Nominal Rigidities, Asset Returns and Monetary Policy

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Abstract

We analyze the asset pricing implications of price and wage rigidities and monetary policies in a general equilibrium model with recursive preference, two industries with different levels of price rigidities, and three types of shock: permanent productivity shock, transitory productivity shock, and monetary policy shock. The model is calibrated to match the observed Sharpe ratio, in addition to the volatilities of risk-free rate, inflation, hours, consumption, and consumption growth rate. We find that among the three types of shocks, permanent productivity shocks contribute more than 97 percent to the risk premium. Both price and wage rigidities are shown to increase expected excess returns, however wage rigidities have significantly larger impact. The monetary policies that show greater tendency of interest rate smoothing, react more aggressively to inflation or less aggressively to output lead to higher equity premium. In the cross section, the relation between price rigidities and industrial returns depends on both the substitutability among goods within the industry and the substitutability between the two industrial goods.

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1 Introduction

Explaining both asset return and aggregate business cycle fluctuations in a unified framework remains an important challenge in financial economics. Standard real business cycle models imply a counterfactually low compensation for risk in asset returns because production factors can be freely adjusted to reduce consumption risk.\(^1\) This has motivated the introduction of frictions to these models, such as investment adjustment costs and imperfect factor mobility,\(^2\) to undermine the households’ abilities to smooth consumption. In this paper, we incorporate a particular friction, rigidities in nominal product prices and wages, in a general equilibrium model to address (i) how nominal rigidities and monetary policies affect equity premiums, and (ii) how productivity shocks and policy shocks affect stock returns differently.

The introduction of nominal rigidities to the analysis of asset returns is motivated first by ample evidence of their existence in the data. For instance, Nakamura and Steinsson (2007) report a median duration of prices between 8 and 11 months, and Taylor (1999) suggests an average wage duration of 12 months.\(^3\) Second, nominal rigidities play a critical role in generating consistent business cycle dynamics in general equilibrium models such as Christiano, Eichenbaum and Evans (2005) or Smets and Wouters (2007). Third, the existence of nominal rigidities is the most widely studied channel through which monetary policies affect real economies and allow us to explore the link between monetary policy and excess stock returns. Understanding this link is important to policymakers and, to our knowledge, it has not been studied in the theoretical literature.

Our main findings are as follows. First, both price and wage rigidities improve the ability of real business cycle models to generate a large and positive equity premium. The increased premium is mainly a compensation for permanent productivity shocks. Without rigidities, the equity premium is negative under our benchmark calibration that matches the business cycle dynamics. Second, the quantitative impact of wage rigidities on the equity premium is much larger than the impact of price rigidities. Third, monetary policy shocks contribute less than 1% to the equity premium.
but more than 60% to the variance of excess stock returns. Fourth, monetary policies with greater tendency of interest rate smoothing, higher responsiveness to inflation or lower responsiveness to output lead to larger equity premiums. Finally, both the product substitutability within each industry and that across industries affect the return difference between the industry with high price rigidities and the industry with low price industry.

We model a two-sector production economy with four main ingredients. First, a representative household with Epstein and Zin (1989) recursive preference over consumption and leisure. Recursive preferences disentangle the elasticity of intertemporal substitution from risk aversion. As illustrated by Tallarini (2000), this separation is useful to keep reasonable values for the elasticity of substitution to match macroeconomic dynamics, while having values for risk aversion that match empirical Sharpe ratios of financial assets. Second, nominal rigidities are modeled in a staggered wage and price setting following Calvo (1983). The representative household provides differentiated labor types to the production sectors and has monopolistic power to set wages. However, at each point of time the household can only adjust the wage optimally for a fraction of labor types. Similarly, firms provide differentiated products and have monopolistic power to set their prices. At each point of time a firm can only adjust the price optimally with some positive probability. We allow for different probabilities for the two sectors to analyze implications of heterogeneous price rigidities on cross-industry asset returns. Third, monetary policy is modeled as a Taylor (1993) policy rule to set the level of a nominal interest rate, which responds to the last period’s interest rate, inflation, and output and contains unpredictable policy shocks. Fourth, the model incorporates three types of shocks: permanent productivity shocks, transitory productivity shocks, and monetary policy shocks. Campbell (1994) shows that permanent and transitory shocks have different effects on optimal consumption and asset returns. Alvarez and Jermann (2005) find empirically that there is a significant permanent component in the pricing kernel. Bernanke and Kuttner (2005) show that a unexpected 25-basis-point cut in the federal funds rate leads to about one percent increase in broad stock indexes. To our knowledge, this is the first theoretical paper
that analyzes the differences of the all three shocks in terms of their effects on asset returns.

We calibrate the model to match the quarterly U.S. data between 1982:1 to 2010:4. Specifically, the price rigidities of the two sectors and the wage rigidity are chosen to match the mean and dispersion of price duration and the mean wage duration. The dynamics of the three shocks, the parameters of the utility function, and the parameters of the monetary policy are calibrated to match the volatilities of interest rate, inflation, hours, and de-trended consumption explained by the three shocks, respectively. The risk aversion is calibrated to match the Sharpe ratio. In particular, our calibration results in an EIS of around 0.15 and a relative risk aversion coefficient of 20.5. Risk aversion is high with respect to the empirical and experimental evidence, but significantly lower than the implied value by standard business cycle models such as Tallarini (2000). This improvement is a result of introducing permanent productivity shocks and nominal rigidities.

In our benchmark calibration, we find that permanent productivity shocks contribute more than 97% to the equity premium while the other two shocks contribute 3% each. However, almost 70% of the variance in stock returns come from monetary policy shocks while 30% from permanent productivity shocks and a negligible fraction from transitory productivity shocks. The extremely low price of risk for the uncertainties induced by policy shocks is driven by the fact that those shocks contribute less than 1% to the variance of the pricing kernel.

Wage rigidity is the main driver of the positive and large equity premium under our benchmark calibration, even though price rigidity is also found to increase the equity premium. In fact, permanent productivity shocks result in a negative equity premium without rigidities, echoing the results in Bansal and Yaron (2004) and Kaltenbrunner and Lochstoer (2010) for their models with an EIS lower than one. In such a case, the wealth effect dominates the substitution effect, leading to a countercyclical price-dividend ratio and hence a negative equity premium.

In the presence of nominal rigidities, the substitution effect outweighs the wealth effect and the model generates a positive equity premium. The critical difference from the frictionless economy
is that labor supply becomes procyclical, which amplifies the effect of the shock for the current period and hence the substitution effect. As wages and prices are adjusted gradually to the optimal levels, this amplified effect is reverted back partially, reducing the wealth effect. Quantitatively, labor supply is much more procyclical under wage rigidities than under price rigidities. With only price rigidities, the equity premium is larger than the level in a frictionless economy although still negative.

The two-sector model allows us to analyze the link between industry price rigidity and industry expected asset returns. Because wages are assumed to be universal across industries, difference in returns of the claims on industrial dividends is driven by the difference in product prices due to heterogenous price rigidities. However, the relation between the relative price and the difference in industrial returns depends on the parameter values. Higher product price of one industry relative to the other one leads to two opposite effects on its profits: a lower output demand (the output effect) and a higher markup (the markup effect) relative to the other industry. The product substitutability across industries determines the magnitude of the difference in industry output demands. The product substitutability within industries determines the magnitude of the difference in industry markups. Therefore, the industry with higher price rigidity could earn higher or lower expected return than the one with lower price rigidity, depending on the relative magnitude of the two elasticities of substitution.

The existence of nominal rigidities leads to the non-neutrality of monetary policy. We show that monetary policies with higher responsiveness to inflation, lower responsiveness to output, or higher tendency of interest rate smoothing amplifies the effects of permanent productivity shocks and hence lead to higher expected stock returns. However, the differences in stock returns are quantitatively small.

Related literature

Our paper belongs to the literature that links the real economy to financial markets in a unified framework. It builds on the pioneer work of Kydland and Prescott (1982), and is mostly
related to Boldrin, Christiano and Fisher (2001) and Christiano, Eichenbaum and Evans (2005). Boldrin, Christiano and Fisher (2001) show that frictions in the production sector are critical for real business cycle models to capture salient asset pricing dynamics. They find that frictions in intersectoral factor mobility and habit formation in preferences can simultaneously reproduce important business cycle properties, a high price of risk, and the observed equity premium. However, habit formation in their model also leads to a counterfactual high volatility in the risk-free rate. Our model instead relies on Epstein and Zin (1989) recursive preferences and permanent productivity shocks to achieve both a high price of risk and low volatility in the risk-free rate. As in Christiano, Eichenbaum and Evans (2005), frictions in our model result from nominal price and wage rigidities, and allow us to analyze the effects of monetary policy on asset prices. However, Christiano, Eichenbaum and Evans (2005) focus on the business cycle implications of monetary policy shocks and do not analyze the dynamics of asset returns and the effects of productivity shocks.

Our paper is also related to the literature that studies the response of the stock market to monetary policy shocks, e.g., Thorbecke (1997), Bernanke and Kuttner (2005) and Rigobon and Sack (2004), among others. Consistent with what our model predicts, these empirical studies find a positive (negative) reaction in the stock market value to expansionary (contractionary) policy shocks. For instance, Bernanke and Kuttner (2005) find that a surprise cut of 25 basis points in the federal funds rate translates into an increase of 1.25% in the value of the aggregate stock market, which is quantitatively similar to what we find in the impulse response function.

Our paper joins recent attempts to understand the effects of labor markets on financial asset returns. Lettau and Uhlig (2000) find that adding labor negatively affects the performance of habit models since labor provides an additional channel to smooth consumption. Uhlig (2007) shows that real wage rigidities can improve the ability of habit models to capture a high equity premium. In the same spirit, Favilukis and Lin (2011) analyze the time series and cross sectional asset return implications of infrequent renegotiation of wages. We focus on nominal wage rigidities.
rather than real wage rigidities to understand the implications of monetary policy on asset returns.

Finally, our paper is related to Bhamra, Fisher and Kuehn (2011) who provide an alternative channel for monetary policies to affect the real economy when firms are levered and coupon payments are in nominal terms, i.e., nominal rigidities in debt obligations. Moreover, the focus of their paper is firms’ default decision while ours is on asset prices.

The paper is organized as follows. Section 2 presents the model and its optimality conditions. Section 3 explains the mechanism that links expected returns and nominal rigidities, and shows the quantitative implications of the calibration. Section 4 concludes.

## 2 The Model

We model a production economy where households derive utility from the consumption of a basket of two goods and disutility from supplying labor for the production of these goods. The two goods are produced in two different industries characterized by monopolistic competition and nominal price and wage rigidities. We allow for heterogenous degrees of price rigidity in the two industries to learn about the effects of different rigidities on the cross-section of stock returns.\(^5\)

Nominal rigidities generate real effects of monetary policy. If some producers are not able to adjust prices optimally and/or if households are not able to adjust their wages optimally, inflation generates distortions in relative prices and/or relative real wages that affect production decisions. Since inflation is determined by monetary policy, different policies have different implications for real activity, and affect the returns on financial claims linked to production (e.g., stocks). We model monetary policy as an interest-rate policy rule that reacts to inflation and deviations of output from a target. Risk in the economy is driven by permanent and transitory productivity shocks and monetary policy shocks. In section 3, we analyze how nominal rigidities and monetary policy affect the compensation for these shocks in production claims.
2.1 Households

A representative household maximizes its recursive utility

\[ V_t = U_t + \beta Q_t^{\frac{1-\psi}{\gamma}}, \]

where

\[ U_t = \frac{C_t^{1-\psi}}{1-\psi} - \kappa_t \frac{(N_t^s)^{1+\omega}}{1+\omega}, \quad \text{and} \quad Q_t = \mathbb{E}_t \left[ V_{t+1}^{\frac{1-\gamma}{\gamma}} \right]. \]

The parameters \( \psi \) and \( \gamma \) characterize the elasticity of intertemporal substitution of consumption and risk aversion, respectively. The particular case \( \psi = \gamma \) corresponds to the standard power utility specification. \( C_t \) is the consumption of the final good, and \( N_t^s \) is the aggregate supply of labor at time \( t \). The process \( \kappa_t \) is added to obtain balanced growth and is defined in Section 2.2. Growth is the result of permanent shocks to productivity. These shocks are described in the production sector section. The final good is a basket of two intermediate goods produced in two industries. We refer to these industries as \( I = \{H, L\} \), to indicate industries with high and low price rigidities, respectively. The consumption of each industry’s good is \( C_{I,t} \), and the final good is given by

\[ C_t = \left[ \varphi_H^{1/\eta} C_{H,t}^{\eta-1} + \varphi_L^{1/\eta} C_{L,t}^{\eta-1} \right]^{\eta / \eta - 1}, \]

where \( \varphi_I \) is the weight of industry \( I \) in the basket (\( \varphi_L \equiv 1 - \varphi_H \)), and \( \eta > 1 \) is the elasticity of substitution between industry goods. Each industry good is a Dixit-Stiglitz aggregate of a continuum of differentiated goods, defined as

\[ C_{I,t} = \left[ \int_0^1 C_{I,t}(j)^{\frac{\theta-1}{\theta}} \, dj \right]^{\frac{\theta}{\theta-1}}, \]

where the elasticity of substitution across differentiated goods is \( \theta > 1 \).
The intertemporal budget constraint faced by the household is

$$
E_t \left[ \sum_{s=0}^{\infty} M^s_{t,t+s} P_{t+s} C_{t+s} \right] \leq E_t \left[ \sum_{s=0}^{\infty} M^s_{t,t+s} P_{t+s} \left( LI_{t+s} + P_{t+s} \sum_{j \in \{H,L\}} \int_0^1 D_{t,t+s}(j) dj \right) \right],
$$

(4)

where $M^s_{t,t+s} > 0$ is the nominal pricing kernel that discounts nominal cash flows at time $t + s$ to time $t$, $P_t$ is the price of the final good, $LI_t$ is the real labor income from supplying labor to the production sector, and $D_{t,t}(j)$ is the real profit from the production of the differentiated good $j$ in industry $I$.

The maximization of (1) subject to (4) provides us with the intertemporal marginal rate of substitution of consumption for the economy. The marginal rates of substitution of consumption between period $t$ and period $t + 1$ in real and nominal terms are

$$
M_{t,t+1} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \left( \frac{V^{1/(1-\psi)}_{t+1}}{Q^{1/(1-\gamma)}_t} \right)^{\psi-\gamma},
$$

(5)

and

$$
M^s_{t,t+1} = M_{t,t+1} \left( \frac{P_{t+1}}{P_t} \right)^{-1},
$$

(6)

respectively. From these two equations we can compute the real and nominal (gross) one-period risk-free rates as

$$
R_{f,t} = \frac{1}{E_t [M_{t,t+1}]} \quad \text{and} \quad R^s_{f,t} = \frac{1}{E_t [M^s_{t,t+1}]},
$$

(7)

respectively. These rates are important to compute excess real and nominal returns on stocks. The one-period nominal risk-free rate is the instrument of monetary policy.

**Wage Setting**
We follow Schmitt-Grohe and Uribe (2007) to model an imperfectly competitive labor market where the representative household monopolistically provides a continuum of labor types indexed by $k \in [0, 1]^6$. Specifically, the supply of labor type $k$ satisfies the demand equation

$$N^s_t(k) = \left( \frac{W_t(k)}{W_t} \right)^{-\theta_w} N^d_t,$$

where $N^d_t$ is the aggregate labor demand of the production sector, $W_t(k)$ is the wage for labor type $k$, and $W_t$ is the aggregate wage index given by

$$W_t = \left[ \int_0^1 W_t^{1-\theta_w} (k) dk \right]^{\frac{1}{1-\theta_w}}.$$

The labor demand equation (8) is derived in the production sector section below. The household chooses optimal wages $W_t(k)$ for all labor types $k$ under Calvo (1983) staggered wage setting. Specifically, each period the household is only able to adjust wages optimally for a fraction $1 - \alpha_w$ of labor types. A fraction $\alpha_w$ of labor types keeps their previous period wages. The optimal wage maximizes equation (1) subject to the demand function in equation (8) and the budget constraint in equation (4), where real labor income is given by

$$LI_t = \int_0^1 \frac{W_t(k)}{P_t} N^s_t(k) dk.$$

Because the demand curve and the cost of labor supply are identical across different labor types, the household chooses the same optimal wage $W^*_t$ for all the labor types subject to a wage change at time $t$. Appendix A shows that the optimal wage is the markup-adjusted marginal rate of substitution between labor and consumption and satisfies

$$\frac{W^*_t}{P_t} = \mu_{\omega,t} \kappa_t (N^s_t) \omega_t C^\psi_t,$$
where $\mu_{w,t}$ is the optimal time-varying wage markup, whose derivation is given in the appendix, and $N_s = \int_0^1 N_s(k) dk$ is the aggregate labor supply. In the absence of wage rigidities ($\alpha_w = 0$), the optimal wage markup is a constant given by $\mu_w \equiv \frac{\theta_w}{\theta_w - 1}$.

### 2.2 Firms

The production of the final consumption good uses two intermediate goods from industry $H$ and $L$ via the aggregator

$$Y_t = \left[ \varphi_{H}^{1/\eta} Y_{H,t}^{-\frac{1}{\eta}} + \varphi_{L}^{1/\eta} Y_{L,t}^{-\frac{1}{\eta}} \right]^{\frac{\eta}{\eta - 1}}.$$

Within each industry, there is a continuum of firms indexed by $j \in [0, 1]$. The final output of industry $I \in \{H, L\}$ is given by the Dixit-Stiglitz aggregator

$$Y_{I,t} = \left[ \int_0^1 Y_{I,t}^{\frac{\eta - 1}{\eta}} (j) \, dj \right]^{\frac{\eta}{\eta - 1}}.$$ 

The production technology of firm $j$ in industry $I$ is given by

$$Y_{I,t}(j) = A_t N^d_{I,t}(j),$$

where $A_t$ is labor productivity and $N^d_{I,t}(j)$ is firm $j$’s labor demand. We assume that labor productivity contains permanent and transitory components. Specifically,

$$A_t = A^p_t Z_t,$$

where the permanent and transitory components follow processes

$$\Delta \log A^p_{t+1} = (1 - \phi_a) g_a + \phi_a \Delta \log A^p_t + \sigma_a \varepsilon_{a,t+1},$$
and
\[
\log Z_{t+1} = \phi_z \log Z_t + \sigma_z \varepsilon_{z,t+1},
\]
respectively, with \( g_a \) as the constant growth rate, \( \Delta \) as the difference operator, and innovations \( \varepsilon_{a,t} \) and \( \varepsilon_{z,t} \sim \text{IID} N(0,1) \). To ensure a balanced growth path on which \( Y_t, Y_{I,t}, W_t, \) and \( W^*_t \) are growing at the same rate, \( \kappa_t \) follows
\[
\kappa_t = (A^p_t)^{1-\psi}.
\]

The labor input in production is a continuum of differentiated labor types indexed by \( k \in [0,1] \) via the aggregator
\[
N_{I,t}^d(j) = \left[ \int_0^1 N_{I,t}^d(j,k) \frac{\theta_w-1}{\sigma_w} \, dj \right] \frac{\theta_w}{\sigma_w-1},
\]
where \( \theta_w \) is the elasticity of substitution across differentiated labor types.

Producers have market power to set the price of their differentiated goods in a Calvo (1983) staggered price setting. That is, with some positive probability a producer is unable to change the product price at any point of time. We allow for different probabilities across the two industries to capture heterogeneous degrees of price rigidities. The probability of not changing the price of a differentiated good at a particular time in industry \( I \) is \( \alpha_I \). When the producer is able to set a new price for the good, the price is set to maximize the expected present value of all future profits, taking into account the probability of not changing that price in the future. The maximization problem is
\[
\max_{\{P_{I,t}(j)\}} \mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} \alpha_I^{\tau} M^S_{t,t+\tau} (P_{I,t}(j)Y_{I,t+\tau|t}(j) - W_{t+\tau|t}(j)N_{I,t+\tau|t}^d(j)) \right],
\]
subject to the demand function (see appendix B for its derivation)

\[ P_{I,t}(j) = P_{I,t+\tau} \left( \frac{Y_{I,t+\tau|t}(j)}{Y_{I,t+\tau}(j)} \right)^{-1/\theta}, \]  

(12)

and the production function

\[ Y_{I,t+\tau|t}(j) = A_{t+\tau} N_{I,t+\tau|t}^d(j), \]  

(13)

where \( Y_{I,t+\tau|t}(j) \) is the level of output of firm \( j \) in industry \( I \) at time \( t + \tau \) when the last time the price was reset was at \( t \). A similar definition applies to \( N_{I,t+\tau|t}^d(j) \) and \( W_{t+\tau|t}(j) \). All firms within an industry adjusting their product price optimally face the same optimization problem and choose the same optimal price \( P_{I,t}^* \). Appendix B shows that the optimal price is the markup-adjusted marginal labor cost and satisfies

\[ \frac{P_{I,t}^*}{P_t} = \mu_t \frac{W_t}{P_t A_t}, \]  

(14)

where \( \mu_t \) is the optimal time-varying product markup, whose derivation is given in the appendix.

In the absence of price rigidities (\( \alpha_I = 0 \)), the optimal markup is a constant given by \( \mu = \frac{\theta}{1-\theta} \).

### 2.3 Monetary Authority

We model a monetary authority that sets the level of a short-term nominal interest rate. For simplicity, we define the continuously compounded one-period nominal rate, \( i_t \equiv \log(R_{f,t}^s) \). Monetary policy is described by the policy rule

\[ i_t = \rho i_{t-1} + (1 - \rho) (\bar{\rho} + t_t \pi_t + t_x x_t) + u_t, \]  

(15)

where the interest rate is set responding to the lagged interest rate, aggregate inflation \( \pi_t \equiv \log P_t - \log P_{t-1} \), the output gap \( x_t \), and a policy shock \( u_t \). The output gap is defined as the
deviation of total output with respect to the output that would be obtained under perfectly flexible prices and wages, $Y_t^f$. That is,

$$x_t \equiv \log Y_t - \log Y_t^f.$$  

It can be shown that real output and real wages in a flexible price and wage economy are

$$Y_t^f = \left( \frac{A_t^{1+\omega}}{\mu \mu_w \kappa_t} \right)^{1/(\omega + \psi)}, \text{ and } W_t^{\text{real}, f} = \frac{A_t}{\mu},$$  

respectively. The policy shock follows the process

$$u_{t+1} = \phi_u u_t + \sigma_u \varepsilon_{u,t+1},$$

with $\varepsilon_u \sim \text{IID}\mathcal{N}(0, 1)$.

### 2.4 Asset Returns

We define stocks as claims on future cash flows in either monetary term or real term. The real stock price for claim $X$ is defined as

$$S_{X,t} = \mathbb{E}_t \left[ \sum_{n=1}^{\infty} M_{t,t+n} X_{t+n} \right]$$

and the associated one-period real return is

$$R_{X,t+1} = \frac{X_{t+1} + S_{X,t+1}}{S_{X,t}} = \frac{X_{t+1}}{X_t} \left( \frac{1 + P_{X,t+1}}{P_{X,t}} \right),$$

with

$$S_{X,t} = \mathbb{E}_t \left[ \sum_{n=1}^{\infty} M_{t,t+n} X_{t+n} \right]$$

and the associated one-period real return is

$$R_{X,t+1} = \frac{X_{t+1} + S_{X,t+1}}{S_{X,t}} = \frac{X_{t+1}}{X_t} \left( \frac{1 + P_{X,t+1}}{P_{X,t}} \right),$$

with

$$S_{X,t} = \mathbb{E}_t \left[ \sum_{n=1}^{\infty} M_{t,t+n} X_{t+n} \right]$$

and the associated one-period real return is

$$R_{X,t+1} = \frac{X_{t+1} + S_{X,t+1}}{S_{X,t}} = \frac{X_{t+1}}{X_t} \left( \frac{1 + P_{X,t+1}}{P_{X,t}} \right),$$
where $P_{X,t}$ is the price-dividend ration on claim $X$ and defined as

$$P_{X,t} = \frac{S_{X,t}}{X_t}.$$  

We are interested in analyzing the expected stock returns for claims on aggregate consumptions ($X = C$), labor income ($X = LI$), outputs of industry $H$ and $L$ ($X = Y_I, I \in \{H, L\}$), total dividends of the production sectors ($X = D$), and dividends of industry $H$ and $L$ ($X = D_I, I \in \{H, L\}$). Appendix F shows that the expected excess return on claim $X$ is given by

$$\log \mathbb{E}_t [R_{X,t+1}] - \log R_{f,t} = -\text{cov}_t(m_{t,t+1}, \log R_{X,t+1})$$

$$= -\text{cov}_t (m_{t,t+1}, \Delta x_{t+1}) - \text{cov}_t (m_{t,t+1}, \log (1 + P_{X,t+1})), \quad (21)$$

where $R_{f,t}$ refers to the risk-free rate and lower case of a variable refers to its logarithmic, i.e.,

$$m_{t,t+1} = \log(M_{t,t+1}) \quad \text{and} \quad x_t = \log(X_t).$$

2.5 Equilibrium

The equilibrium of the economy requires product, labor, and financial market clearing.

Product market clearing

The product market clearing conditions are $C_t = Y_t$, and $C_{I,t} = Y_{I,t}$, for $I = \{H, L\}$.

Labor market clearing

In equilibrium, supply and demand of labor type $k$ employed by firm $j$ in industry $I$ are equal. That is, $N^s_{t,t}(j, k) = N^d_{I,t}(j, k)$. From it, Appendix C shows that equilibrium in the aggregate labor
market implies \( N_t^s = N_t^d F_{w,t} \), where aggregate demand satisfies \( N_t^d = \frac{Y_t}{A_t} F_t \). The wage distortion

\[
F_{w,t} = \int_0^1 \left( \frac{W(k)}{W_t} \right)^{1-\theta_w} \frac{d^w_w}{dk} \, dk,
\]

is the result of wage dispersion across labor types from wage rigidities. The price distortion

\[
F_t = \varphi_H \left( \frac{P_{H,t}}{P_t} \right)^{-\eta} F_{H,t} + \varphi_L \left( \frac{P_{L,t}}{P_t} \right)^{-\eta} F_{L,t},
\]

where

\[
F_{I,t} = \int_0^1 \left( \frac{P_{I,t}(j)}{P_{I,t}} \right)^{-\theta} \, dj,
\]

is the result of price dispersion across firms and industries from price rigidities. Appendix C shows that \( F_{w,t} \) and \( F_t \) quantify the inefficiency due to nominal rigidities, which lead to lower output level compared to that in a frictionless economy:

\[
Y_t = \frac{A_t N_t^s}{F_{w,t} F_t} < A_t N_t^s.
\]

*Financial market clearing*

In equilibrium, the nominal interest rate from household maximization in equation (7) matches the interest rate set by the monetary authority. That is,

\[
-\log [M_t^{s}] = \rho i_{t-1} + (1 - \rho) (\bar{i} + i_t \pi_t + i_t x_t) + u_t.
\]

Appendix E provides a summary of the system of equations describing the equilibrium of the model. We solve the model numerically, applying a second-order approximation of the optimality conditions.\(^7\) A second-order approximation is required to capture expected excess returns on financial claims.
3 Calibration and Model Implications

We analyze the implications of nominal rigidities and monetary policy on expected asset returns at both aggregate and industry level. We focus on expected excess returns of claims on all future output (consumption) and profits. The effects of nominal rigidities on expected excess returns can be understood by their impact on the pricing kernel, output, and production markups. We calibrate the model to capture important dynamics of U.S. macroeconomic variables and stock returns. We compare different model specifications to highlight the most important channels driving the results.

3.1 Calibration

We use quarterly U.S. data from 1982:1 to 2010:4 for consumption, inflation, the short-term nominal interest rate, and stock returns to calibrate the model. We focus on the Greenspan-Bernanke period to avoid changes in the monetary policy regime, as suggested by Clarida, Galí and Gertler (2000). The consumption series was constructed using data on real consumption of nondurable and services from the Bureau of Economic Analysis. The series is de-trended using a Hodrick-Prescott filter. The inflation series was constructed to capture inflation related only to consumption of non-durables and services, following the methodology in Piazzesi and Schneider (2007). The short-term nominal rate is the 3-month T-bill rate from the Fama risk-free rates database. The stock market data are the quarterly returns of the market portfolio obtained from the Center for Research in Security Prices (CRSP). The model is calibrated at the quarterly frequency. Table 1 presents the parameter values for the baseline calibration.

The constant growth rate of the permanent productivity shock is chosen to match the growth rate of consumption for our sample period. The value of $\theta$ measures the elasticity of substitution for goods within each industry and is chosen to provide a markup of 20%, which is the value for the “high markup” specification in Altig et al. (2011) (hereafter ACEL). We set the elasticity of
substitution across industry goods, $\eta$, equal to $\theta$. In the analysis of the cross section of stock returns, we present results for specifications for $\eta$ different than $\theta$, since this difference has important cross sectional implications.

The price rigidity parameter values for $\alpha_H$ and $\alpha_L$ are chosen such that the average price duration $\overline{dur}$ and dispersion of price duration across industries $\sigma(dur)$ are, respectively,

$$\overline{dur} = -\varphi_H \frac{1}{\log \alpha_H} - \varphi_L \frac{1}{\log \alpha_L} = 2.2 \text{ quarters},$$

and

$$\sigma(dur) = \left[ \varphi_H \left( -\frac{1}{\log \alpha_H} - \overline{dur} \right)^2 + \varphi_L \left( -\frac{1}{\log \alpha_L} - \overline{dur} \right)^2 \right]^{1/2} = 2.13 \text{ quarters.}$$

These values are consistent with the empirical evidence in Bils and Klenow (2004). For simplicity, we assume same weights for industries $H$ and $L$, $\varphi_H = \varphi_L = 0.5$. The value of $\theta_w$ is chosen to have an average markup of wages over the marginal rate of substitution between leisure and consumption of 5%. The parameter $\alpha_w$ implies a duration of wages of four quarters, as estimated in ACEL. The parameter $\beta$ (and $\bar{\psi} = -\log(\beta) + \psi_{gal}$) is chosen to match the average level of the nominal risk-free rate. The interest rate rule parameters $\rho$, $\tau_\pi$, and $\tau_x$ are chosen to be consistent with the evidence for the Greenspan era according to Clarida, Galí and Gertler (2000).

The parameter values for the elasticities $\psi$, $\omega$, and the autocorrelations and conditional volatilities of productivity and policy shocks are chosen to match the variance decompositions for consumption, inflation, the short-term nominal interest rate, and hours worked presented in ACEL. ACEL use a VAR to identify productivity and policy shocks and obtain a variance decomposition for different macroeconomic variables. Table 2 presents their variance decomposition for inflation, consumption and the short-term interest rate.\(^8\) Productivity and policy shocks explain a small fraction of the total volatility of the three macroeconomic variables. Based on this decomposition, we choose parameter values to match the contribution of these shocks to the total variability of the macroeconomic series. Since our model has both permanent and transitory productivity shocks,
we require additional restrictions to identify how much of the variability explained by productivity shocks is the result of permanent and transitory shocks. We choose a mix of shocks that matches the volatility of consumption growth. Specifically, a calibration in which all productivity shocks are permanent implies a volatility of consumption growth significantly higher than in the data. On the other hand, a calibration where all productivity shocks are transitory implies a very low volatility in consumption growth. The combination of permanent and productivity shocks with policy shocks matches the volatility of consumption growth in the data. A significant fraction of this volatility is attributed to permanent shocks.

Table 2 shows that the model is able to match the contributions of productivity and policy shocks to the total variability of consumption, hours worked, inflation, and the nominal interest rate. The calibration implies a low elasticity of intertemporal substitution of consumption of $1/6.5 \approx 0.15$, and a Frisch elasticity of labor supply of $1/0.35 \approx 2.86$.

Finally, we choose $\gamma$ to match the stock market quarterly Sharpe ratio of 0.213 for the period. Consistent with the empirical practice, we use the nominal expected asset returns and risk-free rate of the model to calculate the model implied Sharpe ratio. Alternatively, we could have chosen $\gamma$ to match the equity premium. However, profit claims in the model are not directly comparable to dividend claims of the aggregate U.S. stock market, which are the payoffs to the equities of all public firms. The reasons are (1) profits in the model include profits of all corporate sectors, both private and public; (2) profits in the model include claims on both equity and claims on liabilities. Therefore, we match the Sharpe ratio as in Tallarini (2000) instead.

The recursive utility specification is critical for the model to match the Sharpe ratio, which allows us to increase risk aversion without affecting the elasticity of intertemporal substitution. By doing so, the macroeconomic properties of the model are not significantly affected by the degree of risk aversion, as shown by Tallarini (2000). In the presence of leisure preferences, the coefficient of constant relative risk aversion is not only determined by $\gamma$, which is calibrated as 111 in our model. The household’s attitude toward risk is also affected by their willingness to supply labor
in different states of the world. As shown by Swanson (2011), the (average) coefficient for the recursive preferences in equation (1) is

\[
\frac{\psi}{1 + \frac{\psi}{\omega \mu}} + \frac{\gamma - \psi}{1 - \frac{1-\psi}{1+\omega}} \approx 20.5.
\]

This value is still high according to empirical and experimental evidence,\textsuperscript{11} but significantly lower than the values required by standard real business cycle models to match Sharpe ratios, for example around 1,000 in Tallarini (2000).

### 3.2 Model implications on asset returns

Table 3 presents summary statistics for our benchmark calibration along with those from alternative model specifications: models with only one kind of shock and models with only one kind of rigidities. The alternative specifications help us understand the main channels driving the results. There are three main findings from this table: (1) product markup is procyclical and dividend is more volatile than output; (2) the equity premium is mainly a risk compensation for permanent productivity shocks; (3) both price rigidities and wage rigidities increase equity premium, however the latter has a significantly larger impact.

In the benchmark calibration, the quarterly volatility of dividend growth is 0.673\% while the volatility of consumption growth is only 0.373\%, calibrated to match the data. This is a direct result of the variabilities in production markups induced by nominal rigidities. Procyclical markups, indicated by the positive correlation between consumption growth and markup, make dividend claim riskier than output claim. The expected quarterly excess return of a claim on outputs is 0.169\%, lower than the expected return of 0.182\% on dividends.

Columns (2) to (4) allow us to quantify the contributions of the three different shocks to the results. Each column corresponds to the baseline calibration with only one shock affecting the economy (the volatility of the two other shocks is set to zero). It is clear from this table that most
of the premium is a compensation for permanent productivity shocks. These shocks contribute 17.7 bps to the premium, while the total contribution of transitory productivity and policy shocks is only 0.6 bps. The differences are also reflected in the implied Sharpe ratios. The Sharpe ratio for permanent shocks is significantly higher than the Sharpe ratios for the other two shocks, 0.361 compared to 0.018 and 0.004.

Columns (5) to (7) present the results from model specifications with no rigidities, with only wage rigidities, and with only price rigidities, respectively. The economy related to column (5) can be seen as a frictionless real business cycle economy. In the absence of nominal rigidities, our model implies negative expected excess returns on both output claims and dividend claims, consistent with the results in Kaltenbrunner and Lochstoer (2010). Once wage rigidities are present, the expected excess returns become positive. With price rigidities, the expected excess returns are still negative but with a smaller magnitude.

Time-varying markups

The difference between consumption and dividends comes solely from labor income in the model. Without rigidities, prices and wages adjust in response to shocks such that labor income is a fixed fraction of the total output, i.e., product markup is constant. Consequently, the volatility of dividends is identical to the volatility of consumption. However, with rigidities, product markup deviates from the constant and becomes time-varying. Table 3 shows that product markup is countercyclical in an economy with only price rigidities while stays constant in an economy with only wage rigidities. In the benchmark calibration, the effect of wage rigidities dominates that of price rigidities and product markup is procyclical.

The intuitions are as follow. After a negative productivity shock, in the presence of only wage rigidities, even though wages of some labor types cannot adjust downward, prices can freely adjust upward to compensate for the higher labor cost and obtain the optimal markup. On the contrary, with only price rigidities, prices of some products cannot adjust downward. Because wage is universal for all producers, it is not possible to maintain an optimal markup for every
The overall markup is higher than it is in an economy with no rigidities, i.e., markup is countercyclical. With both wage rigidities and price rigidities, wages are too high and prices cannot adjust upwards to compensate for the high labor costs. Consequently, markup is lower than it is in an economy with no rigidities, leading to a procyclical markup. Both the procyclical markup and procyclical profits implied by our benchmark calibration are consistent with the empirical findings in Rotemberg and Woodford (1999).

**Importance of permanent productivity shocks**

To see why permanent shocks have the largest impact on the excess stock returns, it is useful to conduct a variance decomposition on the pricing kernel $M_{t,t+1}$ and the stock return $R_{t+1}$. Table 7 shows that in the benchmark calibration, even though the combination of the transitory productivity shocks and policy shocks contribute more than 70% to the variance of stock returns, it contributes less than 1% to the variance of the pricing kernel. On the contrary, more than 99% of the variance in the pricing kernel comes from the permanent productivity shocks. Similar patterns are observed for the model specifications with only wage rigidities and only price rigidities, except for the model with no rigidities, policy shocks do not affect either asset returns or the pricing kernel. Equation (21) shows that the excess return fully depends on the covariance between the pricing kernel and the return. Therefore, the permanent productivity shocks are the main driving force for equity premium in the model.

The recursive utility is responsible for the above result. Equation 5 shows that the pricing kernel not only depends on the current period consumption growth but also the utilities in the future, while the latter would be absent under time-separable preferences. While all the shocks have similar impacts on the current consumption, only the permanent shocks have long-lasting impacts on the future utilities and hence generate more volatilities in the pricing kernel.

**Compensation for policy shocks**

Panel C of Table 4 shows compensations for policy shocks in economies with and without
rigidities. Different from productivity shocks, policy shocks do not generate risks in real terms in an economy without rigidities and therefore commands no compensation for risk. The effect of the policy shocks on the nominal interest rate is transmitted completely to inflation and leave both the real interest rate and excess returns unaffected. In the presence of rigidities, policy shocks command a positive compensation for risk. A positive shock to the policy rule in equation (15) increases the nominal interest rate.\textsuperscript{13} In the presence of wage rigidities, the wage stickiness implies that producers obtain their optimal markup by reducing their product prices by less than under flexible wages. As shown in Figure G, output and dividend decline, the marginal utility of consumption increases, and expected excess returns on output and dividend claims are positive. Price rigidities also generate a positive premium for policy shocks. Since some product prices do not adjust downwards after an expansionary shock, output demand declines. Real wages also decline and increase the markup, reducing the riskiness of dividend claims relative to output claims. However, all these effects on excess returns are very small quantitatively.

More interestingly, our calibration implies that as a result of nominal rigidities, a significant component of the return volatility is the result of policy shocks. Table 7 shows that monetary policy shocks contribute 64% to the variance of the excess return to the output claim and 57% to the variance of the excess return to the dividend claim. The impulse response functions in Figure G indicate that a 0.15\% increase in the nominal interest rate leads to 0.6\% drop in the excess return to the dividend claim. Our result is similar in magnitude to the empirical finding in Bernanke and Kuttner (2005), who show that a unanticipated 25-basis-point cut in the federal funds rate target is associated with about a one percent increase in broad stock indexes.

\textit{Nominal rigidities and asset returns}

From the previous analysis, we know that permanent productivity shocks are the primary cause of equity premium. Therefore, we focus on the interaction between nominal rigidities and permanent productivity shocks and show how that interaction affects the dynamics of asset returns. Table 3 shows that stock returns are negative in an economy with no rigidities, which is a standard result
in the presence of permanent productivity shocks and a lower than one EIS.\textsuperscript{14}

Consider the return on the output/consumption claims, which is the same as the return on dividend claim in a frictionless economy. The first term in equation (21) generates a positive premium because the negative shock leads to a higher marginal rate of substitution and lower output growth. However, the second term generates a negative premium because the negative shock leads to a higher price-dividend ratio, $P_{Y,t+1}$. Two opposite effects drive this result: (1) a substitution effect: the demand for assets is low, therefore low $P_{Y,t+1}$, because household would like to consume more to smooth consumption; (2) a wealth effect: the demand for assets is high, therefore high $P_{Y,t+1}$, because the shock is permanent and future outputs are also low. When EIS is lower than one, the wealth effect dominates the substitution effect, leading to higher $P_{Y,t+1}$ after a negative permanent productivity shock. When the negative contribution of the second term dominates the positive contribution of the first term, the equity premium becomes negative.

Appendix G conducts a log linearization of the model with no rigidities and shows that $P_{Y,t}$ is given by

$$
\log (P_{Y,t}) = \frac{\phi_a (1 - \psi)}{1 - \kappa_1 \phi_a} \Delta a_t
$$

where $\kappa_1$ is a positive constant less than one defined in the appendix. It is clear that $P_{Y,t}$ is negative when $\psi$ is larger than one.

In the presence of nominal rigidities, labor supply/demand is no longer a constant and becomes procyclical, which is critical for the model to generate a positive equity premium. In Appendix G, a log linear solution of the model gives that

$$
\log (N_t^d) = n_a \Delta a_t \quad \text{and} \quad \log (P_{Y,t}) = \frac{[\phi_a - (1 - \phi_a) n_a] (1 - \psi)}{1 - \kappa_1 \phi_a} \Delta a_t.
$$

Procyclical labor demand means a positive $n_a$, which leads to a less countercyclical or even procyclical $P_{Y,t}$ if $n_a$ is large enough. Therefore, the negative effect of $P_{Y,t}$ on the equity premium is weakened due to nominal rigidities. With wage rigidities, the effect of the procyclical labor supply
is large enough so that the equity premium becomes positive; while with price rigidities, such an effect only makes the equity premium less negative.

The economic intuition for a positive $n_a$ is as follows. After a negative productivity shock, wage rigidities make labor costs too high and reduce the supply of output, while price rigidities make output prices too high and reduce the demand for outputs. In either case, rigidities reduce the output level further down from the level in a frictionless economy, resulting in a procyclical labor supply/demand.

The effect of a negative shock on output/consumption is strongest for the current period due to rigidities. Over time, prices and wages gradually adjust to the optimal level and part of the negative effect on output will be reversed. Consequently, the desire to consume at the current period is stronger and the demand for assets is lower than the levels in a frictionless economy. Therefore, nominal rigidities strengthen the substitution effect and weaken the wealth effect, leading to a positive equity premium for the output/consumption claim. The expected excess return for the dividend claim is larger than that for the output claim due to the procyclical markups.

### 3.3 Monetary Policy Rule and Asset Returns

In this section, we analyze how the responsiveness of the monetary authority to economic conditions affect asset returns. In the absence of nominal rigidities, the dynamics of real variables and, therefore, real asset returns are not affected by the policy rule. Nominal rigidity is the only channel in our model through which monetary policies affect asset returns. In the analysis below, we focus on how monetary policies interact with the permanent productivity shock, whose effects on asset returns dominate the effects of the other types of shocks.

*Changes in the response to inflation*

Panel A of Table 6 presents summary statistics for economies where the response to inflation, $\tau_\pi$, is lower or higher than in the baseline calibration. The effects of $\tau_\pi$ on expected asset returns
depend on the particular type of rigidities affecting the economy. In an economy with only wage rigidities, an increase in $\tau_x$ increases expected excess returns. In an economy with only price rigidities, an increase in $\tau_\pi$ reduces expected excess returns. After a negative productivity shock, output level decreases and the real interest rate goes down. Under wage rigidities, inflation goes up to compensate for the high labor costs. A positive response to inflation increases the nominal interest rate and part of that increase is transmitted to the real interest rate due to rigidities, which exacerbates the negative effect of the productivity shock on outputs and dividends and raises the expected excess returns. The stronger the response to inflation, the larger the increases in excess returns. On the contrary, under price rigidities, inflation goes down after a negative permanent productivity shock. The response of the monetary policy to inflation countermands partially offsets the effect of the negative shock and lead to lower expected excess returns. Quantitatively, the effect of wage rigidities in the calibration is stronger than the effect of the price rigidity. For the benchmark calibration, an increase in the reaction coefficient from 1.5 to 1.75 increases the expected quarterly excess returns by 1.2 bps.

Changes in the response to the output gap
Panel B of Table 6 shows that an increase in the response to the output gap, $\tau_x$, decreases the expected excess returns on output and profit claims in the presence of either type of rigidities. The intuition is simple. After a negative permanent productivity shock, output level goes down under both types of rigidities. Monetary policies that respond to the output gap positively set a lower nominal interest rate and part of the decrease is transmitted to the real interest rate due to rigidities, which negates partially the negative effect of the productivity shock on the output level. Therefore, the output level becomes less volatile and the expected excess returns are smaller. And the stronger the response of the monetary policy to the output gap, the larger decreases in expected returns. Quantitatively, an increase in the reaction to the output gap from 0 to 0.125 reduces the expected quarterly excess returns on output and profit claims by 0.1 bps in the benchmark calibration.
Changes in interest rate smoothing

Panel C of Table 6 shows that nominal rigidities affect the response of expected excess returns to changes in the interest rate smoothing coefficient $\rho$. An increased weight of the policy rule on the lagged interest rate decreases the responsiveness of the monetary policy to both inflation and output gap. Our previous analysis shows that weaker response to inflation leads to higher excess returns while weaker response to output gap leads to higher excess returns. Our calibration implies that the effect from the response to inflation dominates the effect from the response to output gap. In our benchmark calibration, an increase in $\rho$ from 0.63 to 0.83 leads to a decrease of 1.1 bps in expected quarterly excess returns.

3.4 Heterogeneity in Price Rigidities and the Cross-Section of Returns

Differences in the degree of price rigidity across industries may be reflected in differences in the expected returns of their production claims. We compare the returns of the industry output and profit claims for industries $H$ and $L$. To illustrate the main mechanism, consider the valuation of claims on industry output and profits that pay off only one-period in the future. Appendix F shows that the difference in expected returns on dividend claims across industries can be approximated as

$$\log E_t [R_{H,t+1}] - \log E_t [R_{L,t+1}] = -\text{cov}_t(m_{t,t+1}, \Delta d_{H,t+1} - \Delta d_{L,t+1})$$

$$\approx -\text{cov}_t(m_{t,t+1}, \Delta y_{H,t+1}^{\text{real}} - \Delta y_{L,t+1}^{\text{real}}) + (1 - \theta)\text{cov}_t(m_{t,t+1}, p_{R,t+1})$$

$$= - (\theta - \eta)\text{cov}_t(m_{t,t+1}, p_{R,t+1}).$$

Therefore, the dynamics of the relative price of the two intermediate goods and the elasticities of substitution $\eta$ for goods across industries and $\theta$ for goods within each industry capture differences in expected returns on dividend claims.

The difference in stock returns on dividend claims is the result of the difference in outputs, referred to as the output effect, and the difference in markups, referred to as the markup effect, across the
two industries. After a negative productivity shock, because wages do not fully adjust downwards, prices go up to compensate for the higher marginal costs. The price of goods $H$ is lower than the price of goods $L$ due to higher price rigidities in industry $H$, resulting in a relative higher demand and therefore a higher dividend for goods $H$. The difference in outputs depends on the elasticity of substitution between the two goods $\eta$. However, the positive relative price implies that the markup of industry $H$ is smaller than that of industry $L$. The difference in the markups depends on the elasticity of substitution among the differentiated goods within each industry $\theta$. It is clear that the output effect increases the dividends of industry $H$ while the markup effect decreases the dividends of industry $H$, relative to the dividends of industry $L$ after a negative productivity shock.

Table 5 presents the comparative statics for expected returns of industry claims under model specifications with various values of $\eta$ and $\theta$. The results show that the output effect dominates and $R_{DH} < R_{DL}$ if $\eta > \theta$, the markup effect dominates if $\eta < \theta$ and $R_{DH} > R_{DL}$, and the two effects exactly cancel out if $\theta = \eta$. It seems reasonable to assume that products within the same industry are more substitutable than products from different industries. In such a case, our model implies that industries with higher price rigidities earn higher excess returns on average than industries with lower price rigidities.

4 Conclusion

We explore the asset pricing implications of nominal rigidities and monetary policy in a dynamic equilibrium model with recursive preferences and three types of shocks: permanent productivity shock, transitory productivity shock, and monetary policy shocks. Price and, especially, wage rigidities improve the ability of the model to capture a large and positive equity premium, which is mainly a compensation for the permanent productivity shocks. Differences in price rigidities across industries lead to differences in industry asset returns which depend on the product substitutability
both within and across industries. Monetary policies with a higher tendency of interest rate smoothing, a more aggressive response to inflation or a less aggressive response to output lead to higher equity premium.

We now discuss some limitations of the analysis and potential directions for future research. First, our model abstracts from capital accumulation and therefore ignores any potential effects of nominal rigidities on investment behavior. Jermann (1998), Boldrin, Christiano and Fisher (2001), and Jermann (2010) point out that investment adjustment costs have important asset pricing implications. The joint study of investment dynamics and nominal rigidities merits further exploration. Second, we assume homogeneous wage rigidities across industries. Heterogeneity in wage rigidities and imperfect labor mobility across industries can be an additional source of differences in the cross section of asset returns. Third, our model provides a natural framework to study the returns on human capital and shed light on the empirical findings of Lustig and Nieuwerburgh (2008). Finally, we assume that financial markets are complete and frictionless. The effects of monetary policy and nominal rigidities on asset returns can be amplified by financial frictions such as the financial accelerator in Bernanke, Gertler and Gilchrist (1999) or under limited financial market participation as in Galí, López-Salido and Vallés Liberal (2004).
Campbell and Cochrane (1999) and Bansal and Yaron (2004), among others, have made significant progress in capturing asset pricing dynamics in endowment economies. The success of these models, however, is limited in a production economy framework as shown by Boldrin, Christiano and Fisher (2001) and Kaltenbrunner and Lochstoer (2010), respectively.

See Boldrin, Christiano and Fisher (2001), for instance.

Blinder et al. (1998) conducts surveys on firms’ pricing policies and summarize different theories for the existence of price rigidities based on the nature of costs, demand, contracts, market interactions, and imperfect information.

Cochrane (2005) provides an extensive summary of the main findings and challenges in this literature.

Aoki (2001) studies a particular case for this economy in which one of the industries has perfectly flexible prices, and wages are perfectly flexible. His analysis focuses on the implications for optimal monetary policy in this economy, and does not explore any asset pricing implications.

This approach is different from the standard heterogeneous households approach to model wage rigidities as in Erceg, Henderson and Levin (2000), where each household supplies a differentiated type of labor. In the presence of recursive preferences, this approach introduces heterogeneity in the marginal rate of substitution of consumption across households since it depends on labor. We avoid this difficulty and obtain a unique marginal rate of substitution by modeling a representative agent who provides all different types of labor.

We use the Dynare package available from www.dynare.org to solve the model.

ACEL refers to these productivity shocks as “neutral technology” shocks. The variance decomposition in ACEL for the short-term rate refers to the Federal Funds rate. We assume that the same variance decomposition applies to the three-month T-bill rate. ACEL estimate their VAR using data for 1982-2008. We assume that their variance decomposition also applies to our sample period.

Ideally, we would like to match only the volatility of consumption growth explained by productivity and policy shocks. However, this information is not available. Also, matching the total volatility of consumption growth is helpful to make more direct comparisons with other asset pricing models.

Macroeconomic models usually rely on elasticities of substitution between 0 and 1. The Bansal and Yaron (2004) model requires an elasticity of substitution greater than 1 in order to capture the observed equity premium. Empirical estimates range between 0 and 1. For instance, Hall (1988) provides an estimate very close to zero, and Vissing-Jorgensen (2002) finds an elasticity for stockholders around 0.3 to 0.4, and very close to zero for non-stockholders.

See, for instance, Barsky et al. (1997).
Permanent shocks also have greater effect on the pricing kernel under time-separable utility than other shocks, however the difference is smaller.

This initial increase does not take into account the feedback effects resulting from potential changes in inflation and output caused by the shock.

See Bansal and Yaron (2004) and Kaltenbrunner and Lochstoer (2010).
References


A Household’s Utility Maximization under Wage Rigidities

The household’s problem is

\[
\max_{\{C_t, N_s^t, W_t^*\}} \quad V_t = U_t + \beta Q_t^{1-\psi}
\]

where

\[
U_t = \frac{C_t^{1-\psi}}{1-\psi} - \kappa_t \frac{(N_s^t)^{1+\omega}}{1+\omega}, \quad \text{and} \quad Q_t = E_t \left[ V_{t+1}^{\frac{1-\psi}{\psi}} \right],
\]

subject to the budget constraint

\[
E_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} P_{t+\tau} C_{t+\tau} \right] \leq E_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} P_{t+\tau} (LI_{t+\tau} + D_{t+\tau}) \right],
\]

where \(LI_t\) and \(D_t\) are aggregate labor income and firm profits, respectively. The Lagrangian associated with this problem is

\[
\mathcal{L} = \frac{C_t^{1-\psi}}{1-\psi} - \kappa_t \frac{(N_s^t)^{1+\omega}}{1+\omega} + \beta Q_t^{1-\psi} + \lambda E_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} P_{t+\tau} (LI_{t+\tau} + D_{t+\tau} - C_{t+\tau}) \right].
\]

It can be shown that utility maximization implies \(\lambda = \frac{C_t^{1-\psi}}{P_t}\), and

\[
M^s_{t,t+1} = \frac{\partial V_t}{\partial C_{t+1}} \frac{P_t}{P_{t+1}} = \beta \frac{\partial Q_t}{\partial C_t} \frac{\partial V_t}{\partial Q_t} \frac{P_t}{P_{t+1}} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \frac{V_t^{1/(1-\psi)}}{Q_t^{1/(1-\gamma)}} \psi^{-\gamma} \frac{P_t}{P_{t+1}}.
\]

The \(\tau\)-period nominal pricing kernel is

\[
M^s_{t,t+\tau} = \prod_{s=1}^{\tau} M^s_{t,t+s}.
\]

The household cannot change wages for \(\alpha_w\) fraction of labor types. For the remaining \(1 - \alpha_w\) fraction of labor types \(k\), the household chooses wages \(W_t^*(k)\) to maximize \(V_t\). We assume that the wage choice for one labor type has negligible effects on the aggregate wage index and the aggregate labor demand. To see the impact of \(W_t^*(k)\) on the household’s utility, we rewrite the labor supply at \(t + \tau\) as

\[
N_{t+\tau}^s = \int_0^1 N_{t+\tau}^s(k) \, dk = N_{t+\tau}^d \int_0^1 \left( \frac{W_{t+\tau}(k)}{W_{t+\tau}} \right)^{-\theta_w} \, dk,
\]

and the aggregate labor income at \(t + \tau\) as

\[
LI_{t+\tau} = \int_0^1 \frac{W_{t+\tau}(k)}{P_{t+\tau}} N_{t+\tau}^s(k) \, dk = \frac{N_{t+\tau}^d W_{t+\tau}}{P_{t+\tau}} \int_0^1 \left( \frac{W_{t+\tau}(k)}{W_{t+\tau}} \right)^{1-\theta_w} \, dk.
\]
For the wage of type $k$ labor at $t + \tau$, there are $\tau + 2$ possible values:

$$W_{t+\tau}(k) = \begin{cases} W^*_t, & \text{with prob } = (1 - \alpha_w)\alpha^*_w \text{ for } s = 0, 1, \cdots, \tau \\ W_{t-1}, & \text{with prob } = \alpha^*_w + 1. \end{cases}$$

We obtain derivatives

$$\frac{\partial N^s_{t+\tau}}{W^*_t(k)} = N^d_{t+\tau}(1 - \alpha_w)\alpha^*_w \left( -\frac{\theta_w}{W^*_t(k)} \right) \left( \frac{W^*_t}{W^*_{t+\tau}} \right)^{-\theta_w},$$

$$\frac{\partial LH_{t+\tau}}{\partial W^*_t(k)} = N^d_{t+\tau}(1 - \alpha_w)\alpha^*_w(1 - \theta_w) \left( \frac{W^*_t}{W^*_{t+\tau}} \right)^{-\theta_w}.$$  

The first-order condition of the Lagrangian with respect to $W^*_t(k)$ is given by

$$\frac{\partial L}{\partial W^*_t(k)} = \frac{\partial V_t}{\partial W^*_t(k)} + \lambda \mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} P_{t+\tau} \frac{\partial LH_{t+\tau}}{\partial W^*_t(k)} \right] = 0,$$

where

$$\frac{\partial V_t}{\partial W^*_t(k)} = -\mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} P_{t+\tau} \left( \frac{C_{t+\tau}}{C_t} \right)^\psi \kappa_{t+\tau}^{-1} (N^s_{t+\tau})^\omega \frac{\partial N^s_{t+\tau}}{\partial W^*_t(k)} \right].$$

Rearranging terms, we get

$$\mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+\tau} \alpha_w W^\theta_w N^d_{t+\tau} \frac{W^*_t(k)}{P_t} C_t^{-\psi} \right] = \mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M^s_{t,t+1} \alpha_w \left( \frac{P_{t+\tau}}{P_t} \right) W^\theta_w N^d_{t+1} \kappa_{t+\tau}^{-1} (N^s_{t+\tau})^\omega \left( \frac{C_{t+\tau}}{C_t} \right)^\psi \right].$$

Since all labor types face the same demand curve, we have $W^*_t(k) = W^*_t$ for all $k$. We can write the left-hand side of the equation as

$$LHS = C_t^{-\psi} W^\theta_w N^d_t H_{w,t} \frac{W^*_t}{P_t},$$

where

$$H_{w,t} = 1 + \alpha_w \mathbb{E}_t \left[ M^s_{t,t+1} \left( \frac{N^d_{t+1}}{N^d_t} \right) \left( \frac{W_t}{W_{t+1}} \right)^{-\theta_w} H_{w,t+1} \right].$$

Similarly, the right-hand side of the first-order condition can be written as

$$RHS = \mu_w W^\theta_w N^d_t (N^s_t)^\omega G_{w,t} = \mu_w W^\theta_w N^d_t \kappa_t (N^s_t)^\omega G_{w,t}$$

where

$$G_{w,t} = 1 + \alpha_w \mathbb{E}_t \left[ M^s_{t,t+1} \left( \frac{P_{t+1}}{P_t} \right) C_t^{-\psi} \left( \frac{N^d_{t+1}}{N^d_t} \right) \left( \frac{\kappa_{t+1}}{\kappa_t} \right) \left( \frac{N^s_{t+1}}{N^s_t} \right)^\omega \left( \frac{W_t}{W_{t+1}} \right)^{-\theta_w} G_{w,t+1} \right].$$

The optimal real wage and the optimal wage markup $\mu_{w,t}$ are then given by

$$\frac{W^*_t}{P_t} = \mu_{w,t} G_{w,t}^{\psi} (N^s_t) \omega \text{ and } \mu_{w,t} = \mu_w \frac{G_{w,t}}{H_{w,t}}.$$
B Profit Maximization under Price Rigidity

Consider the Dixit-Stiglitz aggregate (3) as a production function, and a competitive “producer” of the industry good facing the problem

$$\max_{\{C(t,j)\}} P_{t,t}C_{t,t} - \int_0^1 P_{t,t}(j)C_{t,t}(j) dj$$

subject to (3). Solving the problem, we find the demand function

$$P_{t,t}(j) = P_{t,t} \left( \frac{C_{t,t}(j)}{C_{t,t}} \right)^{-1/\theta}$$

(22)

The zero-profit condition implies

$$P_{t,t}C_{t,t} = \int_0^1 P_{t,t}(j)C_{t,t}(j) dj = \int_0^1 P_{t,t}C_{t,t} \left( \frac{P_{t,t}(j)}{P_{t,t}} \right)^{-\theta} dj.$$

Solving for $P_{t,t}$, it follows that

$$P_{t,t} = \left[ \int_0^1 P_{t,t}(j)^{1-\theta} dj \right]^{1/\theta},$$

(23)

which can be written as the demand function for each differentiated good in sector $I$

$$C_{I,t}(j) = \left( \frac{P_{I,t}(j)}{P_{I,t}} \right)^{-\theta} C_{I,t}.$$

(24)

Similarly, we can solve the profit maximization problem of the final good industry, which use goods from industry $H$ and $L$ as inputs. The demand function for industry $I$ good is

$$C_{I,t} = \varphi I \left( \frac{P_{I,t}}{P_I} \right)^{-\eta} C_I$$

(25)

where $P_I$ is the final good price, defined as the aggregate price index. The zero profit condition of the final goods production implies

$$P_I = \left[ \varphi P_{H,t}^{1-\eta} + (1 - \varphi)P_{L,t}^{1-\eta} \right]^{1/(1-\eta)}.$$

Notice that these relations imply that consumption in both sectors is related by

$$C_{H,t} = \frac{\varphi}{1 - \varphi} \left( \frac{P_{H,t}}{P_{L,t}} \right)^{-\eta} C_{L,t}.$$

Therefore, when prices are flexible, prices of the sector goods are the same and consumptions in the two sectors are proportional.

The profit maximization problem is

$$\max_{\{P_{t,t}(j)\}} \mathbb{E} \left[ \sum_{\tau=0}^{\infty} M_{t,t+\tau}^\delta \alpha_{\tau}^\gamma \left[ P_{t,t}(j)Y_{t,t+\tau|t}(j) - W_{t+\tau|t}(j)N_{t,t+\tau|t}(j) \right] \right]$$
subject to

\[ Y_{I,t+\tau}(j) = Y_{I,t+\tau} \left( \frac{P_{I,t}(j)}{P_{I,t+\tau}} \right)^{-\theta}, \quad \text{and} \quad Y_{I,t+\tau|t}(j) = A_tN_{I,t+\tau|t}(j). \]

The first-order condition of this problem with respect to \( P_{I,t}(j) \) is

\[
\mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M_{I,t+\tau}^* \alpha I^\tau Y_{I,t+\tau}(j)P_{I,t}(j) \right] = \mathbb{E}_t \left[ \sum_{\tau=0}^{\infty} M_{I,t+\tau}^* \alpha I^\tau Y_{I,t+\tau|t}(j)P_{I,t}(j) \right].
\]

The left-hand side (LHS) of the equation can be written recursively as

\[ LHS = P_{I,t}^* \left( \frac{P_{I,t}}{P_{t}} \right)^{-\theta} Y_{I,t} H_{I,t}, \]

where

\[ H_{I,t} = 1 + \alpha I \mathbb{E}_t \left[ M_{I,t+1}^* \left( \frac{Y_{I,t+1}}{Y_{I,t}} \right) \left( \frac{P_{I,t}}{P_{I,t+1}} \right)^{-\theta} H_{I,t+1} \right]. \]

Similarly, the right-hand side (RHS) of the equation can be written as

\[ RHS = \frac{\mu}{A_t} Y_{I,t} \left( \frac{P_{I,t}}{P_{I,t+1}} \right)^{-\theta} W_t P_t G_{I,t}, \]

where

\[ G_{I,t} = 1 + \alpha I \mathbb{E}_t \left[ M_{I,t+1}^* \left( \frac{Y_{I,t+1}}{Y_{I,t}} \right) \left( \frac{P_{I,t}}{P_{I,t+1}} \right)^{-\theta} \left( \frac{W_{t+1}}{W_t} \right) \left( \frac{A_t}{A_{t+1}} \right) G_{I,t+1} \right]. \]

The optimal price is hence given by

\[ \left( \frac{P_{I,t}}{P_{t}} \right) \left( \frac{P_{I,t}}{P_{I,t+1}} \right)^{1-\theta} H_{I,t} = \frac{\mu W_t}{A_t} G_{I,t}. \]

Here, \( P_{I,t}(j) = P_{I,t}^* \) because all firms changing prices face the same demand curve and hence the same optimization problem. Based on the definition of markup, the optimal time-varying product markup is given by

\[ \mu_t = \frac{\mu G_{I,t}}{H_{I,t}} \quad \text{and} \quad P_{I,t}^* = \frac{\mu W_t}{A_t}. \]

The inflation in price for industry \( I \) is given by

\[ 1 = (1 - \alpha I) \left( \frac{P_{I,t}}{P_{I,t}} \right)^{1-\theta} + \alpha I \left( \frac{P_{I,t+1}}{P_{I,t}} \right)^{1-(1-\theta)}, \]

and the relation between the price index and industry prices is

\[ 1 = \varphi_H \left( \frac{P_{I,t+1}}{P_t} \right)^{1-\eta} + \varphi_L \left( \frac{P_{I,t}}{P_t} \right)^{1-\eta}. \]
C Labor Market Clearing Conditions

The total supply of type $k$ labor to industry $I$ is given by

$$N^s_{I,t}(k) = \int_0^1 N^s_{I,t}(j,k) \, dj = \int_0^1 \frac{N^d_{I,t}(j,k)}{W_t} \, \left[ W_t(k) \right]^{-\theta_w} \, \int_0^1 N^d_{I,t}(j) \, dj,$$

From the production function $Y_{I,t}(j) = A_t N_{I,t}(j,k)$, we obtain

$$N^s_{I,t}(k) = \left( \frac{W_t(k)}{W_t} \right)^{-\theta_w} \int_0^1 \frac{Y_{I,t}(j)}{A_t} \, dj = \left( \frac{W_t(k)}{W_t} \right)^{-\theta_w} \int_0^1 \frac{P_{I,t}(i)}{P_{I,t}} \, dj,$$

where the second equality follows from the product demand function (12). Defining the price dispersion aggregator within industry $I$, and the wage dispersion aggregator by

$$F_{I,t} \equiv \int_0^1 \left( \frac{P_{I,t}(j)}{P_{I,t}} \right)^{-\eta} \, dj, \quad \text{and} \quad F_{w,t} \equiv \int_0^1 \left( \frac{W_t(k)}{W_t} \right)^{-\theta_w} \, dk,$$

respectively, it follows that

$$N^s_{I,t} = \frac{Y_{I,t} F_{I,t} F_{w,t}}{A_t}.$$

Aggregate labor supply is then

$$N^s_t = N^s_{H,t} + N^s_{L,t} = \left( \frac{Y_{H,t} F_{H,t}}{A_t} + \frac{Y_{L,t} F_{L,t}}{A_t} \right) F_{w,t} = \frac{Y_t F_t F_{w,t}}{A_t},$$

where the third equality comes from the relation between final goods output and intermediate goods output

$$Y_{I,t} = \varphi I \left( \frac{P_{I,t}}{P_t} \right)^{-\eta}.$$

$F_t$ is the price dispersion aggregator

$$F_t \equiv \varphi H \left( \frac{P_{H,t}}{P_t} \right)^{-\eta} F_{H,t} + \varphi L \left( \frac{P_{L,t}}{P_t} \right)^{-\eta} F_{L,t}.$$

From the resource constraint

$$N^d_t = \sum_{I \in \{H,L\}} \int_0^1 N^d_{I,t}(j) \, dj,$$

it can be shown that $N^d_t = N^s_t / F_{w,t} = \frac{Y_t F_t}{A_t}$. Note that the wage dispersion $F_{w,t}$ is bounded below by one.

$$F_{w,t} = \int_0^1 \left[ \left( \frac{W_t(k)}{W_t} \right)^{1-\theta_w} \right]^{-\eta} \, dk \geq \int_0^1 \left( \frac{W_t(k)}{W_t} \right)^{1-\theta_w} \, dk \geq 1^{1-\eta} = 1.$$
where the second equality is due to Jensen’s inequality for \( \frac{-\theta}{1-\theta} > 1 \). Similarly, we can show that \( F_{H,t} \) and \( F_{L,t} \) are both bounded below by one, which leads to the same conclusion for \( F_t \).
D A Return Representation of the Pricing Kernel

The pricing kernel in terms of consumption and continuation utility is

\[ M_{t,t+1} = \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \left( \frac{V_{t+1}^{1/(1-\psi)}}{Q_t^{1/(1-\gamma)}} \right)^{\psi-\gamma}, \]

where

\[ V_t = \frac{C_t^{1-\psi}}{1-\psi} - \kappa_t \left( N_s \right)^{1+\omega} + \beta Q_t^{\frac{1-\psi}{1-\gamma}}, \quad \text{and} \quad Q_t = \mathbb{E}_t \left[ \frac{V_{t+1}^{1-\psi}}{1-\gamma} \right]. \]

Using the definitions of \( Q_t \) and \( M_{t,t+1} \), we have

\[ \beta Q_t^{\frac{1-\psi}{1-\gamma}} = \beta Q_t^{\frac{1-\psi}{1-\gamma}} = \beta \mathbb{E}_t \left[ V_{t+1} V_{t+1}^{\frac{1-\psi}{1-\gamma}} Q_t^{\frac{1-\psi}{1-\gamma}} \right] = C_t^{\psi} \mathbb{E}_t \left[ M_{t,t+1} C_{t+1}^{\psi} V_{t+1} \right]. \]

Equation (9) shows that the optimal wage is set as

\[ \frac{W_t^*}{P_t} = \mu_w C_t^{\psi} \kappa_t \left( N_s \right)^{\omega} \frac{G_{w,t}}{H_{w,t}}. \]

Therefore, the household’s utility can be written as

\[ V_t = \frac{C_t^{1-\psi}}{1-\psi} - \frac{1}{1+\omega} \frac{1}{\mu_w} L I_t^* - C_t^{\psi} + \beta Q_t^{\frac{1-\psi}{1-\gamma}}, \]

where we define

\[ L I_t^* = \frac{W_t^*}{P_t} N_s \frac{H_{w,t}}{G_{w,t}}. \]

Notice the \( L I_t^* \) can be interpreted as the labor income if all labor supply is paid at the nominal wage \( W_t^* \) adjusted by \( \frac{H_{w,t}}{G_{w,t}} \). If wages are perfectly flexible, \( L I_t^* = L I_t \). Substituting the expression for \( \beta Q_t^{\frac{1-\psi}{1-\gamma}} \) and solving \( V_t \) recursively, we get

\[ (1-\psi) C_t^{\psi} V_t = C_t + S_{C,t} - \bar{\nu} \left( L I_t^* + S_{L I^*,t} \right) \]

where \( \bar{\nu} = \frac{1-\psi}{1+\omega} \frac{1}{\mu_w} \).

\[ S_{C,t} = \mathbb{E}_t \left[ \sum_{s=1}^{\infty} M_{t,t+1} C_{t+s} \right], \quad \text{and} \quad S_{L I^*,t} = \mathbb{E}_t \left[ \sum_{s=1}^{\infty} M_{t,t+1} L I_{t+s}^* \right]. \]

\( S_{C,t} \) is the present value of all future consumption and \( S_{L I^*,t} \) is the present value of all future adjusted labor income \( L I^* \). It follows that the continuation utility term \( \beta Q_t^{\frac{1-\psi}{1-\gamma}} \) can be written as

\[ \beta Q_t^{\frac{1-\psi}{1-\gamma}} = \frac{C_t^{1-\psi}}{1-\psi} \left[ S_{C,t} - \bar{\nu} S_{L I^*,t} \right]. \]
Therefore, we get

$$\left( \frac{V_{t+1}^{1/(1-\psi)}}{Q_t^{1/(1-\gamma)}} \right)^{\frac{\psi}{\psi-\gamma}} = \left( \frac{V_{t+1}}{Q_t^{1/(1-\gamma)}} \right)^{\frac{\psi}{\psi-\gamma}} = \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \right]^{\frac{\psi}{\psi-\gamma}} \frac{C_{t+1} + S_{C,t+1} - \bar{\nu} \left( L_{I,t+1}^s + S_{LI^*,t+1} \right)}{S_{C,t} - \bar{\nu} S_{LI^*,t}}$$

$$= \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} R_{CL,t+1} \right]^{\frac{\psi}{\psi-\gamma}}$$

where

$$R_{CL,t+1} = (1 - \nu_t) R_{C,t+1} + \nu_t R_{LI^*,t+1},$$

$$R_{C,t+1} = \frac{C_{t+1} + S_{C,t+1}}{S_{C,t}},$$

$$R_{LI^*,t+1} = \frac{L_{I,t+1}^s + S_{LI^*,t+1}}{S_{LI^*,t}},$$

and

$$\nu_t = \frac{\bar{\nu} S_{LI^*,t}}{\bar{\nu} S_{LI^*,t} - S_{C,t}}.$$

The pricing kernel is then given by

$$M_{t,t+1} = \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \right]^{\frac{1-\gamma}{1-\psi}} \left( \frac{1}{R_{CL,t+1}} \right)^{1-\frac{1-\gamma}{1-\psi}}.$$

In the model, consumption is equal to total output. Therefore, the claim on consumption is the same as the claim on output, which leads to

$$M_{t,t+1} = \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\psi} \right]^{\frac{1-\gamma}{1-\psi}} \left( \frac{1}{R_{Y,t+1}} \right)^{1-\frac{1-\gamma}{1-\psi}}.$$
E  Equilibrium Conditions

This appendix provides a summary of the equilibrium equations for the model. These conditions need to be expressed in terms of de-trended variables. In order to obtain balanced growth, we make $\kappa_t = (A_t^p)^{1-\psi}$. This condition ensures that $Y_t, Y_{t,t}, W_t, \text{ and } W_t^*$ are growing at the same rate. Therefore, the equations can be written in terms of $\hat{Y}_t = \frac{Y_t}{A_t^p}$, $\hat{Y}_{t,t} = \frac{Y_{t,t}}{A_t^p}$, $\hat{W}_t = \frac{W_t}{A_t^p}$, and $\hat{W}_t^* = \frac{W_t^*}{A_t^p}$.

Wage Setting

\[
\frac{W_t^*}{\hat{P}_t} = \mu_w \kappa_t \left( \frac{N_t^f}{N_t^g} \right) C_t^\psi \frac{G_{w,t}}{H_{w,t}},
\]

\[
H_{w,t} = 1 + \alpha_w \hat{E}_t \left[ M_{w,t+1}^g \left( \frac{N_{t+1}^d}{N_t^g} \right) \left( \frac{W_t}{\hat{W}_{t+1}} \right)^{-\theta_w} \right] H_{w,t+1},
\]

and \( G_{w,t} = 1 + \alpha_w \hat{E}_t \left[ M_{w,t+1}^g \left( \frac{P_{t+1}}{P_t} \right) \left( \frac{C_{t+1}}{C_t} \right)^\psi \left( \frac{N_{t+1}^d}{N_t^g} \right) \left( \frac{\kappa_{t+1}}{\kappa_t} \right) \left( \frac{N_{t+1}^s}{N_t^s} \right) \omega \left( \frac{W_t}{\hat{W}_{t+1}} \right)^{-\theta_w} G_{w,t+1} \right] \).

Price Dispersion

\[
F_t = \varphi_H \left( \frac{\hat{P}_{H,t}}{P_t} \right)^{-\eta} F_{H,t} + \varphi_L \left( \frac{\hat{P}_{L,t}}{P_t} \right)^{-\eta} F_{L,t},
\]

\[
F_{t,t} = \int_0^1 \left( \frac{\hat{P}_{t,t}(j)}{P_{t,t}} \right)^{-\theta} dj = (1 - \alpha_I) \left( \frac{\hat{P}_{t,t}}{P_{t,t}} \right)^{-\theta} + \alpha_I \left( \frac{\hat{P}_{t,t-1}}{P_{t,t}} \right)^{-\theta} F_{t,t-1}.
\]

Wage Dispersion

\[
F_{w,t} = \int_0^1 \left( \frac{W_t(k)}{\hat{W}_t} \right)^{-\theta_w} dk = (1 - \alpha_w) \left( \frac{W_t^*}{\hat{W}_t} \right)^{-\theta_w} + \alpha_w \left( \frac{W_{t-1}}{\hat{W}_t} \right)^{-\theta_w} F_{w,t-1}.
\]

Wage Aggregator

\[
\left( \frac{\hat{W}_t}{P_t} \right)^{1-\theta_w} = \int_0^1 \left( \frac{W_t(k)}{\hat{P}_t} \right)^{1-\theta_w} dk = (1 - \alpha_w) \left( \frac{W_t^*}{\hat{P}_t} \right)^{1-\theta_w} + \alpha_w \left( \frac{W_{t-1}}{\hat{P}_t} \right)^{1-\theta_w} \left( \frac{\hat{P}_{t-1}}{P_{t-1}} \right)^{1-\theta_w},
\]

Price Setting

\[
\left( \frac{\hat{P}_{t,t}}{P_{t,t}} \right) \left( \frac{\hat{P}_{t,t}}{P_t} \right) H_{t,t} = \frac{\mu_w}{A_t} \frac{W_t}{P_t} G_{t,t},
\]

\[
H_{t,t} = 1 + \alpha_I \hat{E}_t \left[ M_{t,t+1}^g \left( \frac{Y_{t,t+1}}{Y_{t,t}} \right) \left( \frac{\hat{P}_{t,t+1}}{\hat{P}_{t,t}} \right)^{-\theta} H_{t,t+1} \right],
\]

and \( G_{t,t} = 1 + \alpha_I \hat{E}_t \left[ M_{t,t+1}^g \left( \frac{Y_{t,t+1}}{Y_{t,t}} \right) \left( \frac{\hat{P}_{t,t}}{\hat{P}_{t,t+1}} \right)^{-\theta} \left( \frac{W_{t+1}}{\hat{W}_t} \right) \left( \frac{A_t}{A_{t+1}} \right) G_{t,t+1} \right].\)
Industry Output

\[ Y_{I,t} = \varphi_I Y_t \left( \frac{P_{I,t}}{P_t} \right)^{-\eta}, \quad Y_{I,t}^{\text{real}} = \varphi_I Y_t \left( \frac{P_{I,t}}{P_t} \right)^{1-\eta}. \]

Industry Inflation

\[ \frac{P_{I,t+1}}{P_{I,t}} = \frac{P_{I,t+1} P_t}{P_{I,t} P_{I,t}}. \]

Price Aggregators

\[ 1 = (1 - \alpha_I) \left( \frac{P^*_I, t}{P_I, t} \right)^{1-\theta} + \alpha_I \left( \frac{P_{I,t-1}}{P_{I,t}} \right)^{1-\theta} \]

\[ 1 = \varphi_H \left( \frac{P_{H,t}}{P_t} \right)^{1-\eta} + \varphi_L \left( \frac{P_{L,t}}{P_t} \right)^{1-\eta}. \]

Aggregate Labor Supply and Demand

\[ N^*_t = F_{w,t} N^d_t, \quad N^d_t = \frac{Y_t}{A_t} F_t. \]

Markups

\[ \mu_t = \frac{Y_t}{LI_t} = A_t \left( \frac{W_t}{P_t} \right)^{-1}, \quad \mu_I,t = \frac{P_{I,t} Y_{I,t}}{LI_{I,t}} = A_t \left( \frac{W_t}{P_t} \right)^{-1} \left( \frac{P_{I,t}}{P_t} \right). \]

Pricing Kernel

\[ M_{I,t+1} = \beta \left( \frac{Y_{I,t+1}}{Y_t} \right)^{-\psi} \left( \frac{1}{R_{Y,I,t+1}} \right)^{1-\frac{1-\eta}{\psi}}, \]

\[ R_{Y,L,t+1} = (1 - \nu_t) R_{C,t+1} + \nu_t R_{L^I*,t+1}, \]

\[ R_{Y,t+1} = C_{t+1} + S_{Y,t+1}, \quad R_{L^I*,t+1} = \frac{LI_{I,t+1} + S_{L^I*,t+1}}{S_{L^I*,t}}, \]

\[ \nu_t = \frac{\bar{\nu} S_{L^I*,t} - S_{Y,t}}{\bar{\nu} S_{L^I*,t}}. \]

Returns and Price-Payoff Ratios

\[ 1 = \mathbb{E}_t[M_{K,t+1} R_{K,t+1}], \quad \text{for } K = \{Y,D\}, \quad \text{at aggregate and industry level}, \]

\[ R_{Y,t+1} = (1 + P_{Y,t+1}) \left( \frac{Y_{t+1}}{Y_t} \right) \frac{1}{P_{Y,t}}, \quad R_{Y,I,t+1} = (1 + P_{Y,I,t+1}) \left( \frac{Y_{I,t+1}^{\text{real}}}{Y_{I,t}^{\text{real}}} \right) \frac{1}{P_{I,t}}, \]

\[ R_{D,t+1} = (1 + P_{D,t+1}) \left( \frac{Y_{t+1}}{Y_t} \right) \frac{1}{1 - \frac{\mu_{I,t}}{\mu_t}} \frac{1}{P_{D,t}}, \quad R_{D,I,t+1} = (1 + P_{D,I,t+1}) \left( \frac{Y_{I,t+1}^{\text{real}}}{Y_{I,t}^{\text{real}}} \right) \frac{1}{1 - \frac{\mu_{I,t}}{\mu_t}} \frac{1}{P_{D,I,t}} \]

where \( I \in \{H,L\} \).
F  Understanding the Mechanism

Excess expected stock returns

Under the assumption of log-normality, the risk-free rate in equation (7) satisfies

\[ R_{f,t} = \exp \left[ -E_t [m_{t,t+1}] + \frac{1}{2} \text{var}_t (m_{t,t+1}) \right]. \]

The price of claim X can be written as

\[ 1 = E_t [M_{t,t+1} R_{X,t+1}] = \exp \left[ E_t [m_{t,t+1} + \log R_{X,t+1}] + \frac{1}{2} \text{var}_t (m_{t,t+1} + \log R_{X,t+1}) \right] = R_{f,t}\exp \left[ \text{cov}_t (m_{t+1}, \log R_{X,t+1}) \right] E_t [R_{X,t+1}]. \]

Therefore, the expected excess return is given by

\[ \log E_t [R_{X,t+1}] - \log R_{f,t} = -\text{cov}_t (m_{t+1}, \log R_{X,t+1}) \]
\[ = -\text{cov}_t (m_{t,t+1}, \Delta x_{t+1}) - \text{cov}_t (m_{t,t+1}, \log (1 + P_{X,t+1})). \]

Cross-sectional stock returns

Consider the valuation of claims on industry output and profits that pay off only one-period in the future. Appendix B shows that real output in industry I is

\[ Y_{I,t} = \frac{\phi_I (P_{I,t} P_t) - \eta Y_{I,t}}{1 - \eta}. \]

It follows that differences in real output across industries are captured by the relative price \( P_{R,t} \), such that

\[ \frac{Y_{H,t}^{\text{real}}}{Y_{L,t}^{\text{real}}} = \left( \frac{\phi_H}{\phi_L} \right) P_{R,t}^{1-\eta}. \]

Under log-normality assumptions, the difference in expected returns of claims on industry output are

\[ -\text{cov}_t (m_{t,t+1}, \Delta y_{H,t+1}^{\text{real}} - \Delta y_{L,t+1}^{\text{real}}) = -(1 - \eta) \text{cov}_t (m_{t,t+1}, p_{R,t+1}), \]

where \( y_{I,t}^{\text{real}} = \log Y_{I,t}^{\text{real}} \), and \( p_{R,t+1} = \log P_{R,t+1} \). The difference depends on the elasticity \( \eta \) and the covariance of the marginal utility of consumption with the relative price. The industry with higher prices in periods of high marginal utility faces a lower product demand and then has higher expected returns on the output claim. Consider now the valuation of claims on industry profits. Profits in industry I are \( D_{I,t} = Y_{I,t}^{\text{real}} (1 - \frac{1}{\mu_{I,t}}) \), where the industry markup is

\[ \mu_{I,t} = \frac{Y_{I,t}^{\text{real}}}{L_{I,t}} = \frac{A_t}{F_{I,t}} \left( \frac{W_t}{P_t} \right)^{-1} \left( \frac{P_{I,t}}{P_t} \right). \]
It follows that the difference in markups is

\[ \frac{\mu_{H,t}}{\mu_{L,t}} = \left( \frac{F_{H,t}}{F_{L,t}} \right)^{-1} P_{R,t}. \]

This difference is captured by differences in the price distortions \( F_{I,t} \), and the relative price. It can be shown that the difference in expected returns on profit claims across industries can be approximated as

\[ -\text{cov}_t(m_{t,t+1}, \Delta d_{H,t+1} - \Delta d_{L,t+1}) \approx -\text{cov}_t(m_{t,t+1}, \Delta y_{\text{real},H,t+1} - \Delta y_{\text{real},L,t+1}) + (1 - \theta)\text{cov}_t(m_{t,t+1}, p_{R,t+1}) \]

\[ = -(\theta - \eta)\text{cov}_t(m_{t,t+1}, p_{R,t+1}). \]

Therefore, the dynamics of the relative price implied by the two industry goods and the elasticities \( \eta \) and \( \theta \) capture differences in expected returns on output and profit claims. These differences are the result of differences in the covariance of output and markups with the pricing kernel across industries.
G Log-linear solution of Equity Premium

In this section, we provide the analytical solution for the price-dividend ratio using the log-linear approximation. We show that without rigidity, our model with an EIS \(< 1\) leads to a negative equity premium; with rigidities, the model generates a positive equity premium with the same EIS.

The model without rigidities

Without rigidities, markup is constant and the returns on the consumption claim, the dividend claim, and the labor income claim are the same. As shown in Campbell and Shiller (1988), the return on the consumption claim is given by

\[ r_{c,t+1} = \Delta c_{t+1} + \kappa_0 + \kappa_1 p_{c,t+1} - p_{c,t} \]

where \(\kappa_1\) is a constant less than one,

\( p_{c,t} \) is the log of price-consumption ratio.

As shown in Appendix D, the pricing kernel can be written as

\[ m_{t,t+1} = \left( \frac{1 - \gamma}{1 - \psi} \right) \log(\beta) - \psi \left( \frac{1 - \gamma}{1 - \psi} \right) \Delta c_{t+1} + \left( \frac{\psi - \gamma}{1 - \psi} \right) r_{c,t+1} , \]

where

\[ \Delta c_{t+1} = \Delta y^f_t = \Delta a_{t+1} + \frac{1 + \omega}{\omega + \psi} \Delta z_t . \]

Note that the last term in \( m_{t,t+1} \) should be the weighted average of returns to the consumption claim and the labor income claim, which is the same as the return on the consumption claim in an economy without rigidities. We conjecture that the log price-consumption ratio follows

\[ p_{c,t} = p_0 + p_a \Delta a_t + p_z \Delta z_t . \]

The return on consumption claim must satisfy the following Euler equation

\[ \mathbb{E}_t \left[ e^{m_{t,t+1} + r_{c,t+1}} \right] = 1 \]

for any values of the state variables \( \Delta a_t \) and \( z_t \). Therefore, in the above Euler equation, all terms that involves \( \Delta a_t \)

\( \phi_a (1 - \psi) + (\kappa_1 \phi_a - 1) p_a = 0 \)

and all terms that involves \( z_t \)

\( (\phi_z - 1)(1 - \psi)(1 + \omega) - [\phi_z \kappa_1 - 1] p_z = 0 \).

It is straightforward to show that

\( p_a = \frac{\phi_a (1 - \psi)}{1 - \kappa_1 \phi_a} \)

and

\[ p_z = \frac{(\phi_z - 1)(1 - \psi)(1 + \omega)/(\omega + \psi)}{1 - \kappa_1 \phi_z} . \]

With EIS less than one, \( \psi \) is larger than one, leading to a negative \( p_a \) and a positive \( p_z \). This result shows that when there is a positive permanent productivity shock, price-consumption ratio decreases while with a positive
transitory shock, price-consumption ratio increases. Therefore, the risk premium of consumption claim to the permanent shock is negative but positive to the transitory shock.

The model with rigidities

With rigidities, the markup is not constant anymore and the labor supply becomes time-varying. Consequently, the consumption growth also depends on the changes in labor supply:

$$\Delta c_{t+1} = \Delta a_{t+1} + \Delta z_t + \Delta n_{t+1},$$

where we assume that

$$n_t = n_a \Delta a_t + n_z z_t.$$

To simplify the analysis, we assume that

$$r_{c,t+1} \approx r_{CL,t+1}$$

so that we can still write the pricing kernel as

$$m_{t,t+1} = \left(1 - \frac{\gamma}{1 - \psi}\right) \log(\beta) - \psi \left(1 - \frac{\gamma}{1 - \psi}\right) \Delta c_{t+1} + \left(\psi - \frac{\gamma}{1 - \psi}\right) r_{c,t+1}.$$ 

Following the same approach, we can get

$$p_a = \frac{[\phi_a - (1 - \phi_a)n_a](1 - \psi)}{1 - \kappa_1 \phi_a}$$

$$p_z = \frac{(\phi - 1)(1 - \psi)(1 + n_z)}{1 - \kappa_1 \phi_z}.$$ 

When \(n_a\) is positive and large enough, \(p_a\) becomes positive, which is what happens with the existence of wage rigidities. With price rigidities, even though \(n_a\) is positive, but its magnitude is not large enough, hence we still have a negative \(p_a\). But combined with the negative effect on consumption, the return on consumption claims \(r_{c,t+1}\) is positive. Finally, it is straightforward to show that \(p_z\) is positive.

It is easy to show that the persistence of consumption growth is lower than the persistence without rigidities, i.e., \(\phi_a\).

$$cov(\Delta y_{t+1}, \Delta y_t) = cov_t((n_a + 1)\Delta a_{t+1} - n_a \Delta a_t, (n_a + 1)\Delta a_t - n_a \Delta a_{t-1})$$

$$= [(n_a + 1)^2 + n_a^2] \phi_a - n_a(n_a + 1)\phi_a^2 - n_a(n_a + 1)$$

$$var(\Delta y_t) = (n_a + 1)^2 + n_a - 2n_a(n_a + 1)\phi_a$$

$$\rho_y = \phi_a + \frac{n_a(n_a + 1)[\phi_a^2 - 1]}{(n_a + 1)^2 + n_a - 2n_a(n_a + 1)\phi_a} < \phi_a$$

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Table 1: **Baseline Parameter Values**

This table contains the parameter values for the benchmark calibration at the quarterly frequency. Volatilities are presented at per cent per quarter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_a$</td>
<td>long run growth rate of the productivity</td>
<td>0.4695%</td>
</tr>
<tr>
<td>$\beta$</td>
<td>Subjective discount factor</td>
<td>1.0018</td>
</tr>
<tr>
<td>$\psi$</td>
<td>Inverse of elasticity of intertemporal substitution</td>
<td>6.5</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Risk aversion parameter</td>
<td>111</td>
</tr>
<tr>
<td>$\omega$</td>
<td>Inverse of Frisch labor elasticity</td>
<td>0.35</td>
</tr>
<tr>
<td>$\varphi_H$</td>
<td>Weight of industry $H$ good in the basket</td>
<td>0.5</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Elasticity of substitution of differentiated goods</td>
<td>6</td>
</tr>
<tr>
<td>$\eta$</td>
<td>Elasticity of substitution of industry goods</td>
<td>6</td>
</tr>
<tr>
<td>$\theta_w$</td>
<td>Elasticity of substitution of labor types</td>
<td>21</td>
</tr>
<tr>
<td>$\alpha_H$</td>
<td>Price rigidity parameter for industry $H$</td>
<td>0.8</td>
</tr>
<tr>
<td>$\alpha_L$</td>
<td>Price rigidity parameter for industry $L$</td>
<td>0</td>
</tr>
<tr>
<td>$\tilde{\alpha}$</td>
<td>Wage rigidity parameter</td>
<td>0.78</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Interest-rate smoothing coefficient in policy rule</td>
<td>0.63</td>
</tr>
<tr>
<td>$\bar{i}$</td>
<td>Constant in the policy rule</td>
<td>0.029</td>
</tr>
<tr>
<td>$\nu_\pi$</td>
<td>Response to inflation in the policy rule</td>
<td>1.5</td>
</tr>
<tr>
<td>$\nu_x$</td>
<td>Response to output gap in the policy rule</td>
<td>0.125</td>
</tr>
<tr>
<td>$\phi_u$</td>
<td>Autocorrelation of policy shock</td>
<td>0.564</td>
</tr>
<tr>
<td>$\sigma_u$</td>
<td>Conditional volatility of policy shock</td>
<td>0.151</td>
</tr>
<tr>
<td>$\phi_a$</td>
<td>Autocorrelation of permanent productivity shock</td>
<td>0.391</td>
</tr>
<tr>
<td>$\sigma_a$</td>
<td>Conditional volatility of permanent productivity shock</td>
<td>0.202</td>
</tr>
<tr>
<td>$\phi_z$</td>
<td>Autocorrelation of transitory productivity shock</td>
<td>0.985</td>
</tr>
<tr>
<td>$\sigma_z$</td>
<td>Conditional volatility of permanent productivity shock</td>
<td>0.102</td>
</tr>
</tbody>
</table>
Table 2: **Data and Model Volatility.**
The table contains the total volatility of macroeconomic variables and the volatility explained by the model shocks in the data and the model. The variance decomposition is obtained from Altig et al. (2011). Columns labeled “All” refer to the volatility explained by policy and productivity shocks. Columns labeled “Prod.” refer to productivity shocks (permanent and transitory). The column labeled “Perm.” refers to permanent productivity shocks. The column labeled “Trans.” refers to transitory productivity shocks. The row labeled $\hat{c}_t$ refers to de-trended log consumption. Volatilities are measured in per cent per quarter.

### Panel A: Macroeconomic moments

<table>
<thead>
<tr>
<th></th>
<th>Total volatility</th>
<th></th>
<th>Volatility explained by the shocks</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$i_t$</td>
<td>0.648</td>
<td></td>
<td>0.242</td>
<td>0.092</td>
<td></td>
<td>0.244</td>
<td>0.093</td>
</tr>
<tr>
<td>$\pi_t$</td>
<td>0.340</td>
<td></td>
<td>0.076</td>
<td>0.118</td>
<td></td>
<td>0.073</td>
<td>0.112</td>
</tr>
<tr>
<td>$c_t$</td>
<td>0.760</td>
<td></td>
<td>0.170</td>
<td>0.215</td>
<td></td>
<td>0.170</td>
<td>0.217</td>
</tr>
<tr>
<td>$n_t^c$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.170</td>
<td>0.485</td>
</tr>
<tr>
<td>$\Delta c_t$</td>
<td>0.373</td>
<td></td>
<td></td>
<td>0.123</td>
<td>0.352</td>
<td>0.350</td>
<td>0.033</td>
</tr>
</tbody>
</table>

### Panel B: Asset pricing moments

<table>
<thead>
<tr>
<th></th>
<th>Data (1982-2008)</th>
<th></th>
<th>Model</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Sharpe ratio</td>
<td>0.213</td>
<td></td>
<td>0.213</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3: Model Summary Statistics for Different Specifications.

The baseline parameter values are presented in Table 1. “Benchmark” indicates an economy with both price and wage rigidities. “Only A” indicates only permanent productivity shocks ($\sigma_z = \sigma_u = 0$). “Only Z” indicates only transitory productivity shocks ($\sigma_a = \sigma_u = 0$). “Only u” indicates only policy shocks ($\sigma_H = \sigma_L = \tilde{\alpha} = 0$). “No Rig.” indicates no price and wage rigidities ($\alpha_H = \alpha_L = 0$). “Only WR” indicates no price rigidities ($\alpha_H = 0$). “Only PR” indicates no wage rigidities ($\tilde{\alpha} = 0$). The expected excess returns and the Sharpe ratio for asset b are $XR_{b,t} = R_{b,t} + 1 - R_{f,t}$, and $SR_b = \frac{E[XR_{b,t}]}{\sigma(XR_{b,t})}$, respectively. Volatilities and returns are measured in per cent per quarter.

<table>
<thead>
<tr>
<th></th>
<th>Data</th>
<th>Benchmark</th>
<th>Only A</th>
<th>Only Z</th>
<th>Only u</th>
<th>No Rig.</th>
<th>Only WR</th>
<th>Only PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma(\pi)$</td>
<td>0.341</td>
<td>0.133</td>
<td>0.092</td>
<td>0.064</td>
<td>0.073</td>
<td>0.863</td>
<td>0.210</td>
<td>0.594</td>
</tr>
<tr>
<td>$\sigma(y)$</td>
<td>-</td>
<td>0.275</td>
<td>0.167</td>
<td>0.138</td>
<td>0.170</td>
<td>0.117</td>
<td>0.280</td>
<td>0.146</td>
</tr>
<tr>
<td>$\sigma(x)$</td>
<td>0.763</td>
<td>0.239</td>
<td>0.167</td>
<td>0.024</td>
<td>0.170</td>
<td>0.000</td>
<td>0.243</td>
<td>0.089</td>
</tr>
<tr>
<td>$\sigma(w)$</td>
<td>-</td>
<td>0.580</td>
<td>0.113</td>
<td>0.563</td>
<td>0.082</td>
<td>0.593</td>
<td>0.593</td>
<td>0.845</td>
</tr>
<tr>
<td>$\sigma(i)$</td>
<td>0.647</td>
<td>0.261</td>
<td>0.072</td>
<td>0.059</td>
<td>0.244</td>
<td>0.426</td>
<td>0.255</td>
<td>0.262</td>
</tr>
<tr>
<td>$\sigma(r)$</td>
<td>-</td>
<td>0.303</td>
<td>0.047</td>
<td>0.038</td>
<td>0.297</td>
<td>0.559</td>
<td>0.304</td>
<td>0.389</td>
</tr>
<tr>
<td>$\sigma(\log \mu)$</td>
<td>-</td>
<td>0.153</td>
<td>0.113</td>
<td>0.060</td>
<td>0.083</td>
<td>0.000</td>
<td>0.000</td>
<td>0.611</td>
</tr>
<tr>
<td>$\sigma(\hat{d})$</td>
<td>0.160</td>
<td>0.865</td>
<td>0.702</td>
<td>0.401</td>
<td>0.309</td>
<td>0.117</td>
<td>0.280</td>
<td>2.968</td>
</tr>
<tr>
<td>$\sigma(\Delta c)$</td>
<td>0.373</td>
<td>0.373</td>
<td>0.350</td>
<td>0.033</td>
<td>0.123</td>
<td>0.221</td>
<td>0.383</td>
<td>0.262</td>
</tr>
<tr>
<td>$\sigma(\Delta d)$</td>
<td>-</td>
<td>0.673</td>
<td>0.621</td>
<td>0.240</td>
<td>0.097</td>
<td>0.221</td>
<td>0.383</td>
<td>2.183</td>
</tr>
<tr>
<td>$\rho(\pi, x)$</td>
<td>-0.141</td>
<td>-0.564</td>
<td>-0.911</td>
<td>-0.845</td>
<td>-0.337</td>
<td>0.611</td>
<td>-0.633</td>
<td>0.707</td>
</tr>
<tr>
<td>$\rho(\Delta c, \Delta d)$</td>
<td>-</td>
<td>0.906</td>
<td>0.987</td>
<td>0.986</td>
<td>0.397</td>
<td>1.000</td>
<td>1.000</td>
<td>-0.613</td>
</tr>
<tr>
<td>$\rho(\Delta c, \Delta w)$</td>
<td>-</td>
<td>0.808</td>
<td>0.858</td>
<td>0.942</td>
<td>0.689</td>
<td>0.941</td>
<td>0.828</td>
<td>0.875</td>
</tr>
<tr>
<td>$\rho(\Delta d, \Delta w)$</td>
<td>-</td>
<td>0.814</td>
<td>0.832</td>
<td>0.874</td>
<td>-0.392</td>
<td>0.941</td>
<td>0.828</td>
<td>-0.904</td>
</tr>
<tr>
<td>$ar(\pi)$</td>
<td>0.420</td>
<td>0.473</td>
<td>0.403</td>
<td>0.251</td>
<td>0.754</td>
<td>-0.003</td>
<td>0.354</td>
<td>-0.012</td>
</tr>
<tr>
<td>$ar(x)$</td>
<td>0.916</td>
<td>0.606</td>
<td>0.465</td>
<td>0.839</td>
<td>0.737</td>
<td>-</td>
<td>0.589</td>
<td>0.703</td>
</tr>
<tr>
<td>$ar(i)$</td>
<td>0.952</td>
<td>0.852</td>
<td>0.819</td>
<td>0.837</td>
<td>0.855</td>
<td>0.421</td>
<td>0.821</td>
<td>0.347</td>
</tr>
<tr>
<td>$ar(r)$</td>
<td>-</td>
<td>0.838</td>
<td>0.868</td>
<td>0.714</td>
<td>0.840</td>
<td>0.391</td>
<td>0.813</td>
<td>0.383</td>
</tr>
<tr>
<td>$ar(\Delta c)$</td>
<td>0.401</td>
<td>-0.010</td>
<td>-0.002</td>
<td>-0.097</td>
<td>-0.066</td>
<td>0.388</td>
<td>-0.017</td>
<td>0.219</td>
</tr>
<tr>
<td>$ar(\Delta d)$</td>
<td>-</td>
<td>0.057</td>
<td>0.075</td>
<td>-0.129</td>
<td>0.439</td>
<td>0.388</td>
<td>-0.017</td>
<td>-0.161</td>
</tr>
<tr>
<td>$ar(\Delta w)$</td>
<td>-</td>
<td>0.459</td>
<td>0.500</td>
<td>0.155</td>
<td>0.544</td>
<td>0.320</td>
<td>0.320</td>
<td>-0.105</td>
</tr>
<tr>
<td>$E[R_{Y,t}^2] - 1$</td>
<td>1.300</td>
<td>1.295</td>
<td>1.300</td>
<td>2.931</td>
<td>2.938</td>
<td>1.726</td>
<td>1.256</td>
<td>1.628</td>
</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>-</td>
<td>0.169</td>
<td>0.164</td>
<td>0.002</td>
<td>0.003</td>
<td>-0.176</td>
<td>0.200</td>
<td>-0.065</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>-</td>
<td>0.182</td>
<td>0.177</td>
<td>0.003</td>
<td>0.003</td>
<td>-0.176</td>
<td>0.200</td>
<td>-0.097</td>
</tr>
<tr>
<td>$\sigma(R_Y)$</td>
<td>-</td>
<td>0.914</td>
<td>0.455</td>
<td>0.142</td>
<td>0.780</td>
<td>0.764</td>
<td>0.933</td>
<td>0.501</td>
</tr>
<tr>
<td>$\sigma(R_D)$</td>
<td>-</td>
<td>0.912</td>
<td>0.491</td>
<td>0.162</td>
<td>0.751</td>
<td>0.764</td>
<td>0.933</td>
<td>0.497</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>-</td>
<td>0.197</td>
<td>0.361</td>
<td>0.018</td>
<td>0.004</td>
<td>-0.350</td>
<td>0.227</td>
<td>-0.217</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>-</td>
<td>0.213</td>
<td>0.361</td>
<td>0.018</td>
<td>0.004</td>
<td>-0.350</td>
<td>0.227</td>
<td>-0.331</td>
</tr>
</tbody>
</table>

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Table 4: Contribution of Individual Shocks to Expected Excess Returns.
The baseline parameter values are presented in Table 1. “Benchmark” indicates an economy with both price and wage rigidities. “No Rig.” indicates no price and wage rigidities ($\alpha_H = \alpha_L = \tilde{\alpha} = 0$). “Only WR” indicates no price rigidities ($\alpha_H = \alpha_L = 0$). “Only PR” indicates no wage rigidities ($\tilde{\alpha} = 0$). Expected excess returns and Sharpe ratios for asset $b$ are $XR_{b,t} = R_{b,t+1} - R_{f,t}$, and $SR_b = \frac{E[XR_{b,t+1}]}{\sigma(XR_{b,t})}$, respectively. Volatilities and returns are measured in per cent per quarter.

<table>
<thead>
<tr>
<th></th>
<th>Benchmark</th>
<th>No Rig.</th>
<th>Only WR</th>
<th>Only PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: Only $A^p$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>0.164</td>
<td>-0.177</td>
<td>0.194</td>
<td>-0.067</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.177</td>
<td>-0.177</td>
<td>0.194</td>
<td>-0.099</td>
</tr>
<tr>
<td>$\sigma(R_Y)$</td>
<td>0.455</td>
<td>0.761</td>
<td>0.542</td>
<td>0.434</td>
</tr>
<tr>
<td>$\sigma(R_D)$</td>
<td>0.491</td>
<td>0.761</td>
<td>0.542</td>
<td>0.479</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.361</td>
<td>-0.355</td>
<td>0.363</td>
<td>-0.358</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.361</td>
<td>-0.355</td>
<td>0.363</td>
<td>-0.358</td>
</tr>
<tr>
<td>Panel B: Only $Z$</td>
<td></td>
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</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>0.002</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.003</td>
<td>0.001</td>
<td>0.004</td>
<td>0.001</td>
</tr>
<tr>
<td>$\sigma(R_Y)$</td>
<td>0.142</td>
<td>0.065</td>
<td>0.202</td>
<td>0.063</td>
</tr>
<tr>
<td>$\sigma(R_D)$</td>
<td>0.162</td>
<td>0.065</td>
<td>0.202</td>
<td>0.067</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.018</td>
<td>0.014</td>
<td>0.019</td>
<td>0.014</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.018</td>
<td>0.014</td>
<td>0.019</td>
<td>0.014</td>
</tr>
<tr>
<td>Panel C: Only $u$</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>0.003</td>
<td>0.000</td>
<td>0.002</td>
<td>0.001</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.003</td>
<td>0.000</td>
<td>0.002</td>
<td>0.000</td>
</tr>
<tr>
<td>$\sigma(R_Y)$</td>
<td>0.780</td>
<td>0.000</td>
<td>0.733</td>
<td>0.243</td>
</tr>
<tr>
<td>$\sigma(R_D)$</td>
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<td>0.000</td>
<td>0.733</td>
<td>0.115</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.004</td>
<td>-</td>
<td>0.003</td>
<td>0.003</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.004</td>
<td>-</td>
<td>0.003</td>
<td>0.003</td>
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</table>
Table 5: **Summary Statistics for Industry Returns.**

“Benchmark” indicates an economy with both price and wage rigidities. “Only PR” indicates no wage rigidities ($\tilde{a}=0$). Expected excess returns and Sharpe ratios for asset $b$ are $XR_{b,t} = R_{b,t+1} - R_{f,t}$, and $SR_b = \frac{E[XR_{b,t}]}{\sigma(XR_{b,t})}$, respectively. Volatilities and returns are measured in per cent per quarter.

<table>
<thead>
<tr>
<th></th>
<th>Benchmark</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\theta &gt; \eta = 2$</td>
<td>$\theta = \eta = 6$</td>
<td>$\theta &lt; \eta = 20$</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>0.169</td>
<td>0.169</td>
<td>0.169</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{Y,H,t+1}]$</td>
<td>0.166</td>
<td>0.156</td>
<td>0.118</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{Y,L,t+1}]$</td>
<td>0.172</td>
<td>0.182</td>
<td>0.220</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.182</td>
<td>0.182</td>
<td>0.182</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{D,H,t+1}]$</td>
<td>0.193</td>
<td>0.183</td>
<td>0.145</td>
<td></td>
</tr>
<tr>
<td>$E[XR_{D,L,t+1}]$</td>
<td>0.172</td>
<td>0.182</td>
<td>0.220</td>
<td></td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.197</td>
<td>0.197</td>
<td>0.197</td>
<td></td>
</tr>
<tr>
<td>$SR_{Y,H}$</td>
<td>0.194</td>
<td>0.180</td>
<td>0.132</td>
<td></td>
</tr>
<tr>
<td>$SR_{Y,L}$</td>
<td>0.200</td>
<td>0.213</td>
<td>0.253</td>
<td></td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.213</td>
<td>0.213</td>
<td>0.213</td>
<td></td>
</tr>
<tr>
<td>$SR_{D,H}$</td>
<td>0.225</td>
<td>0.213</td>
<td>0.167</td>
<td></td>
</tr>
<tr>
<td>$SR_{D,L}$</td>
<td>0.200</td>
<td>0.213</td>
<td>0.253</td>
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</table>
Table 6: Summary Statistics for Models with Different Reaction Coefficients in the Policy Rule.

“Benchmark” indicates an economy with both price and wage rigidities. “Only WR” indicates no price rigidities ($\alpha_H = \alpha_L = 0$). “Only PR” indicates no wage rigidities ($\tilde{\alpha} = 0$). Expected excess returns and Sharpe ratios for asset $b$ are $XR_{b,t} = R_{b,t+1} - R_{f,t}$, and $SR_b = \frac{E[XR_{b,t}]}{\sigma(XR_{b,t})}$, respectively. Volatilities and returns are measured in per cent per quarter.

<table>
<thead>
<tr>
<th></th>
<th>Benchmark</th>
<th>Only WR</th>
<th>Only PR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panel A: $t_\pi$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(\pi)$</td>
<td>0.133</td>
<td>0.127</td>
<td>0.209</td>
</tr>
<tr>
<td>$\sigma(x)$</td>
<td>0.239</td>
<td>0.238</td>
<td>0.243</td>
</tr>
<tr>
<td>$\sigma(\Delta c)$</td>
<td>0.373</td>
<td>0.375</td>
<td>0.383</td>
</tr>
<tr>
<td>$\sigma(\Delta d)$</td>
<td>0.672</td>
<td>0.671</td>
<td>0.383</td>
</tr>
<tr>
<td>$E[XR_{Y,t+1}]$</td>
<td>0.169</td>
<td>0.179</td>
<td>0.199</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.182</td>
<td>0.192</td>
<td>0.199</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.197</td>
<td>0.210</td>
<td>0.227</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.213</td>
<td>0.225</td>
<td>0.227</td>
</tr>
<tr>
<td>Panel B: $t_x$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\sigma(\pi)$</td>
<td>0.133</td>
<td>0.133</td>
<td>0.208</td>
</tr>
<tr>
<td>$\sigma(x)$</td>
<td>0.249</td>
<td>0.239</td>
<td>0.251</td>
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<tr>
<td>$\sigma(\Delta c)$</td>
<td>0.379</td>
<td>0.373</td>
<td>0.389</td>
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<tr>
<td>$\sigma(\Delta d)$</td>
<td>0.668</td>
<td>0.672</td>
<td>0.389</td>
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<tr>
<td>$E[XR_{Y,t+1}]$</td>
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<td>0.169</td>
<td>0.210</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.192</td>
<td>0.182</td>
<td>0.210</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.199</td>
<td>0.197</td>
<td>0.229</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.214</td>
<td>0.213</td>
<td>0.229</td>
</tr>
<tr>
<td>Panel C: $\rho$</td>
<td>0.63</td>
<td>0.83</td>
<td>0.63</td>
</tr>
<tr>
<td>$\sigma(\pi)$</td>
<td>0.133</td>
<td>0.255</td>
<td>0.209</td>
</tr>
<tr>
<td>$\sigma(x)$</td>
<td>0.239</td>
<td>0.406</td>
<td>0.243</td>
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<tr>
<td>$\sigma(\Delta c)$</td>
<td>0.373</td>
<td>0.419</td>
<td>0.383</td>
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<tr>
<td>$\sigma(\Delta d)$</td>
<td>0.672</td>
<td>0.698</td>
<td>0.383</td>
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<tr>
<td>$E[XR_{Y,t+1}]$</td>
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<td>0.160</td>
<td>0.199</td>
</tr>
<tr>
<td>$E[XR_{D,t+1}]$</td>
<td>0.182</td>
<td>0.171</td>
<td>0.199</td>
</tr>
<tr>
<td>$SR_Y$</td>
<td>0.197</td>
<td>0.112</td>
<td>0.227</td>
</tr>
<tr>
<td>$SR_D$</td>
<td>0.213</td>
<td>0.127</td>
<td>0.227</td>
</tr>
</tbody>
</table>
Table 7: **Variance Decomposition of Asset Returns.**
“Benchmark” indicates an economy with both price and wage rigidities. “Only WR” indicates no price rigidities ($\alpha_H = \alpha_L = 0$). “Only PR” indicates no wage rigidities ($\tilde{\alpha}=0$).

<table>
<thead>
<tr>
<th></th>
<th>$\varepsilon_u$</th>
<th>$\varepsilon_a$</th>
<th>$\varepsilon_z$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Benchmark model</strong></td>
<td></td>
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</tr>
<tr>
<td>$m$</td>
<td>0.02</td>
<td>99.74</td>
<td>0.23</td>
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<tr>
<td>$R_Y$</td>
<td>72.79</td>
<td>24.81</td>
<td>2.40</td>
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<tr>
<td>$R_D$</td>
<td>67.78</td>
<td>29.05</td>
<td>3.17</td>
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<tr>
<td><strong>No rigidities</strong></td>
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<td></td>
</tr>
<tr>
<td>$m$</td>
<td>0.00</td>
<td>99.84</td>
<td>0.16</td>
</tr>
<tr>
<td>$R_Y$</td>
<td>0.00</td>
<td>99.27</td>
<td>0.73</td>
</tr>
<tr>
<td>$R_D$</td>
<td>0.00</td>
<td>99.27</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Only WR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>0.01</td>
<td>99.73</td>
<td>0.26</td>
</tr>
<tr>
<td>$R_Y$</td>
<td>61.61</td>
<td>33.68</td>
<td>4.70</td>
</tr>
<tr>
<td>$R_D$</td>
<td>61.61</td>
<td>33.68</td>
<td>4.70</td>
</tr>
<tr>
<td><strong>Only PR</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$m$</td>
<td>0.01</td>
<td>99.83</td>
<td>0.16</td>
</tr>
<tr>
<td>$R_Y$</td>
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<td>$R_D$</td>
<td>5.37</td>
<td>92.79</td>
<td>1.84</td>
</tr>
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</table>
Figure 1: Impulse responses to a one-standard deviation negative permanent productivity shock for different macroeconomic variables and asset returns. The parameter values are presented in table 1.
Figure 2: Impulse responses to a one-standard deviation negative transitory productivity shock for different macroeconomic variables and asset returns. The parameter values are presented in table 1.
Figure 3: Impulse responses to a one-standard deviation positive policy shock for different macroeconomic variables and asset returns. The parameter values are presented in table 1.