Identifying the Role of Risk Shocks in the Business Cycle Using Stock Price Data*

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Abstract

I analyze the sources of business cycle fluctuations in an estimated DSGE model similar to Smets and Wouters (2007) appended with stock market and tax features similar to McGrattan and Prescott (2005). In the model, risk shocks drive a wedge between the risk-free rate and the required return on stocks, and affect the cost of capital incurred by firms. I use corporate market value and dividend data in the Bayesian estimation to identify these risk shocks. Variance decomposition exercises show that these shocks account for most of the volatility in the stock market at the business cycle frequencies, as well as a substantial part of the developments in the real variables such as output and investment. Historical decomposition points to the important role played by these shocks in the run up of stock prices and output in the late 90's and their reversal in the 2000's, especially during the recent recession.

Keywords: risk shocks, business cycles, stock market, DSGE, Bayesian estimation.

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"Alas, the fact that almost all stock price movements are due to changing expected excess returns rather than to changing expectations of future dividend growth means that we have to tie stock movements to the macroeconomy entirely through harder-to-measure time-varying risk-premia rather than easier-to-understand cash flows." – John H. Cochrane (2008)

1 Introduction

The finance literature on the forecastibility of stock returns has concluded that stock market movements are by-and-large not due to changes in expected future cash flows of firms, but due to changes in the risk-premium, i.e. how these cash flows are discounted by stock market participants (Cochrane, 2008).[1] These changes in risk-premia also have important implications for real variables in the economy, and provide the main link between stock prices and macroeconomic variables [see the quote from Cochrane (2008) above]. An important source of financing for corporate investment is equity, which includes the use of internal funds of corporations as well as new stock issues. Equity prices determine the (opportunity) cost of this type of financing, since retained earnings can alternatively be used to repurchase shares or pay dividends. As such, changes in stock prices alter the cost-of-capital incurred by firms when they finance investment (Tobin, 1969, and Tobin and Brainard, 1977).

This cost-of-capital channel of stock prices is all the more relevant for U.S. corporations which are predominantly financed through equity. The top line in Figure 1 plots credit market liabilities of U.S. non-financial corporations as a percent of the sum of equity and credit market liabilities in their balance sheets.[2] By this measure, debt-financing accounts for about a third of total financing, and equity-financing accounts for about two-thirds. In the bottom line of Figure 1, I follow McGrattan and Prescott (2005), and take into account all financial liabilities (including items such as trade payables), but net out all financial assets to obtain a measure of *net debt*. By this measure, debt-financing accounts for only 15% of total financing, and its importance has declined in the last 20

[1] Cochrane (2008) offers a comprehensive summary of the finance literature tying stock returns to the real economy. See his Section 2.3 and the papers cited there for more on stock market forecastibility. Cochrane (1994) interprets shocks to stock prices as shocks to the discount rate or expected return.

[2] The data are obtained from the Flow of Funds Accounts of the Federal Reserve Board.

years. Note that the series plotted in Figure 1 are *stock* measures as opposed to *flow* measures; i.e. they refer to financing of all past investments and do not necessarily reflect how corporations are financing investment on the margin.[3] In Figure 2, I plot the *flow* counterparts of these series. By both measures, on average, about a fourth of new corporate investment is being financed through issuance of new debt and three fourths are being financed through equity (i.e. the use of internal funds and net new equity issues). I therefore conclude that equity-financing is an integral part of the corporate financing mix used by U.S. corporations, and the expected return on equity is an important indicator of their cost-of-capital.[4]

In this paper, I analyze the contribution of shocks to risk-premia, *risk shocks* for short, to business cycle fluctuations and stock market volatility in an estimated dynamic stochastic general equilibrium (DSGE) model.[5] The core of the model is similar to Christiano et al. (2005) and Smets and Wouters (2007; SW hereafter); a closed economy model with a rich set of nominal and real rigidities (such as sticky prices and wages, price and wage indexation, habit formation in consumption, and costly investment adjustment) and various exogenous disturbances including risk shocks. To get at stock prices directly, I include firm-specific capital, whereby the capital stock is owned by firms which are in turn owned by households through shares (McGrattan and Prescott, 2005). Risk shocks drive a wedge between the policy rate set by the central bank and the required return on stocks, and also affect the consumption behavior of households and the cost of capital incurred by firms. To better identify these shocks, I use corporate market value and dividend data in the Bayesian estimation, along with several other variables used in SW. I then analyze the implications of the model using impulse responses and variance decompositions. The forecast error variance decomposition and historical decomposition exercises indicate that risk shocks capture a substantial part of the volatility in real variables such as output and investment. Risk shocks are

[3]Note that these stock measures may also be biased against debt-financing since most debt items are recorded on a book-value basis in the Flow of Funds, but equity is recorded on market value.

[4]Note that there is significant cyclicality in the financing-mix used by corporations, therefore using a weighted cost-of-capital measure which takes into account debt as well as equity could be more appropriate in the estimation of my model. I leave this for further research.

[5]DSGE models were initiated by the seminal work of Kydland and Prescott (1982), which explored the role of productivity shocks in generating business cycles. Since then, these models have been expanded to include many more shocks and various nominal and real rigidities, and have become commonplace tools in analyzing different sources of economic fluctuations, the impact of fiscal and monetary policy on macroeconomic variables, and forecasting. See Tovar (2008) for a recent discussion of these models and their use in central banks around the world.

also important for explaining stock market volatility, but only at the business cycle frequencies (i.e. only when HP-filtered data is used in the estimation).

With first-differenced data, stock market volatility is captured mainly by shocks to investment-specific technological change, and not by shocks to the risk-premium. An important reason for this result is the divergence of investment and corporate market values in the mid-70's and 80's (see Figure 3). This is a period of fast investment-specific technological change, especially in the form of new information technologies (Greenwood and Jovanovic, 1999) and energy-saving technologies (Alpanda and Peralta-Alva, 2009). Additionally, the government substantially increased investment tax credits and allowed generous expensing of new investment from taxable income (McGrattan and Prescott, 2005). These forces caused an increase in investment, but a sharp and persistent decline in corporate market value and Tobin's average-q as the value of installed capital fell relative to its replacement cost (i.e. old capital owned by firms became relatively "obsolete"). In my model, these patterns are captured by large and persistent shocks to investment-specific technological change, since these shocks are the only ones that can simultaneously generate an increase in investment and a reduction in stock prices. To abstract from some of these low frequency movements in asset prices, I also estimate the model using HP-filtered data. Variance decomposition exercises with HP-filtered data show that stock market volatility is mainly captured by shocks to risk premia, consistent with the finance literature.

The recent recession in the U.S. has highlighted the potential role of financial factors in generating and amplifying business cycles. The notion that financial markets and asset prices do not just passively reflect the conditions on the *real* side of the economy, but may directly affect those very same conditions has long been recognized in the literature and has been appended to medium-size DSGE models.[6] The main innovation in this paper is to identify this two-way link between the real side of the economy and financial markets, and the role of risk shocks, using stock market and dividend data in the estimation. SW introduce risk shocks into their model to generate positive

[6] The theoretical introduction of these mechanisms into DSGE models are due to Kiyotaki and Moore (1997) and Bernanke et al. (1999). There is also a related literature that looks at the importance of bank intermediation for providing liquidity to firms (c.f. Christiano et al., 2005). Nevertheless, there has recently been a flurry of criticism on the current state of macroeconomic theory and its (alleged) lack of emphasis on financial matters. See for example the lead article in The Economist (July 16, 2009) titled *What Went Wrong with Economics?*.

co-movement between consumption and investment, but identify these shocks in their estimation only through non-financial variables. The same is true for most papers emanating from this literature, important exceptions being Christiano et al. (2009) and Gilchrist et al. (2009). They imbed the *financial accelerator* mechanism of Bernanke et al. (1999) into a New Keynesian DSGE model, and identify risk premia using corporate credit spreads as an observable in their estimation. In their models, shocks that increase the net worth of firms reduce the cost-of-capital, which generates a financial accelerator amplifying the effect of the original shocks. In this paper, I abstract from the financial accelerator mechanism and consider the expected excess return on the stock market as the proxy for risk, rather than the corporate bond spreads considered in the aforementioned papers.[7] The importance of equity-financing in the U.S. suggests that stock market data may also contain important information about the cost-of-capital and effective risk-premia faced by firms when financing investment.

In the following section, I describe the model economy. Sections 3 and 4 discuss parameterization, and the main implications of the model respectively. Section 5 concludes.

2 The Model

I consider a closed economy New Keynesian DSGE model with firm-specific capital. Monopolistically competitive intermediate goods producers own the capital stock, and are price-setters in the goods market. Households own shares of the intermediate firms, and are wage-setters in the labor market. For analytical convenience, the model also features perfectly competitive final goods producers and labor intermediaries, who bundle the differentiated goods and labor respectively.

Price and wage stickiness are introduced in the form of quadratic adjustment costs as in Rotemberg (1982) and Chugh (2006); this formulation avoids firm heterogeneity even in the presence of firm-specific capital.[8] The model also features price and wage indexation, external habit formation,

[7] Christiano et al. (2009) also use stock prices in their estimation, but their cost-of-capital measure is identified by data on the excess return on corporate debt.

[8] Calvo-type price and wage setting (Calvo, 1983) in the presence of firm-specific capital leads to firm-heterogeneity (Woodford, 2005). Another alternative way of introducing price and wage stickiness is the staggered contracts model of Taylor (1980). These models feature heterogeneous firms by construction, and are harder to estimate and solve (c.f. Chari et al., 2000).

costly investment adjustment, variable capacity utilization, monetary policy conducted by a Taylor rule, investment-specific technological change, and linear deterministic growth as in SW. I also add a set of proportional taxes as in McGrattan and Prescott (2005), and include a preference shock, and a dividend shock in addition to the seven shocks present in SW.[9]

2.1 Labor Intermediaries

Labor intermediaries are perfectly competitive; they hire the heterogeneous labor services of the households, $h_t^s(j)$, and aggregate them into a composite labor service, h_t, using a Dixit-Stiglitz aggregator (Dixit and Stiglitz, 1977)

$$h_t = \left[\int_0^1 h_t^s(j)^{\frac{\Psi_t - 1}{\Psi_t}} dj \right]^{\frac{\Psi_t}{\Psi_t - 1}}, \tag{1}$$

where $\Psi_t \geq 0$ is the time-varying elasticity of substitution between the differentiated labor services. Let Ψ be the steady-state value of Ψ_t; then at the steady-state, $\psi = \Psi/(\Psi - 1)$ is the gross mark-up of real wages received by households over their marginal rate of substitution between consumption and leisure. I specify an exogenous ARMA(1,1) process for wage mark-up shocks $\psi_t = \Psi_t/(\Psi_t - 1)$ as[10]

$$\log \psi_t = (1 - \rho_\psi) \log \psi + \rho_\psi \log \psi_{t-1} + \varepsilon_{\psi,t} - \varsigma_\psi \varepsilon_{\psi,t-1}. \tag{2}$$

The labor intermediaries solve the following static problem each period:

$$\max W_t h_t - \int_0^1 W_t(j) h_t^s(j) dj, \tag{3}$$

where $W_t(j)$ is the nominal wage rate paid to household j for the purchase of the differentiated labor services, and W_t is the aggregate nominal wage rate received from the intermediate goods producers. In equilibrium, this maximization yields the following labor demand curve that households take as

[9] In Appendix A, I derive all the equilibrium conditions of the model, and their log-linearized versions. In subsection 2.7 of the main text, I summarize the linearized model.

[10] As a convention, I designate the persistence parameters of all the shock processes with ρ's, and their Gaussian innovations as ε's. All shocks follow AR(1) processes; except for the mark-up shocks. The mark-up shocks are ARMA(1,1) as in SW to capture the high-frequency fluctuations in prices and wages.

given:

$$h_t^s(j) = \left[\frac{W_t(j)}{W_t}\right]^{-\Psi_t} h_t. \tag{4}$$

2.2 Households

The economy is populated by a unit measure of infinitely-lived households indexed by j. The population of each household in period t is denoted by N_t, which grows with a constant growth factor η, so $N_{t+1} = \eta N_t$. Household j's intertemporal preferences are described by the following expected utility function:

$$E_t \sum_{\tau=t}^{\infty} \beta^{\tau-t} U_\tau(j) N_\tau, \tag{5}$$

where t indexes time, $\beta < 1$ is the time-discount parameter, and U_t is the period per-capita utility which is defined over surplus consumption, $C_{s,t}$, and labor supply, h_t^s, as[11]

$$U_t(j) = \frac{\upsilon_t}{1-\sigma}\left[C_{s,t}(j)\exp\left(-\xi\frac{h_t^s(j)^{1+\vartheta}}{1+\vartheta}\right)\right]^{1-\sigma}. \tag{6}$$

υ_t is a preference shock which follows an AR(1) process in logs:[12]

$$\log\upsilon_t = \rho_\upsilon \log\upsilon_{t-1} + \varepsilon_{\upsilon,t}. \tag{7}$$

σ determines the elasticity of intertemporal substitution and relative risk-aversion. ϑ regulates the Frisch-elasticity of labor supply, and ξ is a level parameter which, without loss of generality, will be restricted to ensure $h^s = 1$ at the steady-state of the model. Surplus consumption is the difference between current consumption, $C_t(j)$, and a habit level of consumption:

$$C_{s,t}(j) = C_t(j) - \zeta C_{t-1}, \tag{8}$$

[11] Note that the utility function is consistent with a balanced growth path (King et al., 1988). With $\sigma = 1$, the period utility reduces to the more familiar $U_t(j) = \log C_{s,t}(j) - \xi h_t^s(j)^{1+\vartheta} / (1+\vartheta)$.

[12] SW do not include preference shocks, as separate from risk shocks which also affect consumption demand of households. When risk shocks are identified with financial data, a singularity problem arises as the model cannot match consumption for each data point. I therefore include an additional preference shock similar to Gilchrist et al. (2009).

where ζ is a habit parameter, and the habit level of consumption depends on past *aggregate* consumption which is treated as an externality by the households.

Households own the intermediate goods firms (which are of unit measure indexed by i), and participate in asset markets where perfectly-divisible shares, s_t, of these firms are traded. Households also hold nominally-denominated one-period discount bonds issued by the government, B_t. The households' period budget constraint is given by

$$N_t C_t(j) + \int_0^1 \frac{V_t(i)}{P_t}\left[s_t(i,j) - s_{t-1}(i,j)\right] di + \frac{B_t(j)}{\phi_t R_t P_t} + \frac{T_t}{P_t} + \Phi_{w,t}(j)$$
$$\leq (1-\tau_h)\frac{W_t(j)}{P_t} N_t h_t^s(j) + (1-\tau_d)\int_0^1 \frac{D_t(i)}{P_t} s_{t-1}(i,j)\, di + \frac{B_{t-1}(j)}{P_t}, \quad (9)$$

where P_t is the aggregate price level, $V_t(i)$ is the price of a share of intermediate firm i, and $D_t(i)$ is the per-share dividends paid out by this firm. τ_h and τ_d are proportional taxes on labor and dividend income respectively, and T_t is a lump-sum tax.[13] R_t is the gross nominal interest rate set by the central bank, and ϕ_t is a risk premium shock that drives a wedge between the risk-free rate and the return on household assets as in SW. The risk shocks follow an AR(1) process

$$\log \phi_t = \log \phi + \rho_\phi \log \phi_{t-1} + \varepsilon_{\phi,t}, \quad (10)$$

where ϕ is the steady-state value of the risk-premium factor. The risk shock specification here follows SW, and can be interpreted as a time-varying "tax wedge" on bond returns within the *Business Cycle Accounting* framework of Chari et al. (2007, 2009).[14] $\Phi_{w,t}(j)$ is the quadratic cost of wage adjustment given by

$$\Phi_{w,t}(j) = \frac{\kappa_w(\Psi-1)(1-\tau_h)}{2}\left[\frac{W_t(j)/W_{t-1}(j)}{(\pi\gamma)(\pi_{t-1}/\pi)^{\eta_w}} - 1\right]^2 \frac{W_t}{P_t} N_t h_t, \quad (11)$$

[13] Note that prices on the consumption goods are after-tax; consumption taxes are captured by sales taxes at the firm level. I also do not model distortionary taxes on interest income, but these are captured by the risk-premium specification.

[14] Note that the risk premium shock changes the required return on bonds as well as stocks (i.e. with a first order approximation, the return on stocks and bonds are equal due to certainty equivalence). Since bonds play no role in the analysis, I interpret the risk-premium shocks as the difference between the required return on stocks and the risk-free rate (i.e. the policy rate set by the central bank minus expected inflation). I allow for a positive risk-premium at the steady-state, which is matched to the average equity risk-premium in the data.

where κ_w is the cost-of-adjustment parameter, and η_w is a parameter which determines the extent to which wage adjustments are indexed to past aggregate inflation factor, $\pi_{t-1} = P_{t-1}/P_{t-2}$. The $\pi\gamma$ in the denominator corrects for the growth of nominal wage rate along the balanced growth path, where γ is the growth factor of real output-per-capita along the balanced growth path. The adjustment cost is scaled by the total aggregate wage bill in the economy to ensure that it does not become negligible as the economy grows.[15]

The households' objective is to maximize utility subject to the budget constraints, the labor demand curve of the labor intermediaries, and appropriate No-Ponzi conditions.

2.3 Final Goods Producers

Final goods producers are perfectly competitive; they purchase the differentiated output goods of intermediate firms, $Y(i)$, and aggregate them into a final good, Y, using a Dixit-Stiglitz aggregator

$$Y_t = \left[\int_0^1 Y_t(i)^{\frac{\Theta_t - 1}{\Theta_t}} di \right]^{\frac{\Theta_t}{\Theta_t - 1}} \tag{12}$$

where Θ_t is the elasticity of substitution between the intermediate goods. Let Θ be the steady-state value of Θ_t; then at the steady-state, $\theta = \Theta/(\Theta - 1)$ is the gross mark-up of price over marginal cost. The process for price mark-up shocks, $\theta_t = \Theta_t/(\Theta_t - 1)$, are also ARMA(1,1)

$$\log \theta_t = (1 - \rho_\theta) \log \theta + \rho_\theta \log \theta_{t-1} + \varepsilon_{\theta,t} - \varsigma_\theta \varepsilon_{\theta,t-1}. \tag{13}$$

The final goods producers solve the following static problem each period:

$$\max P_t Y_t - \int_0^1 P_t(i) Y_t(i) di, \tag{14}$$

where $P_t(i)$ is the price of the intermediate good i, and P_t is the price of the final good. In

[15]The scaling of κ_w by the constant $(\Psi - 1)(1 - \tau_h)$ is without loss of generality. As shown later, this scaling provides a more convenient expression for the log-linearized version of the Wage-Phillips curve. I will use similar growth corrections and scaling for the other adjustment costs in the model.

equilibrium, this maximization yields the following demand curve for the intermediate goods:

$$Y_t(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\Theta_t} Y_t. \tag{15}$$

2.4 Intermediate Goods Producers

There is a unit measure of monopolistically competitive intermediate goods producers indexed by i. Their technology is described by the following production function:

$$Y_t(i) = z_t \left[u_t(i) K_{t-1}(i)\right]^{\alpha} \left[A_t N_t h_t(i)\right]^{1-\alpha} - (\eta\gamma)^t f \tag{16}$$

where z_t is an aggregate productivity shock, $K_{t-1}(i)$ is the firm-specific capital owned by firm i, $u_t(i)$ is the utilization rate of capital, and $N_t h_t(i)$ is the amount of (homogenous) labor input used in the production of intermediate good i. α is a parameter determining the share of capital in production, and A_t is the trend level of neutral productivity that grows with a constant factor γ; hence $A_t = \gamma^t$. $(\eta\gamma)^t f$ is the fixed cost of production which grows exogenously over time with the growth factor $\eta\gamma$, which is the growth factor of output along the balanced growth path. I set the parameter f such that $(\eta\gamma)^t f/Y_t = \theta - 1$ along the balanced growth path. This condition ensures that pure economic profits of intermediate firms are zero along the balanced growth path, therefore there is no incentive for entry and exit in the long-run of the stochastic economy. The aggregate productivity shock z_t follows an AR(1) process given by

$$\log z_t = \rho_z \log z_{t-1} + \varepsilon_{z,t}. \tag{17}$$

The law of motion of capital accumulation is described by

$$K_t(i) = (1-\delta) K_{t-1}(i) + z_t^x X_t(i) - \frac{\kappa_x}{2}\left(\frac{X_t(i)}{\eta\gamma X_{t-1}(i)} - 1\right)^2 X_t, \tag{18}$$

where δ is the depreciation rate of capital, and κ_x is a parameter regulating the cost of investment adjustment.[16] z_t^x is the investment-specific technological change which follows an AR(1) process given by[17]

$$\log z_t^x = \rho_x \log z_{t-1}^x + \varepsilon_{x,t}. \tag{19}$$

Without loss of generality, I assume there is a single (perfectly-divisible) share outstanding each period for each firm; hence $s_t(i) = 1$, for all t. Dividends paid out to shareholders are equal to total revenue of firms minus payments for wages, investments, taxes and price adjustment costs:

$$\begin{aligned} \frac{D_t(i)}{P_t} &= (1-\tau_s)\frac{P_t(i)}{P_t}Y_t(i) - \frac{W_t}{P_t}N_t h_t(i) - X_t(i) \\ &\quad -\tau_y\left[(1-\tau_s)\frac{P_t(i)}{P_t}Y_t(i) - \frac{W_t}{P_t}N_t h_t(i) - \delta_a K_{t-1}(i)\right] - \Phi_{p,t}(i) + (\eta\gamma)^t\,\Phi_{d,t}, \end{aligned} \tag{20}$$

where τ_s and τ_y are proportional taxes on sales and income respectively.[18] Note that depreciation is deductible from the income tax-base, and the accounting depreciation rate, δ_a, can differ from the economic depreciation rate, δ. The quadratic cost of price adjustment, $\Phi_{p,t}$, is specified as

$$\Phi_{p,t}(i) = \frac{\kappa_p(\Theta-1)(1-\tau_s)(1-\tau_y)}{2}\left[\frac{P_t(i)/P_{t-1}(i)}{\pi(\pi_{t-1}/\pi)^{\eta_p}} - 1\right]^2 Y_t. \tag{21}$$

κ_p is the cost-of-adjustment parameter, and η_p is a parameter which determines the extent to which price adjustments are indexed to past inflation. $(\eta\gamma)^t\,\Phi_{d,t}$ is a transfer from the government which

[16] Note that the investment adjustment cost is defined over *changes* in investment rather than its *level;* this feature generates hump-shaped impulse responses in investment (Christiano et al., 2005).

[17] Note that this specification is equivalent to specifying $1/z_x$ as the relative price of the investment good in the dividend flow equation. Gordon (1990) argues that this relative price is seriously mismeasured in NIPA and contains a strong downward trend. Greenwood et al. (1997) show that allowing for a trend in investment specific technological change alters the balanced growth path of output. For simplicity, I do not include a trend component to the investment-specific technological change in my model specification, similar to SW.

[18] McGrattan and Prescott (2005) also include investment tax credits and property taxes in their dividend flow specification. I abstract from these taxes since they are small.

acts as a shock to dividends. This shock also follows an AR(1) process:[19]

$$\Phi_{d,t} = \rho_d \Phi_{d,t-1} + \varepsilon_{d,t}.$$

The intermediate firms' objective is to maximize the present value of (after-tax) dividends minus pecuniary costs related to capital utilization which affect the utility of firms, but not their cash-flow:

$$E_t \sum_{\tau=0}^{\infty} \beta^{\tau-t} \frac{\Lambda_\tau}{\Lambda_t} \left\{ (1-\tau_d) \frac{D_\tau(i)}{P_\tau} - \frac{\kappa_u (1-\tau_d)}{1+\chi} \left[u_t(i)^{1+\chi} - 1 \right] K_{t-1}(i) \right\}, \tag{22}$$

where κ_u is a scale parameter that, without loss of generality, is set to make sure that utilization rate is equal to 1 at the steady-state, and χ is an elasticity parameter.[20]

2.5 The Government and the Central Bank

Government expenditure, G_t, is equal to $(\eta\gamma)^t g_t$; and the stationary stochastic component, g_t, follows an AR(1) process, but is also affected by domestic productivity innovations:

$$\log g_t = \left(1-\rho_g\right) \log g + \rho_g \log g_{t-1} + \varepsilon_{g,t} + \rho_{gz} \varepsilon_{z,t}. \tag{23}$$

This follows the specification in SW, and is motivated by the fact that the data counterpart of government expenditure used in the estimation includes net exports, which may be affected by

[19] The presence of this shock allows dividends to be used as an observable in the estimation. An alternative is to introduce measurement error in the observed dividend series. Since there is actually very little measurement error in these series, and these shocks can also account for changes in dividends due to taxes, I chose a dividend shock specification. Since this shock is treated as a government transfer, it does not alter the feasibility condition, and does not affect any of the variables in the model except for market values. As shown later, its quantitative importance for accounting for market values is very small.

[20] Christiano et al. (2005) specify utilization costs as deductions in consumption rather than higher depreciation rates for capital. The latter causes utilization rates to fall with respect to an expansionary monetary shock. I follow a similar route, and specify these costs in terms of dividends. Note however I model these costs as affecting the utility of firms rather than their cash-flow. Otherwise, since these costs are not quadratic, they would affect the feasibility condition even after the model is linearized. This may be reasonable, if for example, these utilization costs proxy for intermediate energy costs, but one needs to redefine GDP in this case. I do not follow this route here.

domestic productivity. The government's budget constraint is given by[21]

$$G_t + \frac{B_{t-1}}{P_t} + (\eta\gamma)^t \Phi_{d,t} = Taxes + \frac{B_t}{\phi_t R_t P_t}. \tag{24}$$

The central bank targets the nominal interest rate using a Taylor rule,

$$\log R_t = \rho_r \log R_{t-1} + (1-\rho_r)\left[a_\pi \log \frac{\pi_t}{\pi} + a_y \log \frac{Y_t}{Y_t^n} + a_g \log \frac{Y_t/Y_{t-1}}{Y_t^n/Y_{t-1}^n} + \log R\right] + i_t, \tag{25}$$

where R is the steady-state value of the (gross) nominal policy rate, ρ_i determines the extent of interest rate smoothing, and the parameters a_π, a_y and a_g determine the importance of inflation, output gap and output growth (relative to the natural growth of output) in the Taylor rule. Y_t^n is the natural rate of output, which is defined as the level of output that would be realized in the absence of nominal rigidities in price and wage setting and mark-up shocks. i_t is the monetary policy shock which follows an AR(1) process:

$$i_t = \rho_i i_{t-1} + \varepsilon_{i,t}. \tag{26}$$

2.6 Market Clearing Conditions

The goods market clearing condition is given by

$$N_t C_t + X_t + G_t = Y_t - \Phi_{w,t} - \Phi_{p,t}. \tag{27}$$

Note that wage and price adjustment costs affect the cash-flows in the model, therefore show up in the resource constraint. Since these costs are quadratic however, they play no role in the linearized version of the resource constraint.

[21] I implicitly require that the household's lump-sum taxes respond to the debt level, so that the government does not run a Ponzi scheme (Fernández-Villaverde, 2009). As stated before, government bond returns include the risk premium shocks, but this will not play a role in the model due to the presence of lump-sum taxes paid by households. Also note that revenue from money creation can be added to the model without affecting the results. This would require modeling money demand with a separable specification in the utility function of households (Woodford, 2003).

The labor market clearing condition is given by

$$h_t = \int_0^1 h_t(i)\, di = \left[\int_0^1 h_t^s(j)^{\frac{\Psi_t - 1}{\Psi_t}}\, dj\right]^{\frac{\Psi_t}{\Psi_t - 1}}. \tag{28}$$

The bond and share markets clear; hence,

$$B_t = \int_0^1 B_t(j)\, dj, \text{ and } s_t = \int_0^1 s_t(i)\, di = \int_0^1 \int_0^1 s_t(i,j)\, di dj = 1. \tag{29}$$

The model's equilibrium is defined as prices and allocations such that households maximize utility subject to their budget constraint, the labor intermediaries and final goods producers maximize profits, the intermediate home-goods producers maximize their objective function, and all markets clear. I only consider symmetric equilibria where variables indexed by i and j are equal across all households and intermediate-goods firms.

2.7 Detrending and Log-Linear Approximation

The model economy described above has a balanced growth path where the real aggregate variables grow with a factor of $\eta\gamma$. Consumption, C_t, and real wages, W_t/P_t, are specified on a per-capita basis; hence, they grow with a factor of γ along the balanced growth path. Per-capita labor, h_t, does not grow over time. The Lagrange multiplier, Λ_t, grows with a factor of $\gamma^{-\sigma}$. The nominal variables also grow with an additional trend inflation factor, π.

I first detrend all variables with their corresponding growth factors to render the model stationary. The small-letter version of the variables are stationary, and are obtained by dividing the level variables at period t by their growth factor to the power t (e.g. for the output variable, $y_t = Y_t/(\eta\gamma)^t$). The timing convention is slightly different for capital for convenience; hence, $k_t = K_t/(\eta\gamma)^{t+1}$. After detrending, all variables are log-linearized around their steady-state to obtain a linear system of equations that characterize the equilibrium of the above model.

After some algebraic manipulation, the linear model can be reduced to the following 15 relationships (excluding the exogenous processes):[22] The arbitrage condition between the return on stocks and bonds equates the expected real return on stocks, $E_t \widehat{r}^s_{t+1}$, to the policy rate minus expected inflation plus a risk-premium:

$$E_t \widehat{r}^s_{t+1} = \widehat{r}_t - E_t \widehat{\pi}_{t+1} + \widehat{\phi}_t. \tag{30}$$

The real return from shares is the sum of capital gains and dividend yield, and is related to the *real* share price, $\widehat{vp}_t$, and real dividends, $\widehat{dp}_t$, as[23]

$$\widehat{r}^s_t = \widetilde{\beta} \widehat{vp}_t + \left(1 - \widetilde{\beta}\right) \widehat{dp}_t - \widehat{vp}_{t-1}, \tag{31}$$

where the adjusted time-discount factor is defined as $\widetilde{\beta} = \beta \eta \gamma^{1-\sigma}$.

Consumption demand in the model is characterized by a partially forward-looking IS curve which is obtained from the first-order-condition of the households' maximization problem with respect to consumption and the Euler condition:

$$\widehat{c}_t = c_1 \widehat{c}_{t-1} + (1 - c_1) E_t \widehat{c}_{t+1} + c_2 \left(\widehat{h}_t - E_t \widehat{h}_{t+1}\right) - c_3 E_t \widehat{r}^s_{t+1} + \widetilde{v}_t, \tag{32}$$

where constants are given by $c_1 = (\zeta/\gamma)/(1 + \zeta/\gamma)$, $c_2 = (\sigma - 1)(1 - \zeta/\gamma)\xi/[\sigma(1 + \zeta/\gamma)]$, and $c_3 = (1 - \zeta/\gamma)/[\sigma(1 + \zeta/\gamma)]$. The consumption demand shock was redefined as $\widetilde{v}_t = c_3 (1 - \rho_v) \widehat{v}_t$ to facilitate easier estimation. The IS curve states that current consumption is inversely related to the expected return on household assets, positively related to demand shocks, and is influenced by past and expected future consumption and labor services.

Investment demand is obtained from the optimality condition of intermediate firms with respect to investment:

$$\widehat{x}_t = x_1 \widehat{x}_{t-1} + (1 - x_1) E_t \widehat{x}_{t+1} + x_2 \widehat{q}_t + \widetilde{z}^x_t, \tag{33}$$

[22] There is also a corresponding set of equations which determine the natural rate of output implied by the model. Relative to the 18 equations and 18 unknowns listed in Appendix A, I substitute for c_s, λ, Ω_h and Ω_f, but specify a new variable r^k. As a convention, having no subscript refers to the steady-state value of that (detrended) variable, and a hat over the variable with a time-subscript indicates the variable's log-deviation from its steady-state (i.e. for y_t for example, $\widehat{y}_t = \log y_t - \log y$).

[23] I will follow the convention of labeling real variables by appending p to the name of the variable. For example, wp is the real wage, and dp is the real dividends in my notation.

where $x_1 = 1/\left(1+\widetilde{\beta}\right)$, $x_2 = 1/\left(1+\widetilde{\beta}\right)\kappa_x$ and the investment shock was redefined as $\widetilde{z}_t^x = x_2\widehat{z}_t^x$. This condition relates current investment to Tobin's marginal-q, which is given by $\widehat{q}_t + \widehat{z}_t^x$; but also to past and expected future investment due to the presence of investment adjustment costs.[24] There is also an arbitrage condition which equates the shadow price of capital, $\widehat{q}_t$, to the expected returns next period discounted by the required return on stocks:

$$\widehat{q}_t = q_1 E_t\widehat{q}_{t+1} + (1-q_1)\, E_t\widehat{r}_{t+1}^k - E_t\widehat{r}_{t+1}^s, \tag{34}$$

where $q_1 = (1-\delta)\,\widetilde{\beta}/\eta\gamma$. The second term on the right, $E_t\widehat{r}_{t+1}^k$, is the shadow rental rate of capital which is inversely related to the capital-labor ratio and positively related to the wage rate; and is given by

$$\widehat{r}_t^k = -\left(\widehat{u}_t + \widehat{k}_{t-1} - \widehat{h}_t\right) + \widehat{wp}_t. \tag{35}$$

Price inflation is characterized by a partially forward-looking price-Phillips curve, which is derived from the first-order-conditions of the firms with respect to prices:

$$\widehat{\pi}_t = \pi_1\widehat{\pi}_{t-1} + \pi_2 E_t\widehat{\pi}_{t+1} - \pi_3\left[\widehat{z}_t + \alpha\left(\widehat{u}_t + \widehat{k}_{t-1} - \widehat{h}_t\right) - \widehat{wp}_t\right] + \widetilde{\theta}_t, \tag{36}$$

where $\pi_1 = \eta_p/\left(1+\widetilde{\beta}\eta_p\right)$, $\pi_2 = \widetilde{\beta}/\left(1+\widetilde{\beta}\eta_p\right)$, $\pi_3 = 1/\left(1+\widetilde{\beta}\eta_p\right)\kappa_p$ and the cost-push shock was redefined as $\widetilde{\theta}_t = \pi_3\widehat{\theta}_t$. Current inflation is positively related to marginal labor costs (the difference between real wages, $\widehat{wp}_t$, to the marginal product of labor) and price mark-up shocks, but are also affected by a weighted average of past and expected future inflation due to indexation and forward-looking expectations.

Similarly, wage inflation is characterized by a wage-Phillips curve, which is derived from the

[24] Note that the model counterpart of Tobin's marginal-q is given by $z_t^x q_t$; i.e. the price of installed capital (q_t) relative to its replacement cost ($1/z_t^x$). Tobin's average-q, the market value of firms, relative to the replacement cost of their capital, is given by $(V_t/P_t)/(K_t/z_t^x)$. Average-q can exceed marginal-q due to the presence of monopoly rents (Hayashi, 1982).

first-order-conditions of the household with respect to wages:

$$\widehat{\pi}_t^w - \eta_w \widehat{\pi}_{t-1} = \widetilde{\beta}\left(E_t \widehat{\pi}_{t+1}^w - \eta_w \widehat{\pi}_t\right) - \frac{1}{\kappa_w}\left[\widehat{wp}_t - \left(\vartheta \widehat{h}_t + \frac{1}{1-\zeta/\gamma}\left(\widehat{c}_t - \left(\zeta/\gamma\right)\widehat{c}_{t-1}\right)\right)\right] + \widetilde{\psi}_t, \quad (37)$$

where the wage shock was redefined as $\widetilde{\psi}_t = (1/\kappa_w)\,\widehat{\psi}_t$. Wage inflation is a function of the difference between the marginal rate of substitution to the real wage and wage mark-up shocks. Wage inflation is also a function of past inflation due to indexation, and expected future wages (relative to inflation indexation) due to forward-looking expectations. Price and nominal wage inflation are related to each other with

$$\widehat{\pi}_t^w = \widehat{wp}_t - \widehat{wp}_{t-1} + \widehat{\pi}_t. \quad (38)$$

The law of motion of capital is given by

$$\widehat{k}_t = k_1 \widehat{k}_{t-1} + (1-k_1)\,\widehat{x}_t + k_2 \widetilde{z}_t^x, \quad (39)$$

where $k_1 = (1-\delta)/\eta\gamma$, and $k_2 = (1-k_1)/x_2$. The production function in log-linearized form is

$$\widehat{y}_t = \theta\left[\widehat{z}_t + \alpha\left(\widehat{u}_t + \widehat{k}_{t-1}\right) + (1-\alpha)\,\widehat{h}_t\right], \quad (40)$$

where I utilized the assumption that the ratio of fixed costs in output is $\theta - 1$ along the balanced growth path. The optimality condition for capital utilization implies

$$\widehat{u}_t = \frac{1}{\chi}\widehat{r}_t^k. \quad (41)$$

The definition of real dividends can be written as

$$\frac{dp}{y}\widehat{dp}_t = (1-\tau_y)\left[(1-\tau_s)\,\widehat{y}_t - (1-\alpha)\left(\widehat{wp}_t + \widehat{h}_t\right)\right] - \frac{x}{y}\widehat{x}_t + \tau_y \delta_a \frac{k}{y}\widehat{k}_{t-1} + \widehat{\Phi}_{d,t}, \quad (42)$$

where $dp/y = \left(1/\widetilde{\beta} - 1\right)\eta\gamma k/y$, $x/y = (\eta\gamma - 1 + \delta)\,k/y$ and $k/y = (1-\tau_y)(1-\tau_s)\,\alpha/\left(\eta\gamma/\widetilde{\beta} - 1 + \delta - \tau_y\delta_a\right)$.

The Taylor rule of the central bank, in log-linearized form, is given by

$$\widehat{r}_t = \rho_r \widehat{r}_{t-1} + (1-\rho_r)\left\{a_\pi \widehat{\pi}_t + a_y\left(\widehat{y}_t - \widehat{y}_t^n\right) + a_g\left[\left(\widehat{y}_t - \widehat{y}_t^n\right) - \left(\widehat{y}_{t-1} - \widehat{y}_{t-1}^n\right)\right]\right\} + \widehat{i}_t. \tag{43}$$

Finally, the goods market clearing condition is given by

$$\frac{c}{y}\widehat{c}_t + \frac{x}{y}\widehat{x}_t + \frac{g}{y}\widehat{g}_t = \widehat{y}_t, \tag{44}$$

where the steady-state share of government expenditure, g/y, is a given parameter, and the share of consumption is $c/y = 1 - x/y - g/y$.

3 Parameterization

I conduct the parameterization of the model in two stages. I first calibrate the parameters that determine the levels of variables using the steady-state relationships of the model and the first moments of their data counterparts; in particular I match the components of the national income and product accounts, and the capital-output and market value-to-output ratios (Cooley and Prescott, 1995).[25] The rest of the parameters are estimated using Bayesian likelihood techniques (An and Schorfheide, 2007).[26] In what follows, I describe the calibration and estimation procedures along with the data used in the estimation.

3.1 Calibration

I use data from the National Income and Product Accounts (NIPA), and the Flow-of-Funds (FOF) averaged over 1955q1-2009q3 to calibrate the level parameters of the model. Table 1 presents

[25] Note that, unlike SW, I include a full set of proportional taxes similar to McGrattan and Prescott (2000, 2005) in the model which improves the model's ability to match the first moments of the data. Since some of these steady-state ratios show up in the log-linearized model equations, it is important to match these ratios before assessing the relative importance of shocks in accounting for business cycles. Since taxes are not time-varying however, their impact on the dynamics of the model and the overall results is limited.

[26] Although early DSGE models were typically parameterized by calibration, the presence of a large number of shocks and structural parameters in the more recent models has necessitated more formal estimation. The use of Bayesian priors with maximum likelihood techniques have become commonplace in these estimations, due to the relative scarcity of macroeconomic data, and identification problems (Canova and Sala, 2006 and Fernández-Villaverde, 2009).

the income and product accounts and the balance sheet ratios in the data versus the model.[27] The model accounts were generated using the parameter values listed in Table 2. The calibration procedure that was used is as follows:

The parameters, η and γ, are set to 1.0035 and 1.0042 to match the average quarterly growth factors of population and per-capita output respectively during 1955-2009. The tax rate on dividend income, τ_d, is set to 22.2% to match the following steady-state relationship of the model linking market value of firms to the value of their tangible assets:[28]

$$\frac{vp}{y} = (1 - \tau_d)\,\frac{\gamma\eta k}{y} = q\frac{\gamma\eta k}{y}. \tag{45}$$

The adjusted time-discount factor, $\widetilde{\beta}$, is set to 0.994 to match the steady-state relationship between market values and dividends:[29]

$$\frac{vp}{y} = \frac{\widetilde{\beta}}{1-\widetilde{\beta}}\,(1 - \tau_d)\,\frac{dp}{y}. \tag{46}$$

The sales tax rate, τ_s, is set to 9.0% to match the share of indirect business taxes in the income account.[30] The share of labor compensation in total income, wp/y, averaged 65.3% between 1960-2006, hence I set the capital share parameter, α, to 0.282 using the following steady-state relationship[31]

$$(1 - \tau_s)\,(1 - \alpha) = \frac{wp}{y}. \tag{47}$$

[27] NIPA data are published by the Bureau of Economic Analysis, and FOF data are issued by the Federal Reserve Board. The expenditure shares in the data refer to the economy as a whole. For the income account and balance sheet ratios, I use value added shares and balance sheet ratios of non-financial corporations.

[28] Note that dividend income tax rates, measured by a weighted average of distribution and capital gains taxes, averaged about 25% in the post-war period; although the rates were higher in the first half of the period than the second half (McGrattan and Prescott, 2005). In this paper, I abstract from the effects of changes in dividend income taxation, and the presence of intangible assets.

[29] Note that I do not need to set a value for the actual time-discount factor, β, which is related to the adjusted factor $\widetilde{\beta}$ with $\widetilde{\beta} = \beta\eta\gamma^{1-\sigma}$, since β does not enter any of the log-linearized conditions. Finite utility, and therefore existence of equilibrium, requires that $\widetilde{\beta} < 1$, but β can be greater than 1. This, in fact, can help account for the low risk-free rates observed in the data (Abel, 1999). Arguably though, it is still desirable to have $\beta < 1$ because simple introspection suggests that people discount the future even in the presence of growth (Mehra and Prescott, 2003).

[30] The share of indirect business taxes in the data is 0.089. I match τ_s to a slightly different number to match a slightly higher capital share parameter α, and therefore allow the model to match the capital-output and market value-to-output ratios exactly. These small changes do not affect the results in any crucial way.

[31] SW estimates rather than calibrates this parameter. Their implied estimate for the average labor share in total income is 81%, as opposed to 65-70% observed in the data. This is probably related to the estimation's effort to match a low rate of return on capital (given the observed interest rates) in a model that does not include any distortionary taxes on capital income.

The *accounting* depreciation rate, δ_a, is set to 1.4% to match the share of accounting depreciation in the income account, and the capital-output ratio. The quarterly *economic* depreciation rate, δ, is set to 1.28% using the reported capital-output and investment-output ratios, and the steady-state condition corresponding to the law of motion of capital.

The tax on firm income, τ_y, is calibrated to 32.0% to match the share of corporate income tax in the income account. Finally, the share of government expenditure, g/y, is set to 19.1%, which is equal to its data counterpart for the economy as a whole.

Although not necessary to get the above steady-state relationships, I calibrate a few other level parameters. I set the tax rate on labor income, τ_h, to 35% to reflect the marginal rate on labor compensation including social security taxes. I calibrate the trend inflation factor, π, and average (gross) nominal interest rate, R, to their respective averages between 1955-2009 which are 1.0087 and 1.0136. The calibrated parameters imply that the (quarterly) real return on stocks is 1.4%, and the average (quarterly) risk-premium is 0.91% given the following steady-state relationships between gross returns:

$$\frac{\eta\gamma}{\widetilde{\beta}} = r^s = \frac{\phi R}{\pi}. \tag{48}$$

3.2 Bayesian Estimation

The remaining parameters are estimated using Bayesian likelihood methods as in SW. Let Π denote the vector of parameters to be estimated, $\Pr(\Pi)$ be the prior density function of the parameters, and ξ^* denote the observable variables. By Bayes' rule, the posterior distribution of the parameters, $\Pr(\Pi|\xi^*)$, is proportional to the product of the prior and the likelihood function, $L(\xi^*|\Pi)$:

$$\Pr(\Pi|\xi^*) \propto \Pr(\Pi) \cdot L(\xi^*|\Pi). \tag{49}$$

For a given set of parameters, the rational expectations solution to the linearized model can be obtained using the method laid out in Blanchard and Kahn (1980). This solution has a state-space representation, and the Kalman filter can be used to evaluate the likelihood function $L(\xi^*|\Pi)$ and the posterior value $\Pr(\Pi|\xi^*)$ for a given vector of parameters. Markov Chain Monte Carlo (McMc) simulation methods can then be used to construct the entire posterior distribution, and identify its corresponding moments (An and Schorfheide, 2007, and Fernandez-Villaverde and Rubio-Ramirez, 2004).[32]

3.2.1 The Data

The estimation uses nine U.S. time series; these series (with their model counterparts in parentheses) are the log-difference in per-capita real GDP $(\ln \gamma + \widehat{y}_t - \widehat{y}_{t-1})$, the log-difference in per-capita real consumption $(\ln \gamma + \widehat{c}_t - \widehat{c}_{t-1})$, the log-difference in per-capita real investment $(\ln \gamma + \widehat{x}_t - \widehat{x}_{t-1})$, percent deviation of per-capita labor hours from its sample average $\left(\widehat{h}_t\right)$, the log-difference in the real wage rate $\left(\ln \gamma + \widehat{wp}_t - \widehat{wp}_{t-1}\right)$, the GDP-deflator inflation rate $(\ln \pi + \widehat{\pi}_t)$, the Federal-Funds rate $(\ln R + \widehat{r}_t)$, the log-difference in per-capita real market value of nonfinancial corporations $\left(\ln \gamma + \widehat{vp}_t - \widehat{vp}_{t-1}\right)$, and the log-difference in per-capita real dividend payments of nonfinancial corporations $\left(\ln \gamma + \widehat{dp}_t - \widehat{dp}_{t-1}\right)$. Per-capita values were obtained by dividing by the Census Bureau's civilian non-institutional population (age 16+) numbers, and real values were obtained through deflating by the GDP-deflator.

The benchmark estimation uses mainly first-differenced data as described above. As an alternative, I also estimate the model using HP-filtered data.[33] This allows the estimated shocks to capture only the business cycle frequency components of the data rather than try to also account for secular changes, which are especially visible in labor and stock price data. The nonlinear trends in labor are mostly related to changes in population growth rates, labor participation of different demographic groups, and changes in tax rates, all of which the model abstracts from. As was discussed in the introduction, stock market data also contain nonlinear trends, especially during the late 70's and 80's.[34]

Tha data are measured at a quarterly frequency for the period 1955q1 - 2009q3. The source of the data on output, consumption, investment, and GDP-deflator is the National Income and

[32] I use *Dynare* to estimate the parameters and compute the solution of the model.

[33] HP-filtered data are in terms of log-deviations of the variables from the steady-state, so the observation equations are modified accordingly in the alternative estimation.

[34] In a recent paper, Boldrin and Peralta-Alva (2009) measure the secular movements of market value using an HP-trend.

Product Accounts of the U.S. published by the Bureau of Economic Analysis. Total labor hours is calculated using data published by the Bureau of Labor Statistics (BLS), and it refers to total employment (from the Current Population Survey) multiplied by the average workweek length of nonsupervisory workers (from the Current Employment Statistics). Wage data refers to the hourly compensation rate in nonfarm business also published by the BLS. The Federal Funds rate data are obtained from the Federal Reserve Board.[35] Market value and dividend data are from the Flow of Funds Accounts also published by the Federal Reserve Board. Market value refers to net debt plus equity value of all non-financial corporations, whereas dividends also include net stock repurchases (i.e. stock repurchases minus new shares issued) of these corporations.[36]

3.2.2 The Prior Distributions

The prior distributions for the parameters are similar to SW (see Tables 3 and 4). For the utility parameters, the habit parameter, ζ, has a beta-distribution prior with a mean of 0.7 and a standard deviation of 0.1. The prior for the risk-aversion parameter, σ, is distributed normally with mean 1.5 and standard deviation 0.37. The parameter ϑ has a normal prior with a mean of 2 (reflecting a Frisch-elasticity of labor supply of 0.5) and a standard deviation of 0.75. The steady-state wage mark-up, ψ, has a normal prior with mean 1.5 and standard deviation of 0.12. The scale parameter, ξ, is not estimated, but is retricted to equal the following expression to ensure that labor services, h, is equal to 1 at the steady-state:

$$\xi = \frac{(1-\tau_h)\, wp/y}{\psi\,(1-\zeta/\gamma)\, c/y}. \tag{50}$$

The capacity utilization elasticity parameter was rescaled as $\chi/(1+\chi)$ to facilitate easier estimation, with a beta prior with mean 0.5 (which implies unit elasticity of utilization to the rental rate of capital) and standard deviation 0.1.[37] The investment cost-adjustment parameter, κ_x, has a

[35] Since the model is quarterly, the measures of inflation rates and interest rates are expressed as non-annualized quarterly rates. The annualized quarterly expressions for the deviations of inflation and interest rate from their steady-states are 4 times their non-annualized quarterly figures.

[36] The regular dividends were obtained from the income accounts of NIPA. Jermann and Quadrini (2009) also include net stock repurchases in their measure of dividends.

[37] The level parameter in the utilization cost, κ_u, was set to $(1-\tau_y)(1-\tau_s)\,\alpha/(k/y)$ to ensure that the utilization

normal prior with mean 4 (reflecting an elasticity of investment with respect to Tobin's-q of about 0.125) and standard deviation 1.5.

I estimate a rescaled version of the wage and price adjustment cost parameters to facilitate easier comparison with SW, which uses Calvo-type price and wage setting and more flexible aggregator functions for labor intermediaries and intermediate goods producers instead of the Dixit-Stiglitz aggregators used in this paper. In particular, I estimate κ_p^e and κ_w^e, where

$$\kappa_p = \frac{[10\,(\theta-1)+1]\,\kappa_p^e}{\left(1-\kappa_p^e\right)\left(1-\widetilde{\beta}\kappa_p^e\right)}, \text{ and } \kappa_w = \frac{[10\,(\psi-1)+1]\,\kappa_w^e}{\left(1-\kappa_w^e\right)\left(1-\widetilde{\beta}\kappa_w^e\right)},$$

each of which have beta priors with mean 0.5 and standard deviation 0.1. These are analogous to assuming 2-quarter price and wage stickiness in a Calvo-pricing setting along with more curvature in the Kimball aggregator functions used in SW. The price and wage indexation parameters, η_p and η_w, have beta priors with a mean 0.5 and standard deviation of 0.15. Similar to the wage mark-up, the price mark-up at the steady-state, θ, is assumed to have a normal prior with mean 1.5 and standard deviation 0.12.

For the Taylor rule parameters, I assume that the prior for the long-run inflation reaction coefficient, a_π, has a normal distribution with a mean of 1.5 and standard deviation 0.25. The long-run reaction coefficients on output and output growth, a_y and a_g, have normal distributions with mean 0.12 and standard deviation 0.05. The prior for the interest rate smoothing parameter, ρ_r, has a normal distribution with a mean of 0.75 and a standard deviation of 0.1.

The priors for the autoregressive and moving average terms in all shocks have beta distributions with mean 0.5 and standard deviation 0.2. The priors for the standard deviations of all the shocks are also fairly uninformative, with inverse-gamma distributions with mean 0.5% and infinite variance.

rate is equal to 1 at the steady-state. This steady-state is already imposed in the log-linear expression for q.

3.2.3 The Posterior Estimates

The benchmark estimates for the mode, the mean and the 5%-95% percentiles of the posterior distributions of the parameters are reported in Tables 3 and 4 along with their corresponding priors.[38] The data are quite informative about all the parameters, and the estimates are by-and-large standard. The habit parameter, ζ, has a mean equal to 0.95, which is fairly high. The risk aversion and labor supply parameters, σ and ϑ, have means of 0.99 and 2.57 respectively; which are within the range of values typically obtained in the literature.

The gross mark-up in prices and wages at the steady-state are estimated to be 1.67 and 1.62 respectively. The estimate for the utilization parameter implies that the elasticity of capacity utilization with respect to the rental rate of capital, $1/\chi$, is around 8.8. Similarly, the investment adjustment cost parameter estimate implies that the elasticity of investment with respect to q is around 0.44. These two elasticities are somewhat larger than the estimates in SW. The price and wage adjustment cost estimates are analogous to about 4.5 quarters of average price stickiness, and about 11.8 quarters of wage stickiness in the Calvo-type setting of SW; these estimates are also somewhat larger than the corresponding estimates in SW.

The indexation parameters in the Phillips curves, η_p and η_w, have estimated means of 0.09 and 0.63, which imply that price indexation is not an important feature of the data, but wage indexation is. The Taylor rule is fairly persistent with mean ρ_r equal to 0.83, and the mean estimates for the long-run reaction coefficients a_π, a_y, and a_g are 1.47, 0.08 and 0.22 respectively.

Among the exogenous processes, risk, investment-specific technological change and dividend shocks are the most volatile. The mean estimate for the standard deviation of the risk shock, σ_ϕ, is 0.79%; this compares to an estimate of only 0.23% in SW. Government expenditure, investment, productivity and risk shocks have the highest persistence; for the risk shocks, the mean estimate for the persistence parameter, ρ_ϕ, is 0.88, compared to an estimate of 0.22 in SW.

The last columns in the tables also report the posterior mode estimates using HP-filtered data. Most of the parameter estimates are similar with the estimates obtained using first-differenced data,

[38] For the Metropolis-Hastings algorithm in *Dynare*, I used two chains of 250,000 draws with a 45% initial burn-in phase. The acceptance rates were about 30%. The plots of the posterior distributions are available upon request.

but there are some important differences. In particular, the investment adjustment cost parameter is much larger with HP-filtered data, which implies a smaller elasticity of investment with respect to q. This elasticity is 0.13 with HP-filtered data compared to 0.44 with first-differenced data.

Using HP-filtered data, the shock persistence parameters are smaller than the benchmark estimation with first-differenced data, suggesting that shocks in the benchmark estimation are capturing some of the low frequency movements of variables. This is especially visible for investment shocks, whose persistence parameter is estimated to be near 0.99 with first-differenced data, but is only 0.15 with HP-filtered data. As argued in the introduction, the high persistence of this shock in the benchmark estimation is due to the large and persistent decline in market values during the mid-70's and 80's, coupled with a persistent increase in investment rates during the same period. The investment shocks are estimated to be more volatile with HP-filtered data however. To summarize, with first-differenced data, the estimation favors high short-term predictability in investment, given a large elasticity of investment with respect to q and a very persistent investment shock. On the other hand, HP-filtered data would tend to attribute more of the short-term variation in investment to innovations in the investment shock process.

4 Results

In this section, I report some of the key implications of the model using impulse responses and variance decompositions.

4.1 Impulse Responses

The impulse responses obtained from the model using the benchmark estimation are by and large standard. Figure 4 plots the impulse response of the key variables in the model, along with their 95% confidence bands, to a one standard-deviation innovation in the risk shock. The mean estimates imply that a near 75 basis points increase in risk, causes market values to decline by almost 2.5% at impact. Consumption and investment demand decline by nearly 0.5 and 10 percentage points respectively, and causes output to fall by about 2.5%, and for a fairly protracted period of time.

The impulses follow a hump-shape usually peaked at around 5-6 quarters. Labor services and real wages also decline along with the fall in economic activity. Inflation falls as well; i.e. risk shocks act as demand shocks which pull output and inflation in the same direction.[39] Note that the impulse response of investment to a risk shock is large due to the high elasticity of investment demand with respect to q, whereas the impulse response of inflation is rather small due to high degrees of nominal rigidities (i.e. the estimated Phillips curves are flat). Unexpectedly, dividends increase as a result of the risk shock despite the decline in economic activity. This is because corporations in the model do not follow an explicit dividend policy, and dividends are determined as a residual after paying for wages, taxes and investment. Given that investment demand declines sharply after a positive risk shock, dividend payments actually increase.[40]

A positive innovation in the Taylor rule (see Figure 5) also leads to qualitatively similar impulse responses from model variables. A 20 basis points increase in the nominal interest rate (80 basis points annualized), causes about an 80 basis points decline in market values. Output decreases by about 55 basis points with a hump-shaped response peaked with a 5 quarter lag. Inflation also acts with a similar hump-shape, but the response magnitudes are again small since the estimated Phillips curve is flat.[41]

Figure 6 plots the impulse responses of the model variables to an innovation in the investment-specific technological change shock (i.e. investment shock). These shocks cause an increase in invesment and output, but a decrease market values as the value of installed capital owned by firms falls. Consumption also falls as agents substitute demand to investment goods.

The impulse responses for the other shocks can be summarized as follows: Productivity shocks increase output and market values while causing a reduction in the inflation rate. Consumption demand shocks increase consumption demand at the expense of investment, but its net effect is to increase output, interest rates and market values. Government expenditure shocks behave in a

[39] Note that open economy interactions, which the model abstracts from, may be important for risk shocks. An increase in risk would also depreciate the dollar, and may cause a temporary increase in inflation due to exchange rate pass-through in imported goods.

[40] A more elaborate modeling of corporate dividend payout policy would improve this feature, but I do not expect that the results on the contribution of risk shocks would be significantly altered. I leave this issue for further research.

[41] I experimented with incorporating more restrictive priors on these parameters to make the inflation response to the interest rate more responsive. The basic results regarding the role of risk shocks were essentially the same.

similar fashion although the composition of demand is altered to favor government expenditure at the expense of consumption and investment. Both price and wage cost-push shocks act as adverse supply shocks; they reduce output while increasing inflation, and present a less favorable tradeoff between inflation and output for the central bank. Finally, dividend shocks only affect market values, but not the real side of the economy, as these shocks are modeled as transfers between firms and government.

4.2 Forecast Error Variance Decomposition

Table 5 reports the forecast error variance decomposition (FEVD) of output, inflation, the federal funds rate, real market value, and investment at different forecast horizons with the benchmark estimation.[42] Risk shocks account for only a small portion of the variation in market values. The variation in market values are mainly captured by investment demand shocks (reported as part of overall demand which also includes the contribution of consumption and government expenditure shocks). Risk shocks are very important in accounting for output and investment fluctuations, especially in the shorter horizons. At the 1 year horizon, risk shocks account for 78.5% of the variation in output, 77.3% of the variation in investment, but only 1.9% of the variation in inflation. Risk shocks also capture about a quarter to a half of the variation in the federal funds rate at medium-term horizons.

Demand shocks account for about a third of the variation in output, with higher contributions at the longer horizons since, except for consumption shocks, these shocks are very persistent.[43] They account for a very small portion of the variation in inflation and Federal Funds rate however. Productivity shocks do not seem to play an important role for explaining variation in output at the shorter horizons; at 1 year horizon its contribution is only 5.2%, and it asymptotically explains about 16.5% of the variation in output.

Cost-push shocks explain most of the variation in inflation at all forecast horizons similar to the findings in SW. Monetary shocks do not play a major role, except for explaining fluctuations

[42] I follow SW, and use the mode of the posterior estimates to conduct the forecast error variance decompositions and the historical decompositions presented in the next subsection.

[43] Justiniano et al. (2009) also find an important role for investment shocks in explaining output volatility.

in the Federal Funds rate in the shorter horizons. Finally, dividend shocks are not quantitatively significant, even for market values.

I also conducted a FEVD exercise using the parameter estimates obtained from estimation with HP-filtered data. Most of the results are similar to the benchmark case, but there are some important differences. In particular, with estimates using HP-filtered data, risk shocks account for almost all of the variation in market values at all forecast horizons, in contrast to the benchmark FEVD which emphasized investment shocks. In other words, risk shocks explain the variation of market values at the business cycle frequencies whereas the low frequency movements are mainly captured by shocks to investment-specific technological change.[44]

Note that demand-type shocks (i.e. risk and demand shocks) account for a substantial amount of variation in output even in longer horizons. This is true for FEVD exercises conducted from estimates using first-differenced or HP-filtered data. At face value, this result may seem contradictory to the neo-classical growth model, which emphasizes the role of productivity shocks to account for long run growth, and also the structural VAR (with long-run restrictions) literature which emphasizes the role of supply-type shocks in accounting for the asymptotic forecast error variance of output and other real variables (Shapiro and Watson, 1989).[45] Note however that all the shocks in the model are stationary, and the model's deterministic linear trends from population and productivity growth have been taken out. Therefore, the results basically indicate that demand type shocks are important to account for variation of variables at all forecast horizons, including their asymptotic variance, but only for the stationary components of these data (defined either as linearly-detrended or HP-detrended data). The results do not imply that these shocks can account for the trends in the same data series.[46] The results presented here do stand in contrast with the Real Business Cycle (RBC) literature however, which emphasizes the role of productivity shocks even at the business cycle frequencies.

[44] Another important difference between the FEVD exercises using estimates from HP-filtered vs. first-differenced data is that, with the former, the contribution of risk shocks to investment variation is found to be much smaller. This is because the estimate for the elasticity of investment to Tobin's q, x_2, is rather small with HP-filtered data.

[45] SW also attribute a bigger role for supply-type shocks. They find that about 80% of the variation of output at long forecast horizons is due to productivity and wage mark-up (i.e. labor supply) shocks.

[46] In other words, if we had allowed for unit root processes in productivity and investment-specific technological change, then these shocks would indeed capture all the variation in output asymptotically as in the structural VAR literature. See Pakko (2002) and DiCecio (2009) for examples of unit roots in productivity shocks.

4.3 Historical Decomposition

Figure 7 plots the Kalman-smoothed estimates of the risk variable, $\widehat{\phi}$, along with the NBER recession dates, for the benchmark estimation. Risk is countercyclical with regards to the business cycle; i.e. it tends to decline during expansions and increase during recessions. The correlation of detrended output with the smoothed estimates of risk is -0.56, and risk leads output by about a quarter. The increase in risk seems especially severe for the recessions after the 70's, with the exception of the 1991 recession. The rest of the 90's is characterized by a steadily declining level of risk, consistent with the sharp increase in stock prices and the strong economic expansion observed during this period.[47]

The historical decomposition of (linearly-detrended) output is depicted in Figure 8.[48] The decomposition attributes the expansion during the late 50's and early 60's to favorable cost-push shocks, positive demand shocks, and productivity which is steadily increasing during this period.[49] As expected, the recession in the mid-70's is mainly driven by adverse cost-push shocks reflecting the impact of the oil crisis, but also by the increase in risk shocks during this period. The recessions in the early 80's are driven partly by monetary policy shocks reflecting the impact of the Fed's efforts to curb high inflation during this period by raising interest rates above and beyond what the Taylor rule would imply. The decomposition clearly identifies the fall in risk as a positive contributor to the expansion in the 90's. Demand during this period is contributing negatively to output, although most of this reflects the fall in government expenditure and the trade balance (note that net exports is treated as part of government expenditure demand in the estimation similar to SW). The expansion between 2001 and 2008 is mainly driven by gains in productivity, although loose monetary policy also seems to have played a role. The fall in output during 2008 and 2009 is mainly driven by the increase in risk.

Figure 9 plots the historical decompositions of the (GDP-deflator) inflation rate. Consistent

[47] This characterization of risk implied from stock price data is also consistent with the implied risk from debt data in Gilchrist et al. (2009).

[48] The historical decomposition refers to the *cumulative* impact of the estimated series of each shock on a given variable. The earlier points are less reliable due to the lack of data; for the initial condition, the shocks were weighted by their relative importance in the asymptotic forecast error variance decomposition of the given variable.

[49] Note that the contribution of productivity to output here reflects the contribution solely to linearly-detrended output. The trend growth in output is fully driven by secular growth in population and productivity.

with the FEVD exercise conducted in the previous subsection, most of the historical variation in inflation rates are accounted by cost-push shocks, with productivity and risk shocks being secondary contributors. Monetary shocks do not seem to play much of a role for inflation due to the flat Phillips curve estimates. This is in line with the findings in SW, although they attribute a bigger role for monetary shocks during the earlier years in their sample.

Figure 10 plots the historical decomposition of the Federal Funds rate. The contribution of monetary shocks indicate that monetary policy was lax in the early stages of the oil crisis, but was tightened aggressively during the late 70's and early 80's under Volcker. Again in line with conventional wisdom, monetary policy seems somewhat loose during the late 90's and early 2000's, especially between 1998-2004, when interest rates are lower than what the Taylor rule (without the monetary shocks) would predict.[50] Interestingly, monetary policy seems tighter than what is suggested by the regular Taylor rule for the year 2009, an indication that the zero-bound on the nominal interest rate is binding.

Figure 11 plots the historical decomposition of real (linearly-detrended) market values. As expected from the results presented in the previous subsection, demand shocks (in particular investment shocks) account for almost all of the historical variation in market values. In Figure 12, I conduct an analogous historical decomposition for market values using the alternative estimation utilizing HP-filtered data, which captures only the business cycle components of the data series. Now, risk shocks account for almost all of the historical variation in market values. This suggests that, even though the secular movements in stock prices are driven by investment shocks, the movements at the business cycle frequencies are mainly attributable to changes in the required return on stocks, i.e. risk shocks.

5 Conclusion

This paper explores the source of business cycle fluctuations with emphasis on the role of risk shocks; i.e. shocks that simultaneously affect stock values through changes in their required return,

[50] The Fed has been blamed for being too accommodative during this period, and has been accused of ignoring and contributing to the sharp increases in stock prices and housing prices.

and investment demand through changes in the cost-of-capital. These shocks are well identified in the Bayesian estimation through the use of corporate market value and dividend data. Variance decomposition exercises show that risk shocks account for a substantial part of the volatility in real variables, such as output and investment. They also account for most of the volatility in the stock market, but only at the business cycle frequencies of the data. The low frequency movements in stock prices are accounted by investment shocks, which are the only shocks that can simultaneously increase investment but lower market values. Historical decomposition exercises point to the important role played by risk shocks in the run up of stock prices and output in the late 90's and their reversal during the 2001 and 2008 recessions.

Risk shocks in my model, as in SW, are introduced in a somewhat ad-hoc fashion; therefore future work should concentrate on finding better micro-foundations for these shocks.[51] Risk shocks are also likely to be linked to other developments in the economy. For example, the oil price hikes in the 70's acted as cost-push shocks, but may also have increased the level of perceived risk due to political instability. The oil crisis also led to inflationary expectations, which may have led to an increase in risk-premia due to the rise in uncertainty surrounding the rate of inflation and the central bank's possible response to this inflationary pressure. This points to a possible relationship between risk and inflationary expectations. These and other possible relationships between risk and other variables and shocks need to be explored further. I leave these issues for further research.

It is also an open question in the literature as to whether a central bank should condition on stock market and other asset price movements when it sets its interest rate policy (c.f. Bernanke and Gertler, 2001, and Bullard and Schaling, 2002). Since stock prices lead the business cycle, they contain informative (but noisy) signals regarding the evolution of output and inflation in the near future. Stock prices are very volatile however; conditioning on them would cause frequent changes in interest rates and may increase the variability of output and inflation. The optimal response of a central bank is therefore ambiguous and depends on the quantitative importance of these effects. The investigation of optimal monetary policy vis-à-vis stock prices within the context of the model

[51] In particular, changes in risk-premia could reflect the presence of increased volatility as opposed to a rise in aversion to risk-taking on the part of agents. This would require including volatility shocks in the model, but precludes estimation of the parameters using the linearized version of the model through the Kalman filter (Fernandez-Villaverde, 2009).

presented in this paper is also left for further research.

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A Equilibrium Conditions of the Model and Log-Linearization

This appendix presents the equilibrium conditions of the model and their log-linearized versions after detrending.[52] For the log-linearized equations, a variable with no subscript refers to the steady-state value of the variable, and a hat over a variable with a time-subscript indicates the variable's log-deviation from its steady-state (i.e. for variable y_t, we have $\widehat{y}_t = \log y_t - \log y$).

A.1 Households

The Lagrangian describing the households' problem is

$$\begin{aligned}
&\max E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \frac{\upsilon_t}{1-\sigma} C_{s,t}^{1-\sigma}(j) \exp\left(\frac{\sigma-1}{1+\vartheta} \xi h_t^s(j)^{1+\vartheta}\right) N_t \right. \\
&+\Lambda_t(j) \left[(1-\tau_h) \left(\frac{W_t(j)}{W_t}\right)^{1-\Psi_t} \frac{W_t}{P_t} N_t h_t + (1-\tau_d) \frac{D_t}{P_t} s_{t-1}(j) + \frac{B_{t-1}(j)}{P_t} - \frac{B_t(j)}{\phi_t R_t P_t} - \frac{T_t}{P_t} \right. \\
&\left. - N_t C_t(j) - \frac{V_t}{P_t}\left[s_t(j) - s_{t-1}(j)\right] - \frac{\kappa_w (\Psi - 1)(1-\tau_h)}{2} \left(\frac{W_t(j)/W_{t-1}(j)}{\pi\gamma(\pi_{t-1}/\pi)^{\eta_w}} - 1\right)^2 \frac{W_t}{P_t} N_t h_t \right] \\
&\left. +\Lambda_t(j)\,\Omega_{h,t}(j)(1-\tau_h) \frac{W_t}{P_t} N_t \left[h_t^s(j) - \left(\frac{W_t(j)}{W_t}\right)^{-\Psi_t} h_t \right] \right\}
\end{aligned}$$

where Λ_t is the Lagrange multiplier with respect to the budget constraint, and $\Omega_{h,t}$ is the relative Lagrange multiplier with respect to the labor demand curve. Note that the labor demand is already replaced in the budget constraint (but not in the utility function), and the multiplier $\Omega_{h,t}$ is scaled for analytical convenience.[53]

The equilibrium conditions obtained from the households are

($A1$) Definition of surplus consumption:

$$\begin{aligned}
C_{s,t} &= C_t - \zeta C_{t-1} \\
(1-\zeta/\gamma)\,\widehat{c}_{s,t} &= \widehat{c}_t - (\zeta/\gamma)\,\widehat{c}_{t-1}
\end{aligned}$$

[52] Simple algebraic manipulation of these expressions yield the 15 core model equations presented in Section 2.7.

[53] As shown in equation (A3), $\Omega_{h,t}$ is the inverse of the mark-up of (after-tax) real wage over the marginal rate of substitution.

($A2$) First-order-condition (FOC) with respect to consumption:

$$\begin{aligned} \upsilon_t C_{s,t}^{-\sigma} \exp\left(\frac{\sigma-1}{1+\vartheta}\xi h_t^{1+\vartheta}\right) &= \Lambda_t \\ \widehat{\upsilon}_t - \sigma \widehat{c}_{s,t} + (\sigma-1)\,\xi \widehat{h}_t &= \widehat{\lambda}_t \end{aligned}$$

($A3$) FOC with respect to labor (after combining it with $A2$):

$$\begin{aligned} C_{s,t}\xi h_t^{\vartheta} &= (1-\tau_h)\frac{W_t}{P_t}\Omega_{h,t} \\ \widehat{c}_{s,t} + \vartheta \widehat{h}_t &= \widehat{wp}_t + \widehat{\Omega}_{h,t} \end{aligned}$$

($A4$) FOC with respect to wages:

$$\begin{aligned} &\left[\frac{\pi_t^w/\pi\gamma}{(\pi_{t-1}/\pi)^{\eta_w}} - 1\right]\frac{\pi_t^w/\pi\gamma}{(\pi_{t-1}/\pi)^{\eta_w}} \\ &\quad = \beta E_t\left\{\frac{\Lambda_{t+1}}{\Lambda_t}\left[\frac{\pi_{t+1}^w/\pi\gamma}{(\pi_t/\pi)^{\eta_w}} - 1\right]\frac{\pi_{t+1}^w/\pi\gamma}{(\pi_t/\pi)^{\eta_w}}\frac{\pi_{t+1}^w}{\pi_{t+1}}\frac{\eta h_{t+1}}{h_t}\right\} + \frac{\Psi_t}{(\Psi-1)\,\kappa_w}\left(\Omega_{h,t} - \frac{1}{\psi_t}\right) \\ &\widehat{\pi}_t^w - \eta_w \widehat{\pi}_{t-1} = \beta\eta\gamma^{1-\sigma}\left(E_t\widehat{\pi}_{t+1}^w - \eta_w\widehat{\pi}_t\right) + \frac{1}{\kappa_w}\left(\widehat{\Omega}_{h,t} + \widehat{\psi}_t\right) \end{aligned}$$

($A5$) Relating wage inflation and price inflation:

$$\begin{aligned} \pi_t^w &= \frac{W_t/P_t}{W_{t-1}/P_{t-1}}\pi_t \\ \widehat{\pi}_t^w &= \widehat{wp}_t - \widehat{wp}_{t-1} + \widehat{\pi}_t \end{aligned}$$

($A6$) FOC with respect to bonds:

$$\begin{aligned} 1 &= E_t\left[\beta\frac{\Lambda_{t+1}}{\Lambda_t}\frac{\phi_t R_t}{\pi_{t+1}}\right] \\ \widehat{\lambda}_t &= E_t\widehat{\lambda}_{t+1} + \widehat{r}_t - E_t\widehat{\pi}_{t+1} + \widehat{\phi}_t \end{aligned}$$

($A7$) Definition of real returns from shares:

$$
\begin{aligned}
r_t^s &= \frac{V_t/P_t + (1-\tau_d) D_t/P_t}{V_{t-1}/P_{t-1}} \\
\widehat{r}_t^s &= \beta\eta\gamma^{1-\sigma}\widehat{vp}_t + \left(1-\beta\eta\gamma^{1-\sigma}\right)\widehat{dp}_t - \widehat{vp}_{t-1}
\end{aligned}
$$

($A8$) Asset pricing equation for shares:

$$
\begin{aligned}
1 &= E_t\left[\beta\frac{\Lambda_{t+1}}{\Lambda_t} r_{t+1}^s\right] \\
\widehat{\lambda}_t &= E_t\widehat{\lambda}_{t+1} + E_t\widehat{r}_{t+1}^s
\end{aligned}
$$

A.2 Intermediate goods producers

The Lagrangian describing the intermediate goods producers' problem is

$$
\begin{aligned}
&\max E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t \Bigg\{ (1-\tau_d)\Bigg[(1-\tau_y)(1-\tau_s)\left(\frac{P_t(i)}{P_t}\right)^{1-\Theta_t} Y_t - (1-\tau_y)\frac{W_t}{P_t} N_t h_t(i) - X_t(i) \\
&+\tau_y \delta_a K_{t-1}(i) - \frac{\kappa_p(\Theta-1)(1-\tau_y)(1-\tau_s)}{2}\left(\frac{P_t(i)/P_{t-1}(i)}{\pi(\pi_{t-1}/\pi)^{\eta_p}} - 1\right)^2 Y_t - \frac{\kappa_u}{\chi}\left[u_t(i)^{\chi} - 1\right] K_{t-1}(i)\Bigg] \\
&+\Omega_t^f(i)(1-\tau_d)(1-\tau_y)(1-\tau_s)\left[z_t\left[u_t(i) K_{t-1}(i)\right]^{\alpha}\left[A_t N_t h_t(i)\right]^{1-\alpha} - (\eta\gamma)^t f - \left(\frac{P_t(i)}{P_t}\right)^{-\Theta_t} Y_t\right] \\
&+q_t(i)\left[(1-\delta) K_{t-1}(i) + z_t^x X_t(i) - \frac{\kappa_x}{2}\left(\frac{X_t(i)}{\eta\gamma X_{t-1}(i)} - 1\right)^2 X_t - K_t(i)\right]\Bigg\}
\end{aligned}
$$

where q_t is the Lagrange multiplier with respect to the law of motion of capital, and Ω_t^f is the relative Lagrange multiplier with respect to the demand curve of the final goods producers. Note that this demand function is already replaced in the definition of dividends, and the multiplier Ω_t^f is scaled for analytical convenience.[54]

The equilibrium conditions obtained from the intermediate goods producers are

[54] As shown in equation (A9), Ω_t^f is the marginal labor cost (i.e. the difference between wage and marginal revenue product of labor).

($A9$) FOC with respect to labor:

$$
\begin{aligned}
(1-\tau_s)\,\Omega_t^f\,(1-\alpha)\,\frac{Y_t+(\eta\gamma)^t f}{h_t} &= \frac{W_t}{P_t}N_t \\
\widehat{\Omega}_{f,t}+\frac{1}{\theta}\widehat{y}_t-\widehat{h}_t &= \widehat{wp}_t
\end{aligned}
$$

($A10$) FOC with respect to capital:

$$
\begin{aligned}
q_t &= E_t\left[\beta\frac{\Lambda_{t+1}}{\Lambda_t}\left\{(1-\delta)\,q_{t+1}+(1-\tau_d)\left[\begin{array}{c}\Omega^f_{f,t+1t}\,(1-\tau_y)\,(1-\tau_s)\,\alpha\frac{Y_{t+1}+(\eta\gamma)^{t+1}f}{K_t} \\ -\frac{\kappa_u}{\chi}\left[u_{t+1}\,(i)^{\chi}-1\right]+\tau_y\delta_a\end{array}\right]\right\}\right] \\
\widehat{q}_t &= \beta\gamma^{-\sigma}E_t\left[(1-\delta)\,\widehat{q}_{t+1}+\frac{(1-\tau_y)\,(1-\tau_s)\,\alpha}{k/y}\left(\widehat{\Omega}_{f,t+1}+\frac{1}{\theta}\widehat{y}_{t+1}-\widehat{k}_t-\widehat{u}_{t+1}\right)\right]-\widehat{\lambda}_t+E_t\widehat{\lambda}_{t+1}
\end{aligned}
$$

($A11$) FOC with respect to utilization rate:

$$
\begin{aligned}
\Omega_{f,t}\alpha\frac{Y_t+(\eta\gamma)^t f}{u_t} &= \kappa_u u_t^{\chi-1}K_{t-1} \\
\widehat{\Omega}_{f,t}+\frac{1}{\theta}\widehat{y}_t &= \chi\widehat{u}_t+\widehat{k}_{t-1}
\end{aligned}
$$

($A12$) FOC with respect to price:

$$
\left[\frac{\pi_t/\pi}{(\pi_{t-1}/\pi)^{\eta_p}}-1\right]\frac{\pi_t/\pi}{(\pi_{t-1}/\pi)^{\eta_p}}=\beta E_t\left\{\frac{\Lambda_{t+1}}{\Lambda_t}\left[\frac{\pi_{t+1}/\pi}{(\pi_t/\pi)^{\eta_p}}-1\right]\frac{\pi_{t+1}/\pi}{(\pi_t/\pi)^{\eta_p}}\frac{Y_{t+1}}{Y_t}\right\}+\frac{\Theta_t}{(\Theta-1)\,\kappa_p}\left(\Omega_{f,t}-\frac{1}{\theta_t}\right)
$$

$$
\widehat{\pi}_t-\eta_p\widehat{\pi}_{t-1}=\beta\eta\gamma^{1-\sigma}\left(E_t\widehat{\pi}_{t+1}-\eta_p\widehat{\pi}_t\right)+\frac{1}{\kappa_p}\left(\widehat{\Omega}_{f,t}+\widehat{\theta}_t\right)
$$

($A13$) FOC with respect to investment:

$$
\begin{aligned}
\left(\frac{X_t}{\eta\gamma X_{t-1}}-1\right)\frac{X_t}{\eta\gamma X_{t-1}} &= \beta E_t\left[\frac{\Lambda_{t+1}}{\Lambda_t}\frac{q_{t+1}}{q_t}\left(\frac{X_{t+1}}{\eta\gamma X_t}-1\right)\frac{X_{t+1}^2}{\eta\gamma X_t^2}\right]+\frac{1}{\kappa_x}\left(z_t^x-\frac{1-\tau_d}{q_t}\right) \\
\widehat{x}_t-\widehat{x}_{t-1} &= \beta\eta\gamma^{1-\sigma}\left(E_t\widehat{x}_{t+1}-\widehat{x}_t\right)+\frac{1}{\kappa_x}\left(\widehat{q}_t+\widehat{z}_t^x\right)
\end{aligned}
$$

($A14$) The law of motion of capital:

$$
\begin{aligned}
K_t &= (1-\delta) K_{t-1} + z_t^x X_t - \frac{\kappa_x}{2}\left(\frac{X_t}{\eta\gamma X_{t-1}} - 1\right)^2 X_t \\
\eta\gamma \widehat{k}_t &= (1-\delta)\widehat{k}_{t-1} + (\eta\gamma - 1 + \delta)\left(\widehat{x}_t + \widehat{z}_t^x\right)
\end{aligned}
$$

($A15$) Production function:

$$
\begin{aligned}
Y_t &= z_t \left(u_t K_{t-1}\right)^{\alpha} \left(A_t N_t h_t\right)^{1-\alpha} - \gamma^t f \\
\widehat{y}_t &= \theta\left[\widehat{z}_t + \alpha\left(\widehat{u}_t + \widehat{k}_{t-1}\right) + (1-\alpha)\widehat{h}_t\right]
\end{aligned}
$$

($A16$) Dividends:

$$
\begin{aligned}
\frac{D_t}{P_t} &= (1-\tau_y)\left[(1-\tau_s) Y_t - \frac{W_t}{P_t} N_t h_t\right] - X_t + \tau_y \delta_a K_{t-1} - \Phi_{p,t} + (\eta\gamma)^t \Phi_{d,t} \\
\frac{dp}{y}\widehat{dp}_t &= (1-\tau_y)\left[(1-\tau_s)\widehat{y}_t - (1-\alpha)\left(\widehat{wp}_t + \widehat{h}_t\right)\right] - \frac{x}{y}\widehat{x}_t + \tau_y \delta_a \frac{k}{y}\widehat{k}_{t-1} + \widehat{\Phi}_{d,t}
\end{aligned}
$$

A.3 Taylor rule and market clearing conditions

($A17$) Taylor rule:

$$
\begin{aligned}
\log R_t &= \rho_r \log R_{t-1} + (1-\rho_r)\left[a_\pi \log\frac{\pi_t}{\pi} + a_y \log\frac{Y_t}{Y_t^n} + a_g \log\frac{Y_t/Y_{t-1}}{Y_t^n/Y_{t-1}^n} + \log R\right] + i_t \\
\widehat{r}_t &= \rho_r \widehat{r}_{t-1} + (1-\rho_r)\left\{a_\pi \widehat{\pi}_t + a_y\left(\widehat{y}_t - \widehat{y}_t^n\right) + a_g\left[\left(\widehat{y}_t - \widehat{y}_{t-1}\right) - \left(\widehat{y}_t^n - \widehat{y}_{t-1}^n\right)\right]\right\} + \widehat{i}_t
\end{aligned}
$$

($A18$) Goods market clearing condition:

$$
\begin{aligned}
N_t C_t + X_t + G_t &= Y_t - \Phi_{w,t} - \Phi_{p,t} \\
\frac{c}{y}\widehat{c}_t + \frac{x}{y}\widehat{x}_t + \frac{g}{y}\widehat{g}_t &= \widehat{y}_t
\end{aligned}
$$

Table 1: NIPA and Balance sheet: Model vs. Data (1955-2009)			
(relative to output)	Symbol	Model	Data[a]
Income account (%)			
Compensation of employees	wp/y	65.31	65.31
Depreciation of capital	$\delta_a k/y$	10.91	10.91
Indirect business taxes	τ_s	9.01	8.90
Earnings			
Income Tax		4.73	4.73
Dividends	dp/y	4.90	4.90
Retained Earnings		5.14	5.25
Total Income		100	100
Expenditure account (%)			
Consumption	c/y	64.82	64.82
Investment	x/y	16.06	16.06
Government Expenditure	g/y	19.12	19.12
Total Expenditure		100	100
Capital and Market Value (qrt.)			
Capital (repl. cost, end of period)	$\eta\gamma k/y$	7.816	7.816
Market Value	vp/y	6.129	6.129

Notes: [a]The income account and balance sheet ratios refer to the non-financial corporate sector, and the expenditure account refers to the economy as a whole. The data number for government expenditures includes net exports. Net stock repurchases are included in dividends, but excluded from retained earnings, consistent with the model.

Table 2: Calibrated Parameters	Symbol	Value
Population growth factor	η	1.0035
Trend growth factor of output	γ	1.0042
Trend inflation factor	π	1.0087
Adjusted time-discount factor	$\widetilde{\beta}= \beta\eta\gamma^{1-\sigma}$	0.9938
Share of capital in production	α	0.2822
Economic depreciation rate	δ	0.0128
Accounting depreciation rate	δ_a	0.0140
Share of government expenditure	g/y	0.1912
Average nominal interest rate	R	1.0136
Tax rate on labor income	τ_h	0.35
dividend income	τ_d	0.2219
sales	τ_s	0.0901
firm income	τ_y	0.3200

Table 3: Prior and Posterior Distributions of Structural and Policy Parameters

	Prior[a] (mean, st.dev.)	Posterior first-differenced data[b]			Posterior HP-filtered data[b]
Parameter		Mode	Mean	[5% , 95%]	Mode
Habit, ζ	B (0.7, 0.1)	0.950	0.950	[0.926 , 0.973]	0.972
Risk aversion, σ	N (1.5, 0.37)	0.983	0.993	[0.907 , 1.080]	0.960
Labor supply, ϑ	N (2.0, 0.75)	2.501	2.566	[1.607 , 3.558]	2.375
Utilization, $\chi/(1+\chi)$	B (0.5, 0.15)	0.079	0.102	[0.039 , 0.161]	0.067
Adj. cost - inv., κ_x	N (4.0, 1.5)	2.233	2.246	[1.399 , 3.135]	7.996
- price, κ_p^e	B (0.5, 0.1)	0.781	0.777	[0.734 , 0.822]	0.646
- wage, κ_w^e	B (0.5, 0.1)	0.921	0.915	[0.887 , 0.945]	0.831
Price mark-up, θ	N (1.5, 0.1)	1.668	1.674	[1.562 , 1.727]	1.700
Wage mark-up, ψ	N (1.5, 0.1)	1.601	1.622	[1.552 , 1.789]	1.579
Price indexation, η_p	B (0.5, 0.15)	0.065	0.085	[0.026 , 0.144]	0.250
Wage indexation, η_w	B (0.5, 0.15)	0.647	0.631	[0.496 , 0.778]	0.437
Taylor - inflation, a_π	N (1.5, 0.25)	1.436	1.468	[1.211 , 1.712]	1.061
- output gap, a_y	N (0.12, 0.05)	0.073	0.080	[0.047 , 0.113]	0.190
- output growth, a_g	N (0.12, 0.05)	0.224	0.217	[0.151 , 0.286]	0.150
- smoothing, ρ_i	N (0.75, 0.1)	0.830	0.832	[0.799 , 0.868]	0.770

Notes: [a]B: beta distribution, N: normal distribution, IG: inverse gamma distribution.

[b]The estimations use nine quarterly series from U.S. data covering 1955q1-2009q3. See the main text for data descriptions and sources.

Table 4: Prior and Posterior Distributions of Parameters related to Shock Processes

	Prior (mean, st.dev.)	Posterior first-differenced data			Posterior HP-filtered data
Parameter		Mode	Mean	[5% , 95%]	Mode
AR term - risk, ρ_ϕ	B (0.5, 0.2)	0.892	0.880	[0.834 , 0.927]	0.649
- consumption, ρ_υ	B (0.5, 0.2)	0.146	0.166	[0.063 , 0.266]	0.075
- investment, ρ_x	B (0.5, 0.2)	0.987	0.986	[0.976 , 0.996]	0.149
- gov., ρ_g	B (0.5, 0.2)	0.988	0.986	[0.978 , 0.994]	0.772
- productivity, ρ_z	B (0.5, 0.2)	0.971	0.966	[0.947 , 0.985]	0.820
- price, ρ_θ	B (0.5, 0.2)	0.692	0.669	[0.594 , 0.747]	0.071
- wage, ρ_ψ	B (0.5, 0.2)	0.203	0.207	[0.065 , 0.341]	0.062
- monetary, ρ_i	B (0.5, 0.2)	0.209	0.209	[0.107 , 0.311]	0.142
- dividend, ρ_d	B (0.5, 0.2)	0.816	0.815	[0.769 , 0.860]	0.669
MA term - price, ς_p	B (0.5, 0.2)	0.058	0.094	[0.010 , 0.177]	0.064
- wage, ς_w	B (0.5, 0.2)	0.119	0.158	[0.030 , 0.279]	0.070
Cross g&z, ρ_{gz}	B (0.5, 0.2)	0.780	0.727	[0.526 , 0.943]	0.821
St. dev. - risk, σ_ϕ	IG (0.5%, ∞)	0.74%	0.79%	[0.59% , 0.99%]	2.69%
- consumption, σ_υ	IG (0.5%, ∞)	0.29%	0.29%	[0.25% , 0.33%]	0.30%
- investment, σ_x	IG (0.5%, ∞)	0.24%	0.31%	[0.18% , 0.44%]	2.02%
- gov., σ_g	IG (0.5%, ∞)	1.85%	1.87%	[1.72% , 2.01%]	1.62%
- productivity, σ_z	IG (0.5%, ∞)	0.50%	0.50%	[0.46% , 0.54%]	0.47%
- price, σ_θ	IG (0.5%, ∞)	0.10%	0.10%	[0.08% , 0.12%]	0.20%
- wage, σ_ψ	IG (0.5%, ∞)	0.44%	0.43%	[0.37% , 0.50%]	0.48%
- monetary, σ_i	IG (0.5%, ∞)	0.20%	0.20%	[0.18% , 0.22%]	0.17%
- dividend, σ_d	IG (0.5%, ∞)	1.64%	1.65%	[1.52% , 1.78%]	1.51%

Table 5: Forecast Error Variance Decomposition (%)

Variable	Horizon (qrt.)	Risk	Demand[a]	Productivity	Cost[a]	Monetary	Dividend
Output	1	68.7	21.4	4.4	1.6	4.0	0.0
y	4	78.5	9.4	5.2	2.9	4.1	0.0
	10	74.3	10.6	8.5	3.4	3.1	0.0
	∞	43.2	36.5	16.5	2.3	1.5	0.0
Inflation	1	0.9	0.1	2.0	97.0	0.0	0.0
π	4	1.9	0.3	3.5	94.3	0.0	0.0
	10	3.6	0.7	5.3	90.4	0.1	0.0
	∞	4.9	1.8	5.5	89.3	0.6	0.0
Nom. interest	1	6.5	6.2	1.0	11.5	74.8	0.0
r	4	25.0	3.9	2.8	21.4	46.8	0.0
	10	53.4	2.6	4.1	16.5	23.5	0.0
	∞	64.1	5.5	3.6	12.1	14.7	0.0
Market value	1	8.2	89.4	0.0	0.1	0.9	1.3
vp	4	4.2	94.3	0.0	0.1	0.5	0.8
	10	2.0	97.2	0.0	0.1	0.3	0.4
	∞	3.2	94.7	1.6	0.2	0.2	0.1
Investment	1	81.8	8.7	2.6	2.3	4.6	0.0
x	4	77.3	11.8	3.9	3.2	3.9	0.0
	10	67.7	19.6	6.6	3.4	2.7	0.0
	∞	26.9	62.9	7.7	1.6	0.9	0.0

Notes: [a]Demand shocks refer to the sum of consumption, investment and government expenditure shocks. Cost shocks refer to the sum of price and wage cost-push shocks.

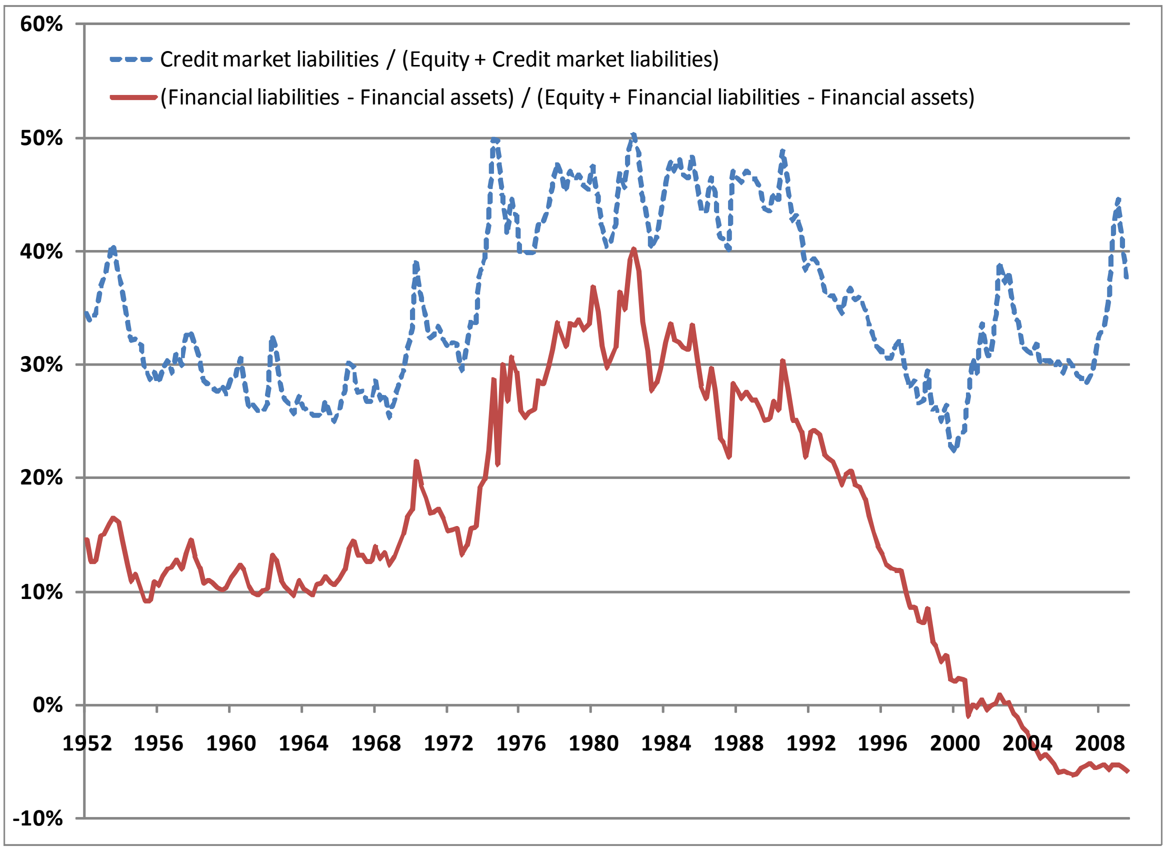

Figure 1: Debt financing as a ratio of total financing for U.S. non-financial corporations (stock measures)

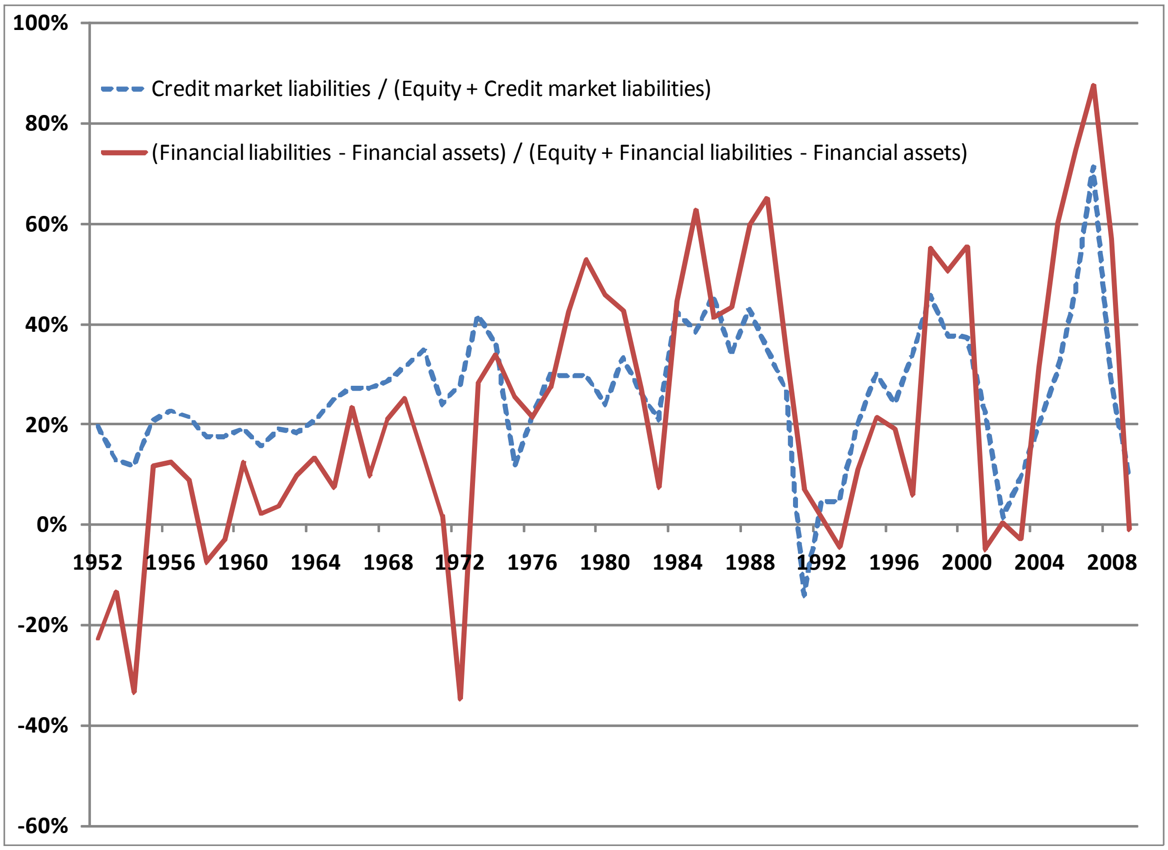

Figure 2: Debt financing as a ratio of total financing for U.S. non-financial corporations (flow measures)

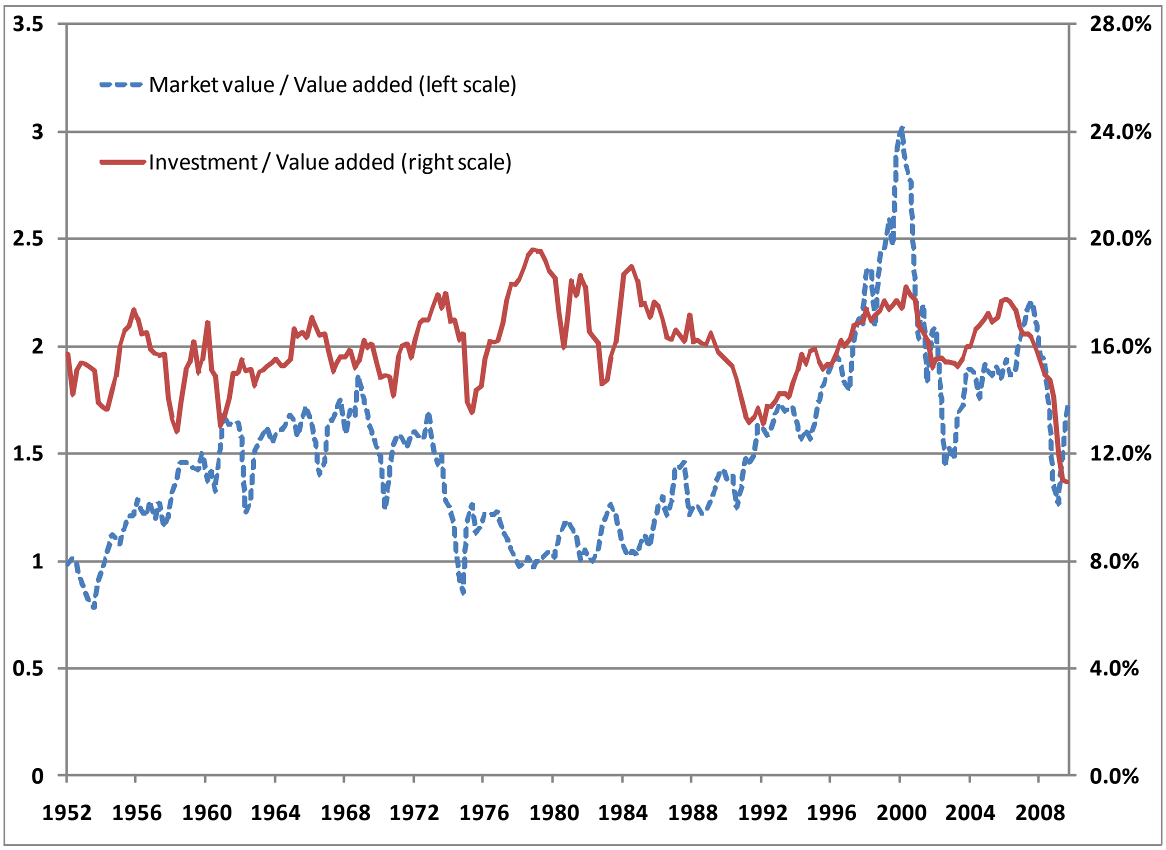

Figure 3: Investment and market value of the non-financial corporate sector (relative to their value added)

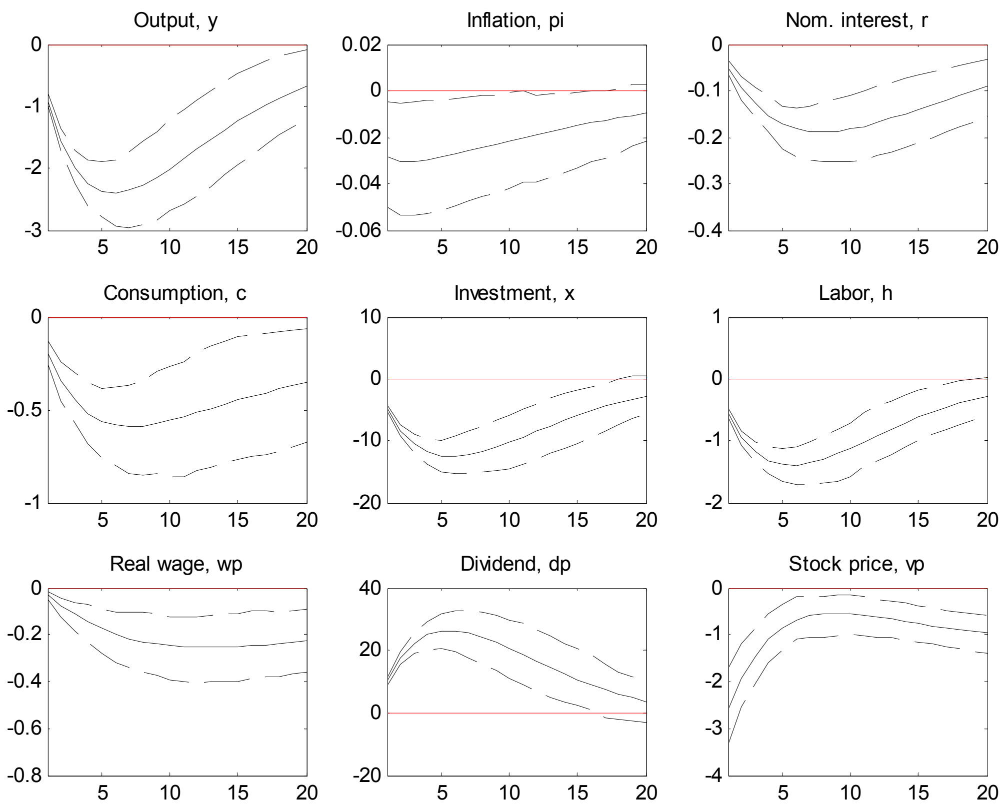

Figure 4: Impulse responses to 1 st.-dev. risk shock (%)

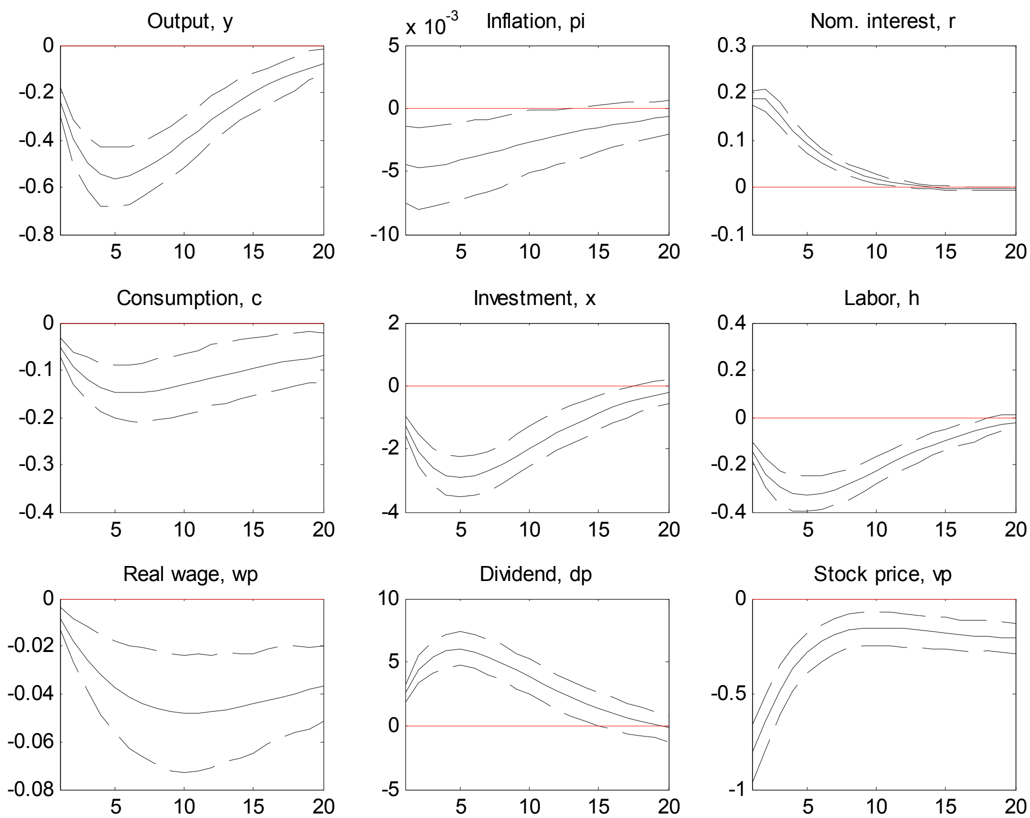

Figure 5: Impulse responses to 1 st.-dev. monetary policy shock (%)

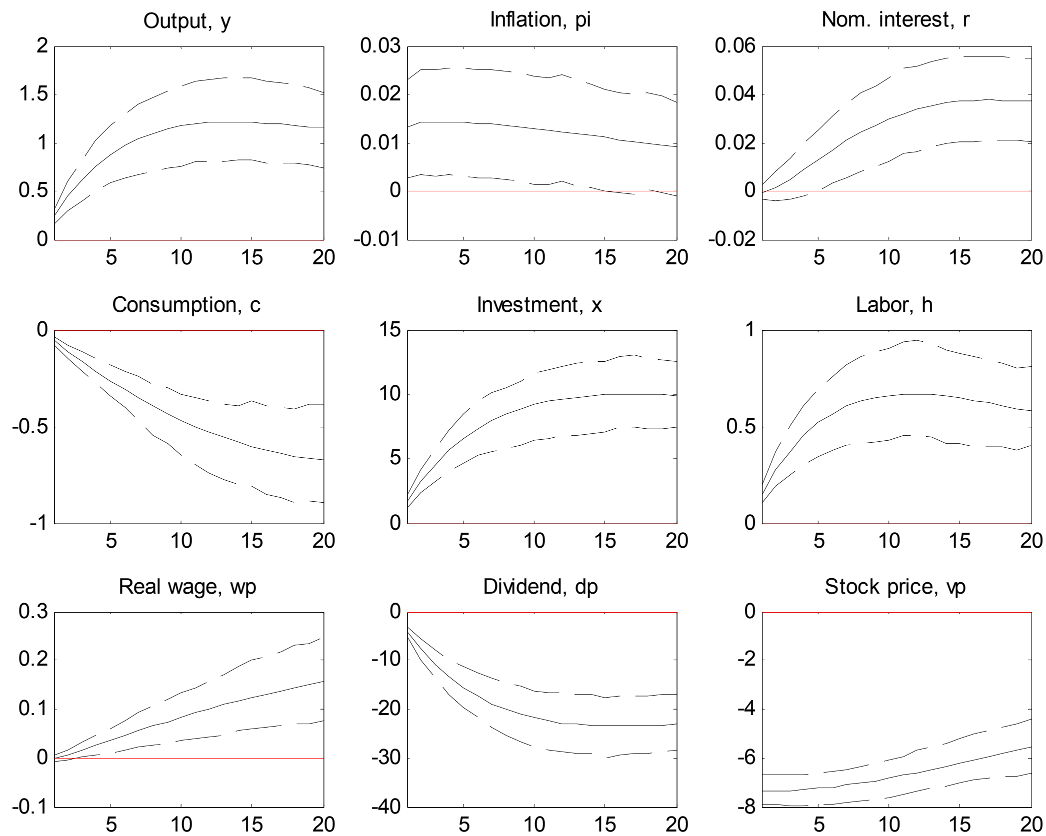

Figure 6: Impulse responses to 1 st.-dev. investment shock (%)

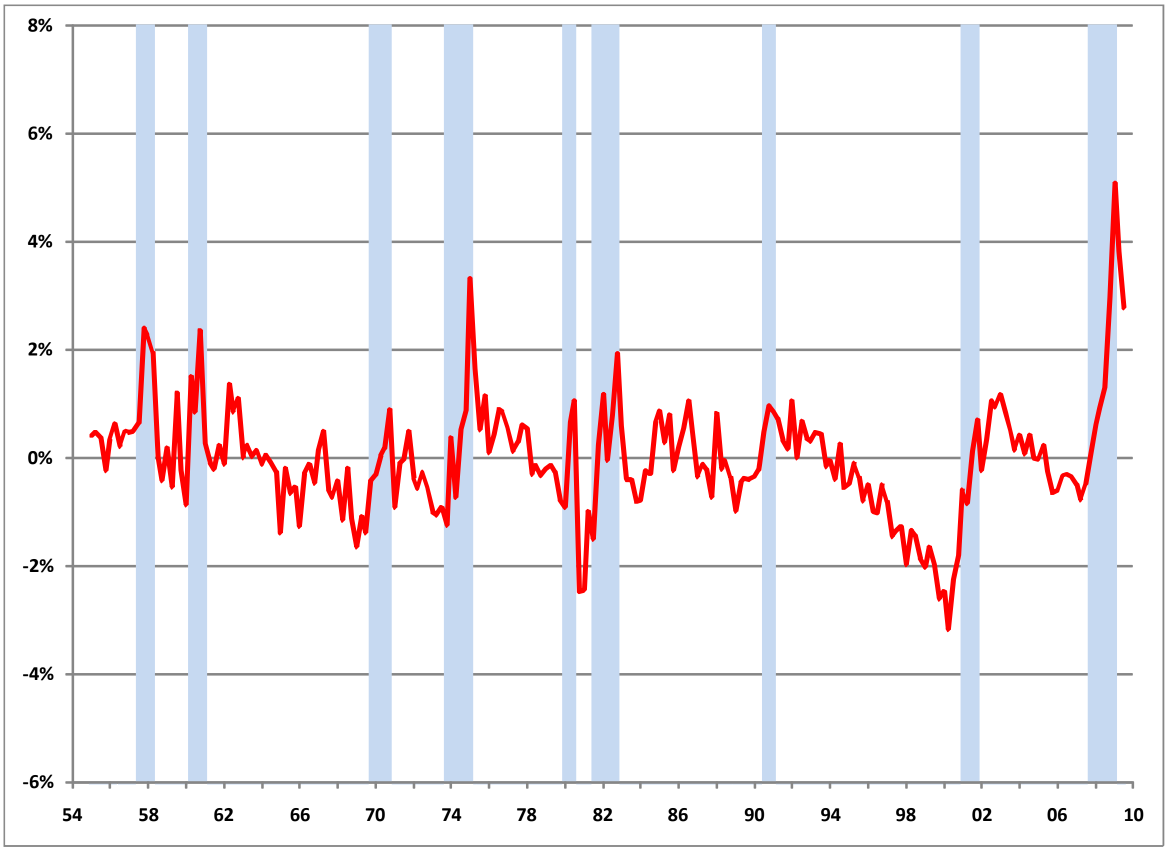

Figure 7: Smoothed estimates of risk, $\widehat{\phi}_t$, and NBER recession dates

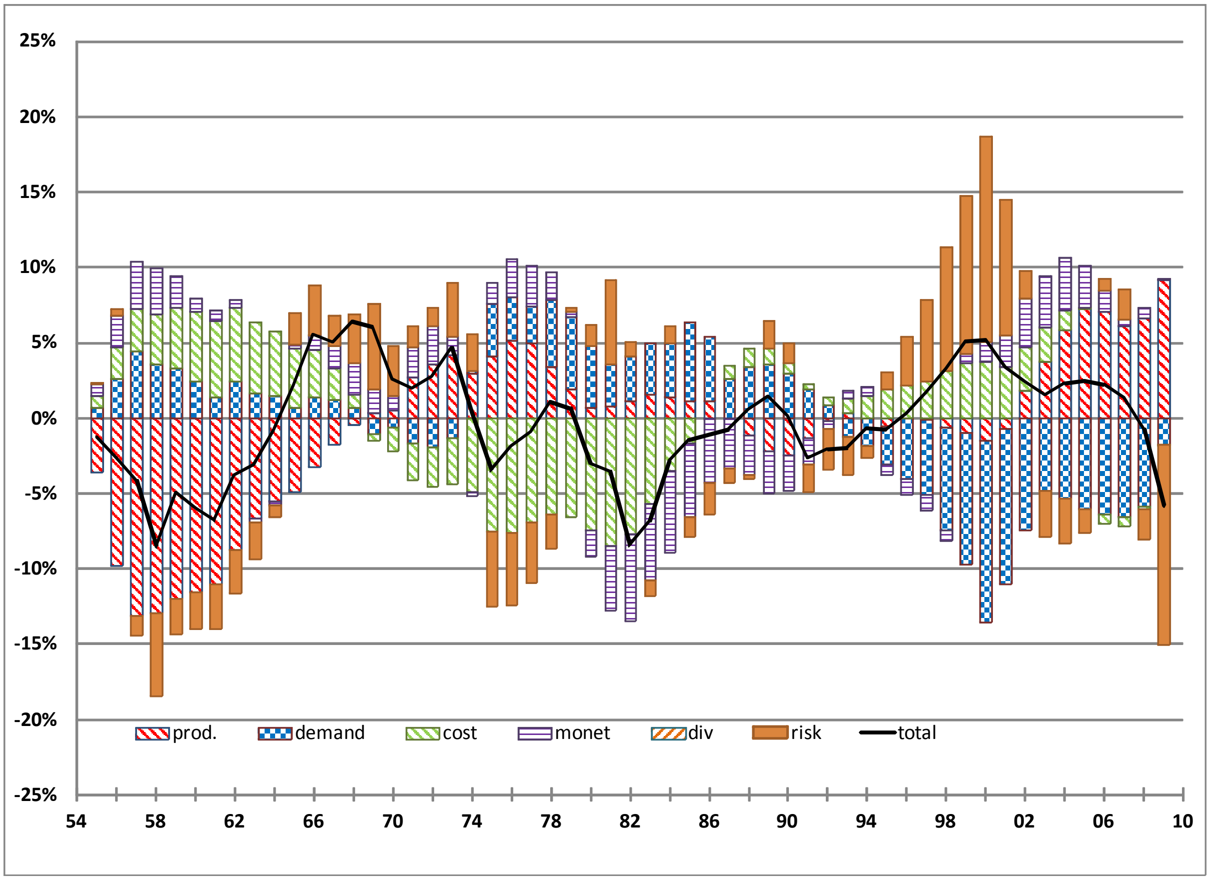

Figure 8: Historical decomposition of linearly-detrended output

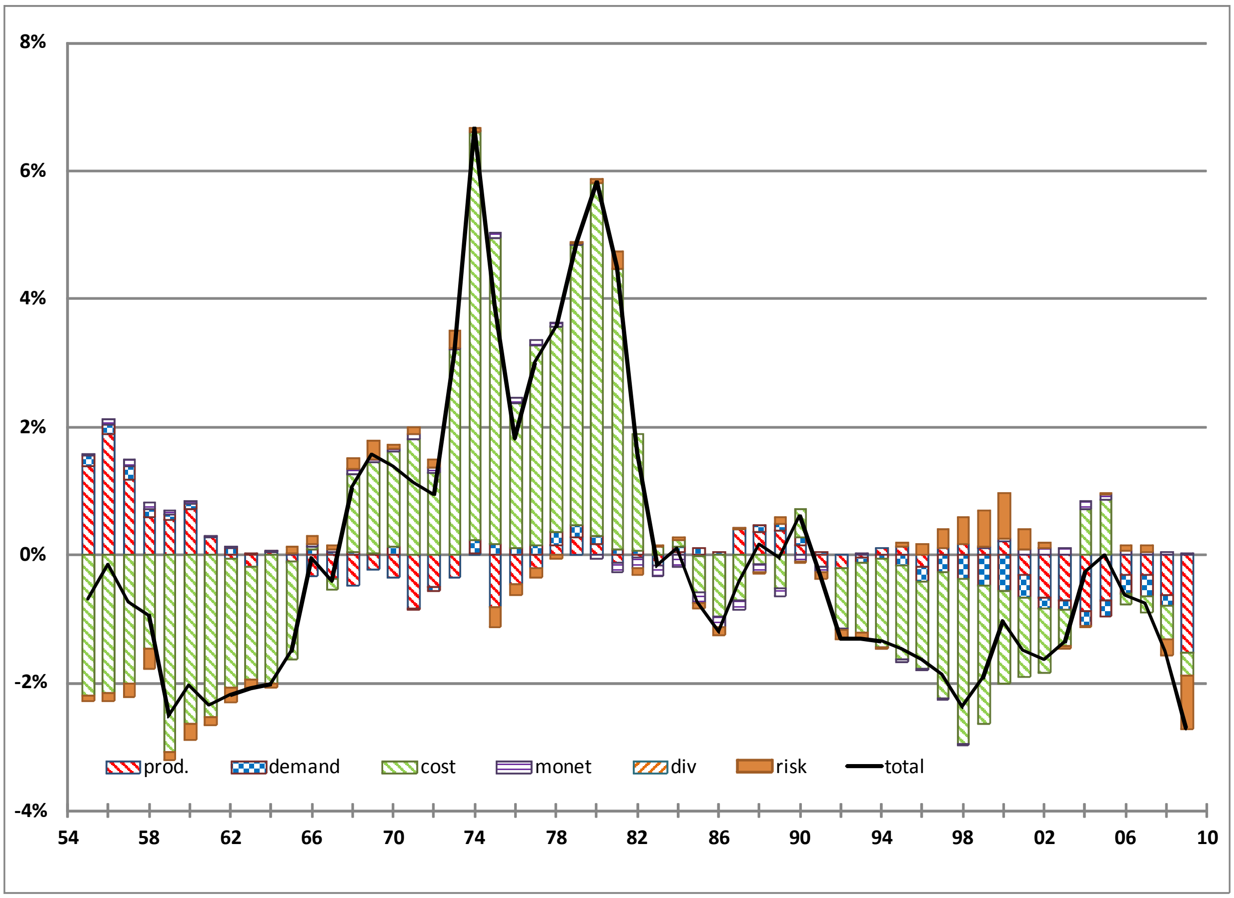

Figure 9: Historical decomposition of inflation

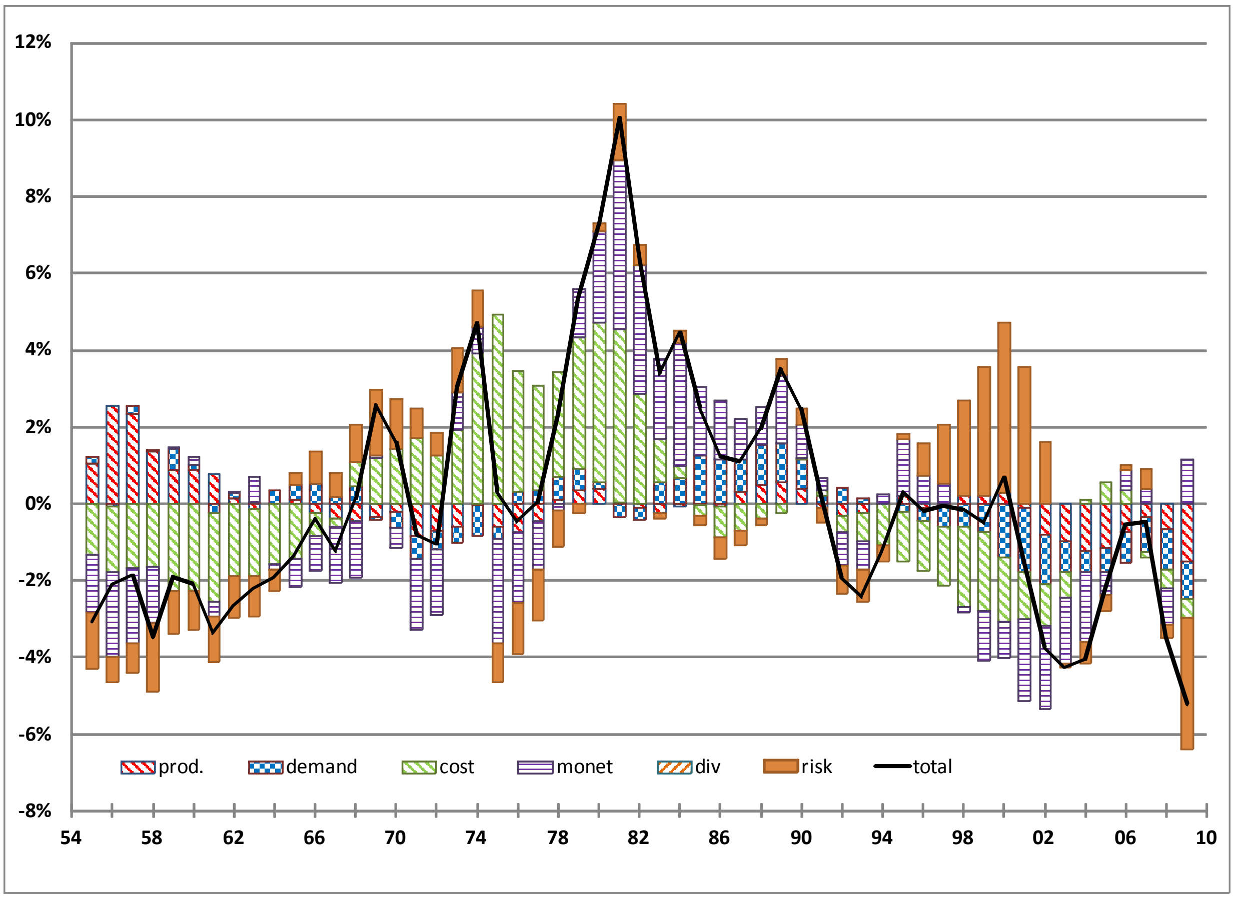

Figure 10: Historical decomposition of the Federal Funds rate

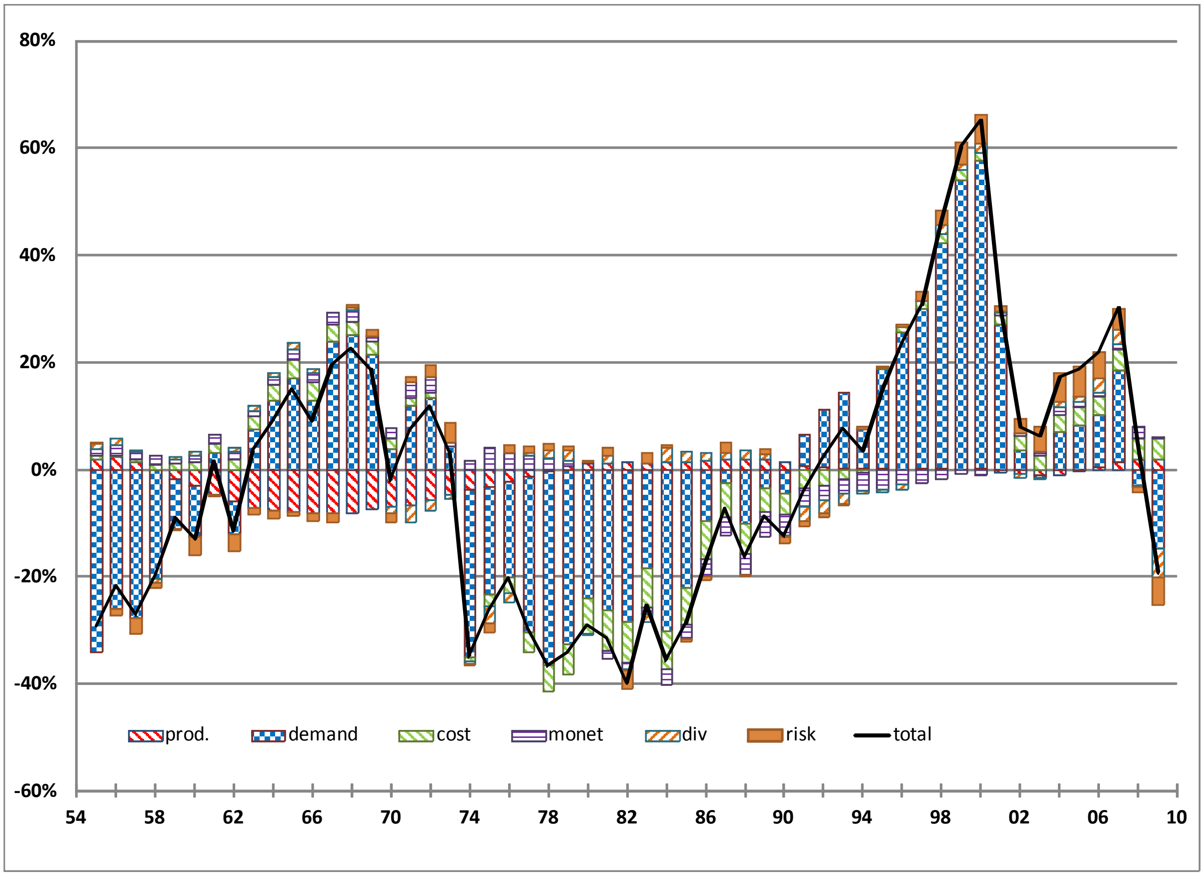

Figure 11: Historical decomposition of linear-detrended market values

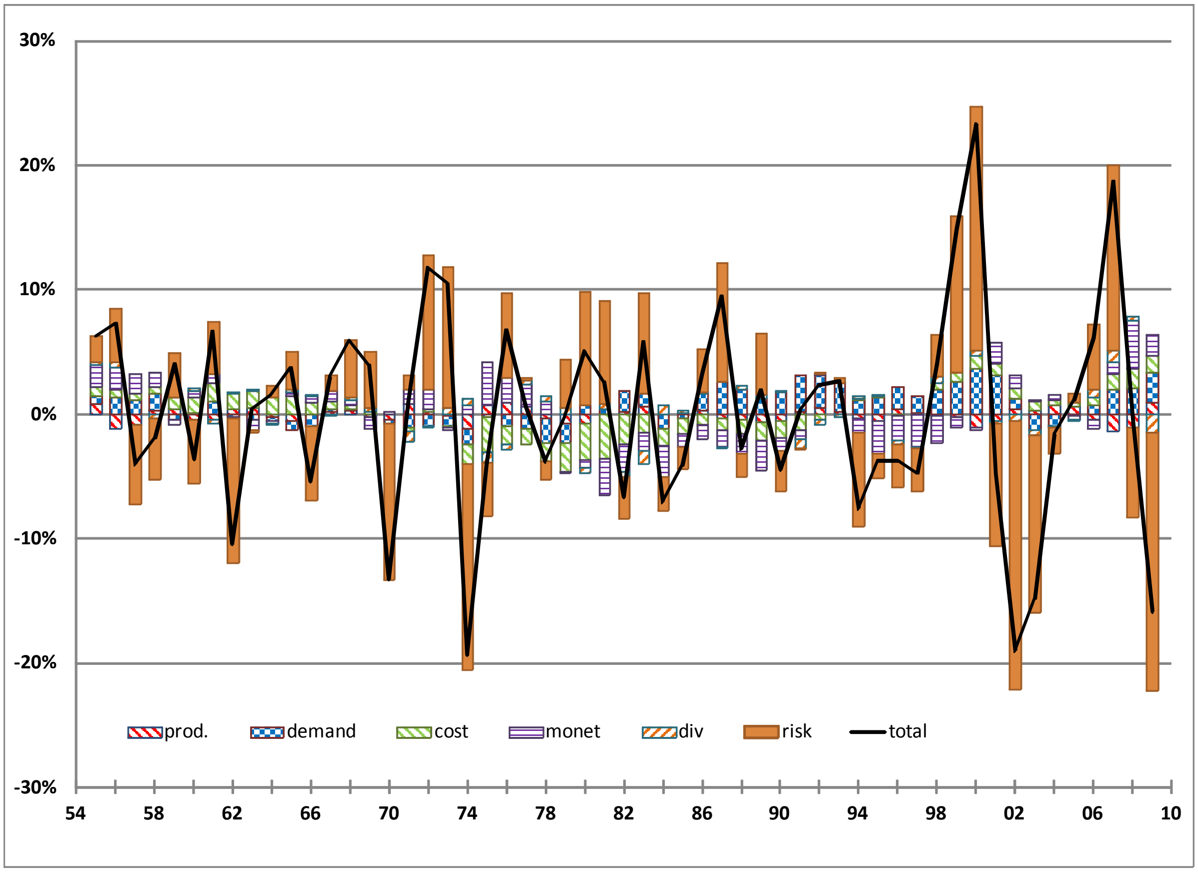

Figure 12: Historical decomposition of HP-detrended market values