 w_t(\iota)^{1-\theta_w} d\iota \right]^{\frac{1}{1-\theta_w}}$, and the demand for household ι's labor service is $(w_t(\iota)/W_t)^{-\theta_w} H_t$.

I introduce nominal wage stickiness following Erceg, Henderson and Levin (2000). A constant fraction $(1 - \zeta)$ of households renegotiates their wage contracts in each period; the other households cannot change their wages in the period. The household being able to reset its contract wage maximizes the expected utility (8) with respect to the wage rate. The first order condition is

$$E_t \left[\sum_{\tau=0}^{\infty} (\beta\zeta)^{\tau} \left(\frac{1}{C_{t+\tau}} \frac{w_t^*}{P_{t+\tau}} - \left(\frac{\theta_w}{\theta_w - 1} \right) \chi_0 l_{t+\tau|t}^{\chi} \right) l_{t+\tau|t} \right] = 0 \tag{13}$$

where

$$l_{t+\tau|t} = \left(\frac{w_t^*}{W_{t+\tau}} \right)^{-\theta_w} H_{t+\tau} \tag{14}$$

I drop the household index ι because all the households who reset their wages in a given period set their wages at the same rate. The real wage rate for a homogenous labor evolves according to

$$\left(\frac{W_t}{P_t} \right)^{1-\theta_w} = (1-\zeta) \left(\frac{w_t^*}{P_t} \right)^{1-\theta_w} + \zeta \left(\frac{W_{t-1}}{P_{t-1}} \frac{P_{t-1}}{P_t} \right)^{1-\theta_w} \tag{15}$$

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2.4 Monetary authority

The nominal interest rate is defined as

$$R_{f,t} \equiv \frac{1}{E_t\left[Q_{t,t+1}\right]} \tag{16}$$

The monetary authority sets this rate according to the feedback rule

$$R_{f,t} = \rho_{mp}R_{f,t-1} + \left(1 - \rho_{mp}\right)\left(\frac{1}{\beta} + \phi_\pi\left(\pi_{t,q}\right) + \phi_c\left(\gamma_{c,j}\right)\right) \tag{17}$$

$\rho_{mp} \in [0,1]$ is the interest rate smoothing, capturing the gradual adjustment of the policy rate. The target rate responds to the inflation rate between periods $t-q$ and t, $\pi_{t,q} \equiv P_t/P_{t-q}-1$ and the growth rate of consumption between periods t and $t-j$, $\gamma_{c,j} \equiv C_t/C_{t-j}-1$. Except that the target variable is consumption but not output, this policy specification is very standard. See, for example, Athanasios Orphanides (2003) for an empirical application and Jesús Fernández-Villaverde, Pablo Guerrón-Quintana and Juan F. Rubio-Ramírez (2010) for a theoretical application.

2.5 Equilibrium

The equilibrium is defined as the sequence of prices and quantities such that (i) they solve the optimization problems of the final good firm, intermediate goods firms, and households, (ii) the nominal interest rate is set according to (17), and (iii) market clearing conditions are satisfied every period, i.e.,

$$\int_{\omega \in \Omega_t} h_t^d\left(\omega\right) d\omega = H_t \tag{18}$$

$$\int_{\omega \in \Omega_t} k_t^d\left(\omega\right) d\omega = K_{t-1} \tag{19}$$

$$Z_t = C_t + I_t + X_t \tag{20}$$

for any $t \geq 0$, where $h_t^d\left(\omega\right)$ is homogenous labor input for product ω and $k_t^d\left(\omega\right)$ is capital input for product ω.

I summarize the system of equations characterizing the equilibrium. Substituting the optimal

price of a typical innovative product $p_{I,t} = (\theta_p/(\theta_p - 1)) MC_t$ and the optimal price of a typical maturing product $p_{M,t} = MC_t$ into the definition of the price index P_t, we find an equation characterizing the real marginal cost:

$$\frac{MC_t}{P_t} = \frac{\theta_p - 1}{\theta_p} N_{t-1}^{\frac{1}{\theta_p - 1}} \left[\frac{\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right)}{\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right) + 1} + \frac{1}{\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right) + 1} \left(\frac{\theta_p}{\theta_p - 1}\right)^{\theta_p - 1} \right]^{\frac{1}{\theta_p - 1}} \tag{21}$$

The per-product labor demand is given by $W_t = MC_t (1 - \alpha) A_t (k_t(\omega)/h_t(\omega))^\alpha$. Integrating it over ω and substituting (18) and (19), we find an equation characterizing the real wage:

$$\frac{W_t}{P_t} = \frac{MC_t}{P_t} (1 - \alpha) A_t \left(\frac{K_{t-1}}{H_t}\right)^\alpha \tag{22}$$

Doing a similar calculation for the capital demand, we find an equation characterizing the real rental price:

$$\frac{R_{K,t}}{P_t} = \frac{MC_t}{P_t} \alpha A_t \left(\frac{K_{t-1}}{H_t}\right)^{\alpha - 1} \tag{23}$$

Finally, from (1), (18), and (19), we find an equation characterizing the final good production

$$Z_t = A_t N_{t-1}^{\frac{1}{\theta_p - 1}} K_{t-1}^\alpha H_t^{1-\alpha} \frac{\left[\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right) + \left(\frac{\theta_p}{\theta_p - 1}\right)^{\theta_p - 1} \right]^{\frac{\theta_p}{\theta_p - 1}}}{\left[\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right) + 1 \right]^{\frac{1}{\theta_p - 1}} \left[\left(\frac{N_{I,t-1}}{N_{M,t-1}}\right) + \left(\frac{\theta_p}{\theta_p - 1}\right)^{\theta_p} \right]} \tag{24}$$

The system of 15 equations, (4), (5), (6), (7), (11), (12), (13), (15), (16), (17), (20), (21), (22), (23), and (24), characterizes the equilibrium dynamics of 15 endogenous variables, C_t, P_t/P_{t-1}, w_t^*/P_t, H_t, W_t/P_t, $R_{K,t}/P_t$, K_t, I_t, MC_t/P_t, $N_{M,t}/N_{I,t}$, N_t, v_t, X_t, Z_t and $R_{f,t}$. The goods producing productivity A_t and the research productivity S_t are two exogenous state variables.

3   Parameter values

I calibrate most parameter values.   See Table 1 for the summary.   Productivity processes are exceptions, which are estimated given calibrated parameters.   The time unit is a quarter of a

year. I set the capital depreciation rate to $\delta_K = .025$ and the subjective time discount rate to $\beta = .995$. These are standard values in the macroeconomics literature. I set the obsolescence rate to $\delta_N = .01$, being guided by the product destruction rate of Christian Broda and David E. Weinstein (2010). I set the maturation rate to $\sigma = .045$ so that $\delta_N = .01$ and $\sigma = .045$ together imply a 20% annual R&D depreciation rate (see Carol Corrado, Charles Hulten and Daniel Sichel (2009)). $\sigma = .045$ also implies that, consistent with Edwin Mansfield, Mark Schwartz and Samuel Wagner (1981), 52% of innovative products are imitated within 4 years after their introduction. I set the elasticity of substitution between every pair of products to $\theta_p = 3$. This choice is guided by both empirical research on the price elasticity of branded products (e.g, Gerard J. Tellis (1988)) and empirical research on the markup (e.g., Robert E. Hall (1988) and Robert B. Barsky, Mark Bergen, Shantanu Dutta and Daniel Levy (2003)).[3] Following Lawrence J. Christiano, Martin Eichenbaum and Charles L Evans (2005), I set the elasticity of substitution between every pair of differentiated labor services to $\theta_w = 20$. I set the degree of the nominal wage stickiness to $\zeta = .82$ (see Barattieri, Basu and Gottschalk (2010)). I set the capital elasticity to $\alpha = .31$ so that the steady state labor share is 68% of GDP. I set the inverse of Frisch elasticity to $\chi = 1.5$, which is in line with estimates from the micro-econometric studies (e.g., Luigi Pistaferri (2003)). I set the scale parameter of the labor disutility to $\chi_0 = .87$ so that the steady state labor hours are normalized to unity. I set the research elasticity to $\nu = .17$ so that the steady state R&D spending is 2% of GDP. Almost identical research elasticity is obtained by Jonathan Eaton and Samuel Kortum (1999), who estimate the parameter with productivity, research employment, and international patent data. I assume that the monetary authority targets one-quarter inflation rate and one-quarter consumption growth, i.e., $j = q = 1$, but results are robust to other variations. I set the interest rate smoothing to $\rho_{mp} = .78$ and the response coefficients to $\phi_\pi = 2.04$ and $\phi_c = 1.50$. These values are taken from OLS estimates, which I discuss later.

Given these parameter values, I estimate the productivity processes by maximum likelihood. I

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[3]Some papers assume 20% markup ($\theta_p = 6$) following Julio J. Rotemberg and Michael Woodford (1992). But notice that Rotemberg and Woodford (1992) state that their choice of the markup is extremely conservative (page 1179).

assume that the two productivities, A_t and S_t, follow stationary AR(1) processes such that

$$\log A_t = \rho_A \log A_{t-1} + \eta_{A,t}, \quad |\rho_A| < 1$$

$$\log S_t = \rho_S \log S_{t-1} + \eta_{S,t}, \quad |\rho_S| < 1$$

with $\eta_t \equiv \left(\eta_{A,t}, \eta_{S,t}\right)' \sim \text{i.i.d.} N(0, \Sigma)$. The system of equations is log-linearized around the non-stochastic steady state, and is fitted to the following two series: (i) linearly detrended quarterly GDP and (ii) linearly detrended annual R&D spending performed by the business sector. See Sungbae An and Frank Schorfheide (2007) for the procedure in detail. The sample period is from the 1st quarter of 1980 to the 4th quarter of 2007. Being after Paul Volker's appointment to the Fed chairman but before the beginning of the great recession, this is arguably the longest single policy regime. The estimated values are $(\rho_A, \rho_S) = (.97, .93)$ for persistence and $\left(\Sigma_{11}^{1/2}, \Sigma_{22}^{1/2}, \Sigma_{12}/(\Sigma_{11}\Sigma_{22})^{1/2}\right) = (.0033, .015, .20)$ for innovations.

4   Main results

I first ask if the benchmark model accounts for Barsky and Sims's empirical findings. For that purpose, I need to characterize a news shock in my model economy. Following the literature, I assume that the observed technology measure—standard TFP calculated with GDP, physical capital, hours worked, and the steady state labor share—is driven by two independent shocks—the news shock and the surprise technology shock—and the news shock is contemporaneously orthogonal to the technology measure. Such a shock is easily identified in the model by appropriately orthogonalizing innovations. In particular, it is a combination of both an improvement in the research productivity and a slight improvement in the goods producing productivity. The latter offsets a decline in the measured TFP due to an increase in the R&D spending.

Figure 1 plots impulse response functions to a one standard deviation news shock. TFP improves with lags because product varieties gradually increase. Consumption rises on impact, and GDP, investment, and hours worked fall on impact because of the wealth effect. Subsequently,

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consumption, GDP, and investment increase, and hours worked return to the steady state level.

The corporate sector's total asset value, defined as $(26\%) K_t + v_t N_{I,t}$, rises on impact. I exclude some of the physical capital from the corporate sector's balance sheet because our definition of investment includes residential investment and personal expenditure on durable goods. The corporate sector possesses, in the steady state, the physical capital worth 65% of annual GDP, which is consistent with the estimate by Robert E. Hall (2001). The corporate sector's total asset value rises because the values of innovative products, as seeds of new products, rise. Product cycle is important here. That is, because innovative products increase relative to maturing products, the corporate profit share relative to the total output (and hence relative to consumption) increases, and this is a strong force raising the corporate asset value. See Jinnai (2010) for more discussion.

Notably, a news shock is disinflationary on impact. A one standard deviation news shock is associated with around .2% fall in the annualized inflation rate. The reasoning goes as follows. Responding to the initial consumption rise, the monetary authority raises the nominal interest rate, but this move, absent a large inflation expectation or a large exogenous productivity improvement, makes the fixed-income bond abnormally attractive. But since the aggregate bond supply is zero, the price has to adjust to restore the equilibrium, which in this economy means that deflation has to push down the target interest rate back to the point at which the fixed-income bond becomes equally attractive to the other assets. Since the nominal wages are sluggish to adjust, real wages rise as a consequence of deflation. These predictions on consumption, output, investment, hours worked, asset prices, inflation rate, and real wages are all consistent with Barsky and Sims's empirical findings.

A surprise technology shock is a combination of both an improvement in the goods producing productivity and a slight improvement in the research productivity. Figure 2 plots impulse response functions to a one standard deviation surprise technology shock. Standard responses are observed. That is, TFP, consumption, GDP, hours worked, investment, and the asset prices all rise on impact and decrease to the steady state levels subsequently. Surprise technology shocks account for the bulk of high frequency variations, also consistent with Barsky and Sims's empirical findings.

The model replicates general patterns of business cycles too. Table 2 reports second moments of

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GDP, consumption, investment, hours worked, and the R&D spending both in the model economy and in the actual economy. Using the band-pass filter of Lawrence J. Christiano and Terry J. Fitzgerald (2003), I extract cyclical components up to 32 quarters for quarterly data and up to 8 years for annual data. The volatilities of the simulated data are close to those of the actual data. The model economy also captures correlations, i.e., strong pro-cyclical movements of consumption, investment, and hours worked, and very weak pro-cyclical movements of the R&D spending at the business cycle frequencies. Therefore, not only conditional responses reported by Barsky and Sims but also unconditional moments of the actual data are replicated by the benchmark model.

5 Consumption-Taylor versus output-Taylor

This section compares the policy rule (17) with its variant

$$R_{f,t} = \rho_{mp}R_{f,t-1} + \left(1 - \rho_{mp}\right)\left(\frac{1}{\beta} + \phi_\pi\left(\pi_{t,q}\right) + \phi_y\left(\gamma_{y,j}\right)\right) \tag{25}$$

where $\gamma_{y,j}$ is the growth rate of GDP between periods t and $t-j$, i.e., $\gamma_{y,j} \equiv Y_t/Y_{t-j} - 1$. For convenience, I call them consumption-Taylor rule and output-Taylor rule, respectively.

I first perform OLS regression. The dependent variable is the annualized Federal Funds rate. The independent variables are the lagged Federal Funds rate, the four-quarter inflation rate, the four-quarter consumption growth rate (i.e., $q = j = 4$) for the consumption-Taylor rule, and the four-quarter GDP growth rate for the output-Taylor rule. The price level is the chain-type GDP deflator. Consumption is the personal expenditure on non-durable goods and services.

Table 3 reports the results. Both specifications fit the actual Funds rate equally well, the adjusted R^2 being .94 for the consumption-Taylor rule and the adjusted R^2 being .95 for the output-Taylor rule. The estimated coefficients are broadly similar in the two specifications, and all of them are statistically significant. Figure 3 plots the target rate estimates and the actual Federal Funds rate. Again, both specifications capture fluctuations in the actual Federal Funds rate equally well.

Next, I compare theoretical predictions. For this exercise, I use the benchmark model as a

laboratory. The policy coefficients are those just estimated, but the results are robust to variations. Productivity processes are those estimated with the consumption-Taylor rule, but re-estimating them with the output-Taylor rule does not change the results.

Stark differences are observed. That is, in a model with the output-Taylor rule, a news shock is, on impact, associated with increases in both GDP and hours worked, as shown in Figure 4. These are inconsistent with Barsky and Sims's empirical findings. The differences are understood as follows. Under the consumption-Taylor rule, the monetary authority raises the nominal interest rate in response to the initial consumption rise, the action leading to a deflation, the deflation raising the real wages, the high real wages then discouraging firms from employment. The output-Taylor rule, however, does not generate as a large deflation as the consumption-Taylor rule does, because GDP does not rise as much as consumption does. Therefore, labor service remains relatively cheap. In addition, because the goods producing productivity slightly improves exogenously, firms expand employment.

This discussion suggests a desirable property of the consumption-Taylor rule. That is, it makes labor allocation efficient by affecting the price level. More specifically, an increase in consumption should raise the real wages because it raises the marginal rate of substitution of consumption for leisure. The wage stickiness, however, can be an obstacle to this adjustment, but the consumption-Taylor rule can mitigate the problem by affecting the general price level, at the right time, in the right direction.

Figure 5 restates the same point visually. It plots how hours worked respond to identical shocks in the following three environments: the flexible wage economy, the sticky wage economy with the consumption-Taylor rule, and the sticky wage economy with the output-Taylor rule. The left panel's common shock is what is identified as a news shock in the sticky wage economy with the consumption-Taylor rule. Hours worked drop similarly both in the flexible wage economy and in the sticky wage economy with the consumption-Taylor rule, but those in the sticky wage economy with the output-Taylor rule largely deviate from them. The right panel's common shock is what is identified as a surprise technology shock in the sticky wage economy with the consumption-Taylor rule. Regardless of the monetary policies, on impact, hours worked rise more in the sticky wage

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economies than in the flexible wage economy. But subsequently, the hours worked decrease, hence coming close to the flexible wage benchmark, more quickly under the consumption-Taylor rule than under the output-Taylor rule, because consumption growth is positive for several quarters after a surprise technology shock while GDP growth does not show such persistence.

Finally, I quantify the importance, using the welfare measure defined as the unconditional expectation of unweighted average of households' utility kernels:

$$E\left[\log C_t - \int_0^1 \chi_0 \frac{l_t(\iota)^{1+\chi}}{1+\chi} d\iota\right] \tag{26}$$

I solve the system of equations augmented with (26) up to the second order, and numerically calculate the welfare measure. A large difference is observed. That is, if the target variable changes from consumption growth to GDP growth, about .54% of welfare is lost. This value is about ten times larger than the welfare costs of business cycles found by Robert E. Lucas, Jr. (1985). But it is important that, while the thought experiment of Lucas is magical removal of all consumption variability, the monetary policy in my economy affects the size of the distortion due to the nominal wage friction. The underlying theme is, therefore, closer to J. Bradford De Long and Lawrence H. Summers (1988) and Darrel Cohen (2000), who find sizable welfare gains of stabilization policy, supposing that the policy affects mean level of economic activities. Unlike this paper, these papers do not present structural models, though.

6 Conclusion

This paper presents a model that accounts for empirical findings of Barsky and Sims. The model features product innovation and imitation, sticky nominal wages, and the monetary authority responding to inflation and consumption growth. The estimated consumption-Taylor rule closely fits the actual Federal Funds rate. In addition, it has an advantage in reducing distortion due to the nominal wage stickiness.

This paper assumes that nominal wages are sticky but nominal prices are flexible. The reality of this setting is an empirical issue, but some recent studies using micro data provide supporting

evidence. For example, Barattieri, Basu and Gottschalk (2010) report substantial wage rigidities, while Mark Bils and Peter J. Klenow (2004) cast doubt on strong price rigidities. In addition, the basic argument about the monetary policy will be robust as long as wage rigidities play a more prominent role than price rigidities.

This paper considers the backward looking monetary policy rule, but main results are robust under broader class of policy rules. That is, the basic argument holds as long as the monetary authority responds to the current economic condition relative to reference. To put it another way, the argument does not survive if the monetary authority only responds to the growth rates forecasts, not at all caring about how heated or how depressed the current economic condition is. But the latter case seems to be unrealistic.

The consumption-Taylor rule can be analyzed in a more standard macroeconomic environment. The policy rule has some intuitive appeal since it is consumption, not output, that enters the households' utility functions. This topic may be worth advancing.

References

An, Sungbae, and Frank Schorfheide. 2007. "Bayesian Analysis of DSGE Models." *Econometric Reviews*, 26: 113–172.

Barattieri, Alessandro, Susanto Basu, and Peter Gottschalk. 2010. "Some Evidence on the Importance of Sticky Wages." National Bureau of Economic Research Working Paper 16130.

Barsky, Robert B., and Eric R. Sims. 2009. "News Shocks." Unpublished.

Barsky, Robert B., and Eric R. Sims. 2010. "News Shocks and Business Cycles." Unpublished.

Barsky, Robert B., Mark Bergen, Shantanu Dutta, and Daniel Levy. 2003. "What Can the Price Gap between Branded and Private-Label Products Tell Us about Markups?" In *Scanner Data and Price Indexes. NBER Chapters*, 165–228. National Bureau of Economic Research, Inc.

Beaudry, Paul, and Bernd Lucke. 2010. "Letting Different Views about Business Cycles Compete." *NBER Macroeconomics Annual*, 24(1): 413–456.

Beaudry, Paul, and Franck Portier. 2004. "An Exploration Into Pigou's Theory of Cycles." *Journal of Moneray Economics*, 51: 1183–1216.

Beaudry, Paul, and Franck Portier. 2006. "Stock Prices, News, and Economic Fluctuations." *American Economic Review*, 96: 1293–1307.

Beaudry, Paul, Martial Dupaigne, and Franck Portier. 2008. "Propagation of International News Shocks." Unpublished.

Bils, Mark, and Peter J. Klenow. 2004. "Some Evidence on the Importance of Sticky Prices." *The Journal of Political Economy*, 112(5): pp. 947–985.

Broda, Christian, and David E. Weinstein. 2010. "Product Creation and Destruction: Evidence and Price Implications." *American Economic Review*, 100: 691–723.

Christiano, Lawrence, Cosmin Ilut, Roberto Motto, and Massimo Rostagno. 2008. "Monetary policy and stock market boom-bust cycles." European Central Bank Working Paper Series 955.

Christiano, Lawrence J., and Terry J. Fitzgerald. 2003. "The Band Pass Filter." *International Economic Review*, 44: 435–465.

Christiano, Lawrence J., Martin Eichenbaum, and Charles L Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy*, 113: 1–45.

Cohen, Darrel. 2000. "A Qantitative Defence of Stabilization Policy." Board of Governors the Federal Reserve System FEDS Working Paper No. 2000-34.

Corrado, Carol, Charles Hulten, and Daniel Sichel. 2009. "Intangible Capital and U.S. Economic Growth." *Review of Income & Wealth*, 55(3): 661 – 685.

De Long, J. Bradford, and Lawrence H. Summers. 1988. "How Does Macroeconomic Policy Affect Output?" *Brookings Papers on Economic Activity*, 1988(2): pp. 433–480.

den Haan, Wouter J., and Georg Kaltenbrunner. 2009. "Anticipated growth and business cycles in matching models." *Journal of Monetary Economics*, 56(3): 309 – 327.

Eaton, Jonathan, and Samuel Kortum. 1999. "International Technology Diffusion: Theory and Measurement." *International Economic Review*, 40: 537–570.

Erceg, Christopher J., Dale W. Henderson, and Andrew T. Levin. 2000. "Optimal monetary policy with staggered wage and price contracts." *Journal of Monetary Economics*, 46(2): 281 – 313.

Fernández-Villaverde, Jesús, Pablo Guerrón-Quintana, and Juan F. Rubio-Ramírez. 2010. "Fortune or Virtue: Time-Variant Volatilities Versus Parameter Drifting in U.S. Data." National Bureau of Economic Research Working Paper 15928.

Fisher, Jonas. 2010. "Comment on "Letting Different Views about Business Cycles Compete"." In *NBER Macroeconomics Annual 2009, Volume 24.* 457–474. National Bureau of Economic Research, Inc.

Hall, Robert E. 1988. "The Relation Between Price and Marginal Cost in U.S. Industry." *Journal of Political Economy*, 96: 921–947.

Hall, Robert E. 2001. "The Stock Market and Capital Accumulation." *The American Economic Review*, 91: 1185–1202.

Hayashi, Fumio. 1982. "Tobin's Q and Average Q: A Neoclassical Interpretation." *Econometrica*, 50: 213–224.

Jaimovich, Nir, and Sergio Rebelo. 2010. "Can News about the Future Drive the Business Cycle?" *American Economic Review*, 99: 1097–1118.

Jinnai, Ryo. 2010. "News Shocks, Product Innovations, and Asset Prices." Unpublished.

Lucas, Jr., Robert E. 1985. *Models of business cycles.* Blackwell.

Mansfield, Edwin, Mark Schwartz, and Samuel Wagner. 1981. "Imitation Costs and Patents: An Empirical Study." *The Economic Journal*, 91(364): 907–918.

Nam, Deokwoo, and Jian Wang. 2010. "The Effects of News About Future Productivity on International Relative Prices: An Empirical Investigation." Unpublished.

Orphanides, Athanasios. 2003. "Historical monetary policy analysis and the Taylor rule." *Journal of Monetary Economics*, 50(5): 983 – 1022.

Pigou, Arthur. 1927. *Industrial Fluctuations.* London:MacMillan.

Pistaferri, Luigi. 2003. "Anticipated and Unanticipated Wage Changes, Wage Risk, and Intertemporal Labor Supply." *Journal of Labor Economics*, 21(3): pp. 729–754.

Rotemberg, Julio J., and Michael Woodford. 1992. "Oligopolistic Pricing and the Effects of Aggregate Demand on Economic Activity." *The Journal of Political Economy*, 100(6): 1153–1207.

Taylor, John B. 1993. "Discretion versus policy rules in practice." *Carnegie-Rochester Conference Series on Public Policy*, 39: 195 – 214.

Tellis, Gerard J. 1988. "The Price Elasticity of Selective Demand: A Meta-Analysis of Econometric Models of Sales." *Journal of Marketing Research*, 25(4): 331–341.

Table 1—Calibrated parameters

Parameter	Description	Value	Source of information
β	Subjective time discount rate	.995	Standard value
δ_K	Physical capital depreciation rate	.025	Standard value
δ_N	Obsolescence rate	.01	Product destruction
σ	Maturation rate	.045	R&D depreciation
θ_p	Elasticity of substitution between products	3	Empirical research
θ_w	Elasticity of substitution between labors	20	Christiano et al. (2005)
ζ	Nominal wage stickiness	.82	Barattieri et al. (2010)
α	Capital elasticity	.31	Labor share
χ	Inverse of Frisch elasticity	1.5	Pistaferri (2003)
χ_0	Scale parameter of the labor disutility	.87	Labor hours
ν	Research elasticity	.17	R&D share
j	Target consumption growth	1	Standard value
q	Target inflation rate	1	Standard value
ρ_{mp}	Interest rate smoothing	.78	OLS Regression
ϕ_π	Response coefficient to inflation	2.04	OLS Regression
ϕ_c	Response coefficient to consumption growth	1.50	OLS Regression

Table 2—Business Cycle Statistics

	U.S. data	Benchmark model
GDP standard deviation	1.14	.87
Consumption standard deviation	.74	.29
Investment standard deviation	4.34	2.68
Hours standard deviation	1.20	.69
R&D standard deviation	1.74	2.18
Consumption co-movement	.79	.89
Investment co-movement	.94	.99
Hours co-movement	.87	.99
R&D co-movement	.24	.19

Source: BEA and BLS

Table 3—Taylor rules estimation

Parameters	Consumption-Taylor	Output-Taylor
ρ_{mp}	.78 (.06)	.78 (.07)
ϕ_π	2.04 (.36)	2.14 (.32)
ϕ_c	1.50 (.23)	
ϕ_y		1.19 (.23)
$\bar{R}^2$	.94	.95

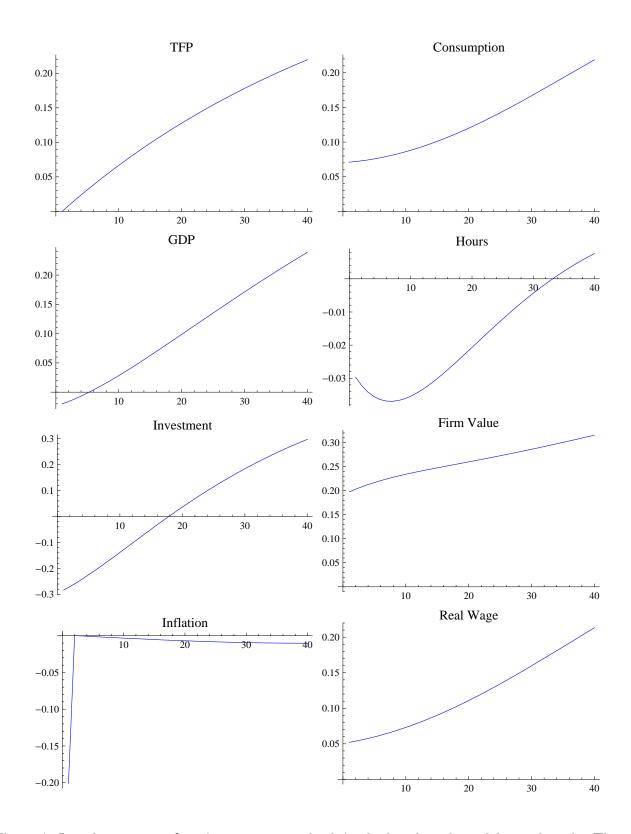HAC standard errors are reported in parentheses.

Figure 1: Impulse response functions to a news shock in the benchmark model are plotted. The vertical axis is percentage deviation from the steady state.
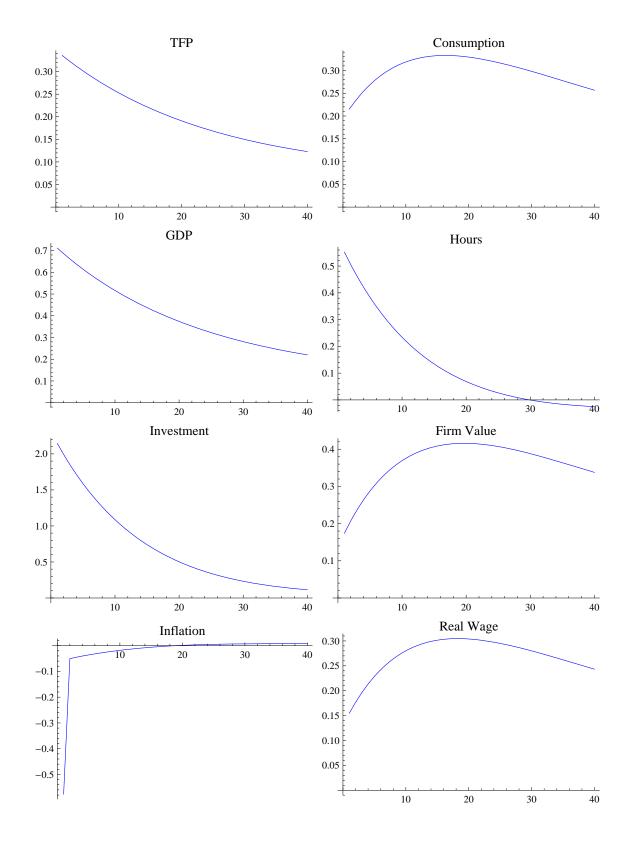
Figure 2: Impulse response functions to a surprise technology shock in the benchmark model are plotted. The vertical axis is percentage deviation from the steady state.
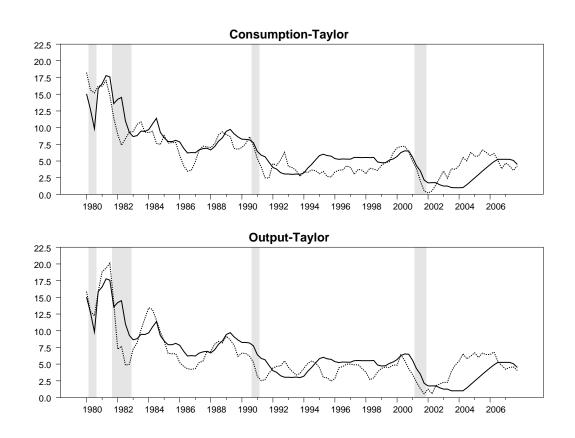
Figure 3: Target rates according to estimated Taylor rules (dotted lines) and the actual Federal Funds rate (solid lines) are plotted.
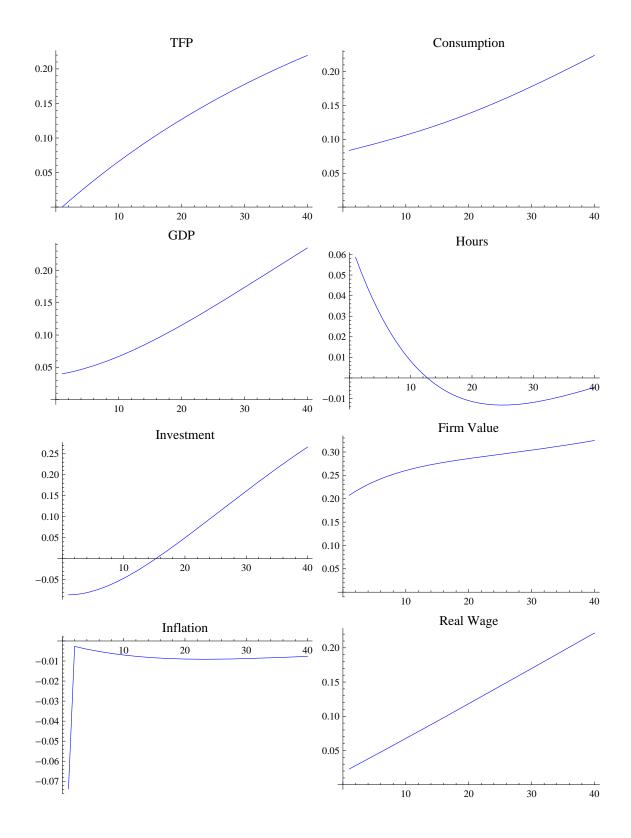
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Figure 4: Impulse response functions to a news shock in a model with the output-Taylor rule are plotted. The vertical axis is percentage deviation from the steady state.
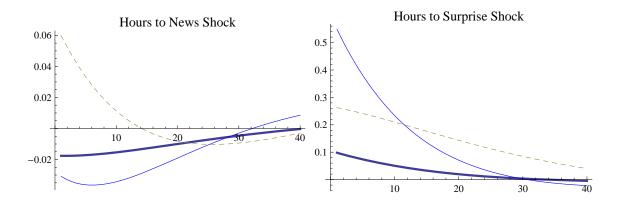
Figure 5: Hours worked responses to identical shocks in the following three environments are plotted: the flexible wage economy (thick lines), the sticky wage economy with the consumption-Taylor rule (thin lines), and the sticky wage economy with the output-Taylor rule (dashed lines). The vertical axis is percentage deviation from the steady state.