

Investment Shocks and the Business Cycle: The View from a Policy-Oriented DSGE model *

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Abstract

We analyze the role of investment shocks in a DSGE model of the U.S. economy that we have been previously used to address a wide range of policy and research questions. We highlight a number of issues that affect our assessment of the importance of such shocks and compare our results to previous work. We find a central role for investment shocks of the “intertemporal IS-curve” type; investment-specific technology shocks are important in our model for matching secular trends, but play a less significant role over the business cycle. Our intertemporal IS-curve shocks are highly correlated with observable financial market data, suggesting the importance of shocks affecting risk premia and extensions of our model to more explicit consideration of financial markets. Moreover, financial market information seem to Granger-cause these exogenous processes, potentially suggesting a role for anticipated or “news” shocks.

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1 Introduction

We have previously presented an estimated dynamic, stochastic, general-equilibrium model of the U.S. economy designed to analyze policy questions and forecasting at the Federal Reserve Board (Edge, Kiley, and Laforge (2007, 2008a, 2008b, 2009)). In this analysis, we examine how our Estimated, Dynamic, Optimization-based model, FRB/EDO, interprets business cycle fluctuations, with a special focus on business investment. We focus on three questions:

- What are the fundamental determinants of business-cycle fluctuations?
- Are the sources of fluctuations in GDP, hours per capita, and inflation similar to those driving more disaggregated spending aggregates—and in particular what are the roles of investment-specific technological change and other investment shocks?
- Are these shocks correlated with observable factors not used in estimation, such as financial market indicators and, if so, are there predictable patterns that may suggest roles for financial market frictions or anticipated (or “news”) shocks?

We think each of these questions is particularly important in the current environment. DSGE models such as ours are playing a larger role in policy analysis; indeed, we regularly present analyses from our model to staff at the Federal Reserve and the Federal Open Market Committee (FOMC). The U.S. economy is in a deep recession in mid-2009 (the time of this writing), and an interpretation of the decline in hours worked and real Gross Domestic Product is central to evaluating policy options. Moreover, there has been an explosion of work emphasizing the role of investment shocks, including investment-specific technological change and shocks to “intertemporal IS-curves”.

Our model is ideally suited to address such questions, as it includes a two-sector structure emphasizing the importance of investment-specific technology for explaining long-run growth facts, and a rich array of investment IS-curve type shocks (as discussed in detail below); its New-Keynesian structure embeds a central role for

monetary policy; and its empirical approach ensures that it can provide a reasonable characterization of the sources of fluctuations over history. This combination of features, and our day-to-day use of the model in a policy environment, is unique in policy and academic circles.

The remainder of this paper is divided into five sections. The first summarizes some related recent research. The second discusses the structure of the FRB/EDO model. The next examines the sources of fluctuations according to EDO. The fourth section considers monetary policy questions. A concluding section provides some thoughts for future research.

2 Related Research

Our focus on the role of investment shocks contributes to a burgeoning literature.

First, our previous work (Edge, Kiley, and Laforge (2007, 2008a, 2008b, 2009)) has consistently shown the importance of intertemporal IS curve shocks – shocks that affect the ability or desirability to smooth consumption across time through the accumulation of business capital, residential capital, or consumer durables stocks. For example, Edge, Kiley, and Laforge (2007) showed that such shocks dominated the fluctuations in perhaps the most obvious cyclical variables – hours worked and the short term nominal interest rate (the federal funds rate). Edge, Kiley, and Laforge (2008a) highlighted the important role of intertemporal IS curve shocks affecting nonresidential (or business) investment in the cycle in their discussion of the natural rates of output and interest. Edge, Kiley, and Laforge (2008b) highlighted the central role of such shocks in the collapse of the housing market post-2005 and the onset of the most recent recession. Edge, Kiley, and Laforge (2008a, 2008b) further highlighted the importance of future research linking such developments to explicit models of the financial sector.

Other work emphasizing the role of investment-specific shocks include the analysis

of investment-specific technological change in Fisher (2006). Fisher (2006) found that such shocks play a very important role in the business cycle. Our earlier work emphasized this possibility, but motivated our two-sector model using long-run growth facts (Edge, Kiley, and Laforge (2007, 2008a)). Herein we will refocus on discussion on the business cycle importance of different type of investment specific shocks in order to connect with this literature, although many of our quantitative findings repeat results we have previously reported in Edge, Kiley, and Laforge (2007, 2008a). To preview our results, we show that investment-specific technology shocks are important for GDP growth according to our model, but that other types of shocks—particularly transitory, IS curve shocks—affect more “cyclical” variables like hours per capita.

Justiniano, Primiceri, and Tamballotti (2008, 2009) consider similar questions to ours. On balance, their findings simply echo those in our previous work (specifically, Edge, Kiley, and Laforge (2007, 2008a, 2008b)). However, our analysis tries to adhere more closely to the standard measures of activity and inflation considered in most policy work and used by most academics. For example, we make special effort to map our model into the measures of Gross Domestic Product produced by the Bureau of Economic Analysis for the U.S. economy. This effort has quantitatively important implications. For example, the official measure of GDP growth that we use has a correlation coefficient with the series constructed by Justiniano, Primiceri, and Tamballotti (2008, 2009) of only 0.8; moreover, the official measure of GDP growth as a correlation with the percent change in detrended hours worked per capita of 0.6, compared to only 0.4 based on these authors’ constructed measure. These differences in correlations are large and may have important effects given the limited amount of data used in evaluating the cyclical implications of different models. Finally, we do build on the analysis in Justiniano, Primiceri, and Tamballotti (2009) in one way: we examine in much more detail the correlation between our intertemporal IS curve shocks and a number of financial market variables.

Finally, we briefly consider the relationship between our analysis and the research

on “news” shocks, such as Schmitt-Grohe and Uribe (2008). In particular, their analysis finds an important role for anticipated shocks. We consider whether our model suggests a role for such shocks, and find suggestive evidence for such a role; we consider expansion of our model in this direction a potentially promising direction.

3 Model Overview and Motivation

The EDO model contains a detailed description of domestic production and expenditures decisions. The heart of the model is a two-sector production structure. In particular, we assume the economy consists of a consumption goods and an investment goods sector.

We discuss the motivation for this basic structure in detail in Edge, Kiley, and Laforge (2007, 2008a, 2008b, 2009). Our assumption of a two-sector production structure is motivated by the trends, or long-run stylized facts, shown by certain relative prices and categories of real expenditure apparent in the data. As reported in Table 1, expenditures on consumer non-durable goods and non-housing services and residential investment have grown at broadly similar real rates over the last 20 years, while real spending on consumer durable goods and on non-residential investment have grown at around significantly faster. The nominal prices of residential investment and consumer non-durable goods and non-housing services have advanced at comparable rates (around 3 percent per year on average). In contrast, the nominal prices of both consumer durable goods and non-residential investment have been roughly flat over this period. Finally, nominal growth has been closer to balanced than has real growth. A one-sector model is unable to deliver long-term growth and relative price movements that are consistent with these stylized facts. As a result, we adopt a two-sector structure, with differential rates of technical progress across sectors. These different rates of technological progress induce secular relative price differentials, which in turn lead to different trend rates of growth across the economy’s expenditure and production

Table 1: Average Growth and Relative Price Changes (1985:1 to 2008:4).

	Average Real Growth Rate	Average Nominal Growth Rate	Average Price Change
Consumer non-durable goods and non-housing services	3 percent	6 percent	3 percent
Consumer housing services	$2\frac{1}{4}$ percent	6 percent	$3\frac{1}{2}$ percent
Consumer durable goods	$5\frac{1}{2}$ percent	5 percent	$-\frac{1}{2}$ percent
Res. investment goods	$1\frac{1}{4}$ percent	$4\frac{1}{2}$ percent	$3\frac{1}{4}$ percent
Non-res. investment goods	$4\frac{1}{2}$ percent	$5\frac{1}{4}$ percent	$\frac{1}{2}$ percent

aggregates. We assume that the output of the slower growing sector is used for consumer non-durable goods and services and residential capital goods and the output of a faster growing sector is used for consumer durable goods and non-residential capital goods, roughly capturing the long-run properties of the data summarized in Table 1. In particular, our implies stable long-run nominal expenditure shares and different long-run real growth rates across different broad categories.¹ Of course, the two-sector structure will also have important business cycle implications as well, particularly related to investment-specific technology shocks. These implications allow our analysis to shed light on the research debates summarized in section 1. The detailed sectoral and expenditure structure of our model also allows us to connect to the specific concerns of policymakers in these areas (e.g., Kohn [2003] and Edge, Kiley, and Laforge (2007, 2008a, 2008b, 2009)).

Figure 1 provides a graphical overview of the economy described by our model.

¹These features build on the literature on multisector growth models, e.g., Greenwood et. al [1997], Greenwood et. al [2000], Whelan [2003], and Fisher [2006].

The model possesses two final goods: slow-growing “CBI” goods—so called because *most* of these goods are used for consumption (C) and because they are produced by the business and institutions (BI) sector—and fast-growing “KB” goods—so called because these goods are used for capital (K) accumulation and are produced by the business (B) sector. The goods are produced in two stages by intermediate- and then final-goods producing firms (shown in the center of the figure). On the model’s demand-side, there are four components of spending (each shown in a box surrounding the producers in the figure): consumer non-durable goods and services (sold to households), consumer durable goods, residential capital goods, and non-residential capital goods. Consumer non-durable goods and services and residential capital goods are purchased (by households and residential capital goods owners, respectively) from the first of economy’s two final goods producing sectors, while consumer durable goods and non-residential capital goods are purchased (by consumer durable and residential capital goods owners, respectively) from the second sector. We “decentralize” the economy by assuming that residential capital and consumer durables capital are rented to households while non-residential capital is rented to firms. In addition to consuming the non-durable goods and services that they purchase, households supply labor to the intermediate goods-producing firms in both sectors of the economy.

The disaggregation of production (aggregate supply) leads naturally to some disaggregation of expenditures (aggregate demand). We move beyond a model with just two categories of (private domestic) final spending and disaggregate along the four categories of private expenditure mentioned earlier: consumer non-durable goods and non-housing services, consumer durable goods, residential investment, and non-residential investment. This rich disaggregation is central to our analysis of the role of investment shocks (of all types).

This remainder of this section provides an overview of the decisions made by each of the agents in our economy. Given some of the broad similarities between our model and others, our presentation is selective.

3.1 The Final Goods Producers' Problem

The economy produces two final goods and services: slow-growing “consumption” goods and services, X_t^{cbi} , and fast-growing “capital” goods, X_t^{kb} . These final goods are produced by aggregating (according to a Dixit-Stiglitz technology) an infinite number of sector-specific differentiated intermediate inputs, $X_t^s(j)$ for $s = cbi, kb$, distributed over the unit interval. The representative firm in each of the consumption and capital goods producing sectors chooses the optimal level of each intermediate input, taking as given the prices for each of the differentiated intermediate inputs, $P_t^s(j)$, to solve the cost-minimization problem:

$$\min_{\{X_t^s(j)\}_{j=0}^1} \int_0^1 P_t^s(j) X_t^s(j) dj \text{ subject to } \left(\int_0^1 (X_t^s(j))^{\frac{\Theta_t^s-1}{\Theta_t^s}} dj \right)^{\frac{\Theta_t^s}{\Theta_t^s-1}} \geq X_t^s, \text{ for } s = cbi, kb. \quad (1)$$

The term Θ_t^s is the stochastic elasticity of substitution between the differentiated intermediate goods inputs used in the production of the consumption or capital goods sectors. Letting $\theta_t^s \equiv \ln \Theta_t^s - \ln \Theta_*^s$ denote the log-deviation of Θ_t^s from its steady-state value of Θ_*^s , we assume that

$$\theta_t^s = \epsilon_t^{\theta,s}, \text{ for } s = cbi, kb, \quad (2)$$

where $\epsilon_t^{\theta,s}$ is an i.i.d. shock process. A stochastic elasticity of substitution introduces transitory markup shocks into the pricing decisions of intermediate-goods producers.

3.2 The Intermediate Goods Producers' Problem

The intermediate goods entering each final goods technology are produced by aggregating (according to a Dixit-Stiglitz technology) an infinite number of differentiated labor inputs, $L_t^s(j)$ for $s = cbi, kb$, distributed over the unit interval and combining this aggregate labor input (via a Cobb-Douglas production function) with utilized non-residential capital, $K_t^{u,nr,s}$. Each intermediate-good producing firm effectively

solves three problems: two factor-input cost-minimization problems (over differentiated labor inputs and the aggregate labor and capital) and one price-setting profit-maximization problem.

In its first cost-minimization problem, an intermediate goods producing firm chooses the optimal level of each type of differential labor input, taking as given the wages for each of the differentiated types of labor, $W_t^s(i)$, to solve:

$$\min_{\{L_t^s(i,j)\}_{i=0}^1} \int_0^1 W_t^s(i) L_t^s(i,j) di \text{ subject to } \left(\int_0^1 (L_t^s(i,j))^{\frac{\Theta^l-1}{\Theta^l}} di \right)^{\frac{\Theta^l}{\Theta^l-1}} \geq L_t^s(j), \text{ for } s = cbi, kb. \quad (3)$$

The term Θ^l is the elasticity of substitution between the differentiated labor inputs; we assume this elasticity is the same in each production sector.

In its second cost-minimization problem, an intermediate-goods producing firm chooses the optimal levels of aggregated labor input and utilized capital, taking as given the wage, W_t^s , for aggregated labor, L_t^s (which is generated by the cost function derived the previous problem), and the rental rate, $R_t^{nr,s}$, on utilized capital, $K_t^{u,nr,s}$, to solve:

$$\begin{aligned} & \min_{\{L_t^s(j), K_t^{u,nr,s}(j)\}} W_t^s L_t^s(j) + R_t^{nr,s} K_t^{u,nr,s}(j) \\ & \text{subject to } (Z_t^m Z_t^s L_t^s(j))^{1-\alpha} (K_t^{u,nr,s}(j))^\alpha \geq X_t^s(j), \text{ for } s = cbi, kb, \text{ but } Z_t^{cbi} \equiv 1. \end{aligned} \quad (4)$$

The parameter α is the elasticity of output with respect to capital, while the Z_t variables denote the level of productivity. The level of productivity has two components. The first, Z_t^m , is common to both sectors and thus represents the level of economy-wide technology. The second, Z_t^s , is sector specific; we normalize Z_t^{cbi} to one, while Z_t^{kb} is not restricted.

The exogenous productivity terms contain a unit root, that is, they exhibit permanent movements in their levels. We assume that the stochastic processes Z_t^m and Z_t^{kb} evolve according to

$$\ln Z_t^n - \ln Z_{t-1}^n = \ln \Gamma_t^{z,n} = \ln (\Gamma_*^{z,n} \cdot \exp[\epsilon_t^{z,n}]) = \ln \Gamma_*^{z,n} + \epsilon_t^{z,n}, \quad n = kb, m \quad (5)$$

where $\Gamma_*^{z,n}$ and $\epsilon_t^{z,n}$ are the steady-state and stochastic components of $\Gamma_t^{z,n}$. The stochastic component $\epsilon_t^{z,n}$ is an i.i.d shock process. It is the presence of capital-specific technological progress that allows the model to generate differential trend growth rates in the economy's two production sectors. In line with historical experience, we assume a more rapid rate of technological progress in capital goods production by calibrating $\Gamma_*^{z,kb} > 1$, where (as is the case for all model variables) an asterisk on a variable denotes its steady-state value.

In its price-setting problem (or profit-maximization), an intermediate goods producing firm chooses its optimal nominal price and the quantity it will supply consistent with that price. In doing so it takes as given the marginal cost, $MC_t^s(j)$, of producing a unit of output, $X_t^s(j)$, the aggregate price level for its sector, P_t^s , and households' valuation of a unit of nominal profits income in each period, which is given by $\Lambda_t^{cnn}/P_t^{cbi}$ where Λ_t^{cnn} denotes the marginal utility of non-durables and non-housing services consumption. Specifically, firms solve:

$$\begin{aligned} \max_{\{P_t^s(j), X_t^s(j), X_t^s(j)\}_{t=0}^\infty} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \{ & P_t^s(j) X_t^s(j) - MC_t^s(j) X_t^s(j) \\ & - \frac{100 \cdot \chi^p}{2} \left(\frac{P_t^s(j)}{P_{t-1}^s(j)} - \eta^p \Pi_{t-1}^{p,s} - (1 - \eta^p) \Pi_*^{p,s} \right)^2 P_t^s X_t^s \} \\ \text{subject to } X_\tau^s(j) = & (P_\tau^s(j)/P_\tau^s)^{-\Theta_\tau^s} X_\tau^s \text{ for } \tau = 0, 1, \dots, \infty \text{ and } s = cbi, kb. \end{aligned} \quad (6)$$

The profit function reflects price-setting adjustment costs (the size which depend on the parameter χ^p and the lagged and steady-state inflation rate). The constraint against which the firm maximizes its profits is the demand curve it faces for its differentiated good, which derives from the final goods producing firm's cost-minimization problem. This type of price-setting decision delivers a new-Keynesian Phillips curve. Because adjustment costs potentially depend upon lagged inflation, the Phillips curve can take the "hybrid" form in which inflation is linked to its own lead and lag as well as marginal cost.

3.3 The Capital Owners' Problem

We now shift from producers' decisions to spending decisions (that is, those by agents encircling our producers in Figure 1). Non-residential capital owners choose investment in non-residential capital, E_t^{nr} , the stock of non-residential capital, K_t^{nr} (which is linked to the investment decision via the capital accumulation identity), and the amount and utilization of non-residential capital in each production sector, $K_t^{nr,cbi}$, U_t^{cbi} , $K_t^{nr,kb}$, and U_t^{kb} . (Recall, that the firm's choice variables in equation 4 is utilized capital $K_t^{u,nr,s} = U_t^s K_t^{nr,s}$.) The mathematical representation of this decision is described by the following maximization problem (in which capital owners take as given the rental rate on non-residential capital, R_t^{nr} , the price of non-residential capital goods, P_t^{kb} , and households' valuation of nominal capital income in each period, $\Lambda_t^{cnn}/P_t^{cbi}$):

$$\begin{aligned} & \max_{\{E_t^{nr}(k), K_{t+1}^{nr}(k), K_t^{nr,cbi}(k), K_t^{nr,kb}(k), U_t^{cbi}(k), U_t^{kb}(k)\}_{t=0}^\infty} \\ & \mathcal{E}_0 \sum_{t=0}^\infty \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \left\{ R_t^{nr} U_t^{cbi}(k) K_t^{nr,cbi}(k) + R_t^{nr} U_t^{kb}(k) K_t^{nr,kb}(k) - P_t^{kb} E_t^{nr}(k) \right. \\ & \quad \left. - \kappa \left(\frac{U_t^{cbi}(k)^{1+\psi} - 1}{1+\psi} \right) P_t^{kb} K_t^{nr,cbi} - \kappa \left(\frac{U_t^{kb}(k)^{1+\psi} - 1}{1+\psi} \right) P_t^{kb} K_t^{nr,kb} \right\} \\ & \text{subject to} \\ & K_{\tau+1}^{nr}(k) = (1 - \delta^{nr}) K_\tau^{nr}(k) + A_\tau^{nr} E_\tau^{nr}(k) - \frac{100 \cdot \chi^{nr}}{2} \left(\frac{E_\tau^{nr}(k) - E_{\tau-1}^{nr}(k) \Gamma_t^{y,kb}}{K_\tau^{nr}} \right)^2 K_\tau^{nr} \text{ and} \\ & K_\tau^{nr,cbi}(k) + K_\tau^{nr,kb}(k) = K_\tau^{nr}(k) \text{ for } \tau = 0, 1, \dots, \infty. \end{aligned} \quad (7)$$

The parameter δ^{nr} in the capital-accumulation constraint denotes the depreciation rate for non-residential capital, while the parameter χ^{nr} governs how quickly investment adjustment costs increase when $(E_\tau^{nr}(k) - E_{\tau-1}^{nr}(k) \Gamma_t^{y,kb})$ rises above zero. The variable A_t^{nr} is a stochastic element affecting the efficiency of non-residential investment in the capital-accumulation process. Letting $a_t^{nr} \equiv \ln A_t^{nr}$ denote the log-deviation of A_t^{nr} from its steady-state value of unity, we assume that:

$$a_t^{nr} = \rho^{nr} a_{t-1}^{nr} + \epsilon_t^{nr}. \quad (8)$$

Higher rates of utilization incur a cost (reflected in the last two terms in the capital owner's profit function). We assume that $\kappa = R_*^{nr}/P_*^{kb}$, which implies that utilization is unity in the steady-state.

The problems solved by the consumer durables and residential capital owners are slightly simpler than the non-residential capital owner's problems. Since utilization rates are not variable for these types of capital, their owners make only investment and capital accumulation decisions. Taking as given the rental rate on consumer durables capital, R_t^{cd} , the price of consumer-durable goods, P_t^{kb} , and households' valuation of nominal capital income, $\Lambda_t^{cnn}/P_t^{cbi}$, the capital owner chooses investment in consumer durables, I_t^{cd} , and its implied capital stock, K_t^{cd} , to solve:

$$\begin{aligned} & \max_{\{E_t^{cd}(k), K_{t+1}^{cd}(k)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \{R_t^{cd} K_t^{cd}(k) - P_t^{kb} E_t^{cd}(k)\} \\ & \text{subject to} \\ & K_{\tau+1}^{cd}(k) = (1 - \delta^{cd}) K_{\tau}^{cd}(k) + A_{\tau}^{cd} E_{\tau}^{cd}(k) - \frac{100 \cdot \chi^{cd}}{2} \left(\frac{E_{\tau}^{cd}(k) - E_{\tau-1}^{cd}(k) \Gamma_{\tau}^{x, kb}}{K_{\tau}^{cd}} \right)^2 K_{\tau}^{cd} \\ & \text{for } \tau = 0, 1, \dots, \infty. \end{aligned} \tag{9}$$

The residential capital owner's decision is analogous:

$$\begin{aligned} & \max_{\{E_t^r(k), K_{t+1}^r(k)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \{R_t^r K_t^r(k) - P_t^{cbi} E_t^r(k)\} \\ & \text{subject to} \\ & K_{\tau+1}^r(k) = (1 - \delta^r) K_{\tau}^r(k) + A_{\tau}^r E_{\tau}^r(k) - \frac{100 \cdot \chi^r}{2} \left(\frac{E_{\tau}^r(k) - E_{\tau-1}^r(k) \Gamma_{\tau}^{x, cbi}}{K_{\tau}^{cd}} \right)^2 K_{\tau}^{cd} \\ & \text{for } \tau = 0, 1, \dots, \infty. \end{aligned} \tag{10}$$

The notation for the consumer durables and residential capital stock problems parallels that of non-residential capital. In particular, the capital-efficiency shocks, A_t^{cd} and A_t^r , follow an autoregression process similar to that given in equation (8).

3.4 The Households' Problem

The final group of private agents in the model are households who make both expenditures and labor-supply decisions. Households derive utility from four sources: their

purchases of the consumer non-durable goods and non-housing services, the flow of services from their rental of consumer-durable capital, the flow of services from their rental of residential capital, and their leisure time, which is equal to what remains of their time endowment after labor is supplied to the market. Preferences are separable over all arguments of the utility function. The utility that households derive from the three components of goods and services consumption is influenced by the habit stock for each of these consumption components, a feature that has been shown to be important for consumption dynamics in similar models. A household's habit stock for its consumption of non-durable goods and non-housing services is equal to a factor h multiplied by its consumption last period E_{t-1}^{cnn} . Its habit stock for the other components of consumption is defined similarly.

Each household chooses its purchases of consumer non-durable goods and services, E_t^{cnn} , the quantities of residential and consumer durable capital it wishes to rent, K_t^r and K_t^{cd} , its holdings of bonds, B_t , its wage for each sector, W_t^{cbi} and W_t^{kb} , and supply of labor consistent with each wage, L_t^{cbi} and L_t^{kb} . This decision is made subject to the household's budget constraint, which reflects the costs of adjusting wages and the mix of labor supplied to each sector, as well as the demand curve it faces for its

differentiated labor. Specifically, the i th household solves:

$$\begin{aligned} & \max_{\{E_t^{cnn}(i), K_t^{cd}(i), K_t^r(i), \{W_t^s(i), L_t^s(i)\}_{s=cbi, kb}, B_{t+1}(i)\}_{t=0}^\infty} \\ & \mathcal{E}_0 \sum_{t=0}^\infty \beta^t \left\{ \varsigma^{cnn} \Xi_t^{cnn} \ln(E_t^{cnn}(i) - h E_{t-1}^{cnn}(i)) + \varsigma^{cd} \ln(K_t^{cd}(i) - h K_{t-1}^{cd}(i)) \right. \\ & \quad \left. + \varsigma^r \ln(K_t^r(i) - h K_{t-1}^r(i)) - \varsigma^l \Xi_t^l \frac{(L_t^{cbi}(i) + L_t^{kb}(i))^{1+\nu}}{1+\nu} \right\}. \end{aligned}$$

subject to

$$\begin{aligned} R_\tau^{-1} B_{\tau+1}(i) &= B_\tau(i) + \sum_{s=cbi, kb} W_\tau^s(i) L_\tau^s(i) + \text{Capital and Profits Income}_\tau(i) - P_\tau^{cbi} E_\tau^{cnn}(i) \\ & - R_\tau^{cd} K_\tau^{cd}(i) - R_\tau^r K_\tau^r(i) - \sum_{s=cbi, kb} \frac{100 \cdot \chi^w}{2} \left(\frac{W_\tau^s(j)}{W_{\tau-1}^s(j)} - \eta^w \Pi_{\tau-1}^{w,s} - (1-\eta^w) \Pi_*^w \right)^2 W_\tau^s L_\tau^s \\ & - \frac{100 \cdot \chi^l}{2} \left(\frac{L_\tau^{cbi} \cdot W_\tau^{cbi}}{L_\tau^{cbi} + L_\tau^{kb}} + \frac{L_\tau^{kb} \cdot W_\tau^{kb}}{L_\tau^{cbi} + L_\tau^{kb}} \right) \left(\frac{L_\tau^{cbi}(i)}{L_\tau^{kb}(i)} - \eta^l \frac{L_{\tau-1}^{cbi}}{L_{\tau-1}^{kb}} - (1-\eta^l) \frac{L_*^{cbi}}{L_*^{kb}} \right)^2 \frac{L_\tau^{kb}}{L_\tau^{cbi}}. \\ L_\tau^{cbi}(i) &= (W_\tau^{cbi}(i)/W_\tau^{cbi})^{-\Theta_\tau^l} L_\tau^{cbi}, \text{ and } L_\tau^{kb}(i) = (W_\tau^{kb}(i)/W_\tau^{kb})^{-\Theta_\tau^l} L_\tau^{kb}, \\ & \text{for } \tau = 0, 1, \dots, \infty. \end{aligned} \tag{11}$$

In the utility function the parameter β is the household's discount factor, ν denotes its inverse labor supply elasticity, while ς^{cnn} , ς^{cd} , ς^r , and ς^l are scale parameter that tie down the ratios between the household's consumption components. The stationary, unit-mean, stochastic variables Ξ_t^{cnn} and Ξ_t^l represent aggregate shocks to the household's utility of nondurable and (nonhousing) services consumption and its disutility of labor. Letting $\xi_t^x \equiv \ln \Xi_t^x - \ln \Xi_*^x$ denote the log-deviation of Ξ_t^x from its steady-state value of Ξ_*^x , we assume that

$$\xi_t^x = \rho^x \xi_{t-1}^x + \epsilon_t^x, \quad x = cnn, l. \tag{12}$$

The variable ϵ_t^x is an i.i.d. shock process, and ρ^x represents the persistence of Ξ_t^x away from steady-state following a shock to equation (12). The household's budget constraint reflects wage setting adjustment costs, which depend on the parameter χ^w and the lagged and steady-state wage inflation rate, and the costs in changing the mix of labor supplied to each sector, which depend on the parameter χ^l . The costs

incurred by households when the mix of labor input across sectors changes may be important for sectoral comovements.

3.5 Gross Domestic Product

The rate of change of Gross Domestic Product (real GDP) equals the Divisia (share-weighted) aggregate of final spending in the economy, as given by the identity:

$$H_t^{gdp} = \left(\left(\frac{X_t^{cbi}}{X_{t-1}^{cbi}} \right)^{P_*^{cbi} X_*^{cbi}} \left(\frac{X_t^{kb}}{X_{t-1}^{kb}} \right)^{P_*^{kb} X_*^{kb}} \left(\frac{\Gamma_t^{x,cbi} \cdot \tilde{X}_t^{HG}}{\tilde{X}_{t-1}^{HG}} \right)^{P_*^{cbi} X_*^{HG}} \right)^{\frac{1}{P_*^{cbi} X_*^{cbi} + P_*^{kb} X_*^{kb} + P_*^{cbi} X_*^{HG}}} . \quad (13)$$

In equation (13), $\tilde{X}_t^{HG}$ represent stationary un-modeled output (that is, GDP other than private final domestic demand, the aggregate of E_t^{cnn} , E_t^{cd} , E_t^r , and E_t^{nr}). To a first approximation, this definition of GDP growth is equivalent to how it is defined in the U.S. NIPA. Stationary un-modeled output is exogenous and is assumed to follow the process:

$$\ln \tilde{X}_t^{HG} - \ln \tilde{X}_*^{HG} = \rho^{HG} \left(\ln \tilde{X}_t^{HG} - \ln \tilde{X}_*^{HG} \right) + \epsilon_t^{HG}.$$

3.6 Monetary Authority

We now turn to the last important agent in our model, the monetary authority. It sets monetary policy in accordance with an Taylor-type interest-rate feedback rule. Policymakers smoothly adjust the actual interest rate R_t to its target level $\bar{R}_t$

$$R_t = (R_{t-1})^{\phi^r} (\bar{R}_t)^{1-\phi^r} \exp[\epsilon_t^r], \quad (14)$$

where the parameter ϕ^r reflects the degree of interest rate smoothing, while ϵ_t^r represents a monetary policy shock. The central bank's target nominal interest rate, $\bar{R}_t$ depends the deviation of output from its stochastic trend ($\tilde{X}^{bn}$, the output gap as defined by Beveridge and Nelson (1981))

$$\tilde{X}_t^{bn} = \mathcal{E}_t \left[\sum_{\tau=-\infty}^t H_{\tau}^{gdp} - \sum_{\tau=-\infty}^{\infty} H_{\tau}^{gdp} \right]. \quad (15)$$

Consumer price inflation and the change in the output gap also enter the target. The target equation is:

$$\bar{R}_t = \left(\tilde{X}^{bn} \right)^{\phi^Y} \left(\tilde{X}_t^{bn} / \tilde{X}_{t-1}^{bn} \right)^{\phi^{\Delta Y}} \left(\frac{\Pi_t^c}{\Pi_*^c} \right)^{\phi^\pi} R_*. \quad (16)$$

In equation (16), R_* denotes the economy's steady-state nominal interest rate and ϕ^Y , $\phi^{\Delta Y}$, ϕ^π , and $\phi^{\Delta\pi}$ denote the weights in the feedback rule. Consumer price inflation, Π_t^c , is the weighted average of inflation in the nominal prices of the goods produced in each sector, $\Pi_t^{p,cbi}$ and $\Pi_t^{p,kb}$:

$$\Pi_t^c = (\Pi_t^{p,cbi})^{1-w_{cd}} (\Pi_t^{p,kb})^{w_{cd}}. \quad (17)$$

The parameter w^{cd} is the share of the durable goods in nominal consumption expenditures.

3.7 Summary of Model Specification

Our brief presentation of the model highlights several important points. First, although our model considers production and expenditure decisions in a bit more detail, it shares many similar features with other DSGE models in the literature, such as, imperfect competition, nominal price and wage rigidities, and real frictions like adjustment costs and habit-persistence. The rich specification of structural shocks (to productivity, preferences, capital efficiency, and mark-ups) and adjustment costs allows our model to be brought to the data with some chance of finding empirical validation.²

Within Edo, fluctuations in all economic variables are driven by eleven structural shocks. For our purposes, it is most convenient to summarize these shocks into three broad categories:

²Interestingly, a common criticism of large econometric models like the FRB/US has been their reliance on adjustment costs; DSGE models similar to that herein have increasingly relied on similar mechanisms when required to fit macroeconomic data, which may be a cause for concern regarding the “structural” interpretation of such models.

- Aggregate supply shocks: This category consists of shocks to technology, labor supply (e.g., the preference for leisure), and price markups.
- Intertemporal IS curve shocks: This category consists of shocks to preferences over consumption and capital accumulation technologies (both of which affect the intertemporal Euler equations for the components of household and business demand) and autonomous demand.
- A monetary policy shock

It is tempting to map these sources of fluctuations into aggregate demand (IS and monetary policy shocks) and aggregate supply in a manner familiar from textbook treatments. However, this mapping is imprecise: for example, technology shocks have significant effects on demand, and demand shocks influence the (short-run) productive potential of the economy through their effect on capital accumulation. For these reasons, we prefer the IS-curve shock terminology.

While the fluctuations in economic variables within the Edo model reflect complex interactions between the large set of decisions made within the economy, we would also highlight a couple of structural features that may play an important role in its forecast performance. First, the model assumes a stochastic structure for productivity shocks in each sector that allows for important business-cycle frequency fluctuations in technology. This view contrasts significantly with the view in early versions of the FRB/US model, where technology was modeled as a linear time trend with breaks. More recent versions of the FRB/US model have allowed for more variation in “trend” total factor productivity, but the structure of the FRB/US model is not embedded in the tradition started by Kydland and Prescott [1982] and, as a result, the role of technology in fluctuations—and forecasts—of economic activity may be quite different between Edo and models or forecasting techniques similar to those embedded in the FRB/US model. The high-frequency movements in technology in our model make appeal to the Beveridge-Nelson trend concept desirable, as it does not impose any smoothness assumption on the estimate of the long-run level of output.

Finally, we would emphasize that the behavior of prices and wages in the Edo model is governed by versions of “New-Keynesian” price and wage Phillips curves. There has been a spirited debate over the empirical performance of such specifications [see Kiley , 2007, Laforte , 2007, Rudd and Whelan , 2007].

3.8 Estimation Strategy

The empirical implementation of the model takes a log-linear approximation to the first-order conditions and constraints that describe the economy’s equilibrium, casts this resulting system in its state-space representation for the set of (in our case 11) observable variables, uses the Kalman filter to evaluate the likelihood of the observed variables, and forms the posterior distribution of the parameters of interest by combining the likelihood function with a joint density characterizing some prior beliefs. Since we do not have a closed-form solution of the posterior, we rely on Markov-Chain Monte Carlo (MCMC) methods.

The model is estimated using 11 data series over the sample period from 1984:Q4 to 2008:Q4. The series are:

1. The growth rate of real gross domestic product;
2. The growth rate of real consumption expenditure on non-durables and services excluding housing services;
3. The growth rate of real consumption expenditure on durables;
4. The growth rate of real residential investment expenditure;
5. The growth rate of real business investment expenditure;
6. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure price index;
7. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure price index excluding food and energy prices;

8. Inflation for consumer durable goods, as measured by the growth rate of the Personal Consumption Expenditure price index for durable goods;
9. Hours, which equals hours of all persons in the non-farm business sector from the Bureau of Labor Statistics;³
10. The growth rate of real wages, as given by compensation per hour in the non-farm business sector from the Bureau of Labor Statistics divided by the GDP price index;
11. The federal funds rate.

Our implementation adds measurement error processes to the likelihood implied by the model for all of the observed series used in estimation except the nominal interest rate series.

Our estimation results depend upon our specification of priors and calibration of certain parameters. A number of parameters are calibrated. As reported in table 2, we fix the household's discount factor (β), the Cobb-Douglas share of capital input (α), the curvature parameter associated with costs of varying capital utilization (ψ), the depreciation rates (δ^{nr} , δ^{cd} , δ^r), and the elasticities of substitution between differentiated intermediate goods and labor input ($\Theta_{*}^{x,cbi}$, $\Theta_{*}^{x,kb}$, Θ_{*}^l). We also calibrate the steady-state growth rates of aggregate technology, investment-specific technology, and the rate of consumer price inflation (at 0 percent, 4.5 percent, and $2\frac{1}{4}$ percent (all at annual rates), respectively); these calibrations ensure our model matches the average behavior of our data over the estimation sample.

Table 3 presents the prior distributions we assume for the estimated parameters and the posterior mode and standard deviation about that mode from our estima-

³We scale up this measure of hours by the ratio of nominal spending in our model to nominal non-farm business sector output in order to model a level of hours more appropriate for the total economy. Moreover, we remove a low-frequency trend from hours via the Hodrick-Prescott filter with a smoothing parameter of 6400; our model is not designed to capture low frequency trends in population growth or labor force participation.

β	α	ψ	δ^{nr}	δ^{cd}	δ^r	Θ_*^{cbi}	Θ_*^{kb}	Θ_*^l
0.990	0.260	5	0.030	0.055	0.004	7.000	7.000	7.000

Table 2: Calibrated Parameters

tions. The parameter values echo results elsewhere in the literature. With regard to monetary policy, smoothing is important (ρ_R near 0.7), the coefficient on the change in the output gap is large ($r_{\Delta y}$ near 0.5), and the coefficients on inflation and the level of the output gap take values near those of Taylor (r_π near 1.5, r_y near 0.5/4, where the division by 4 converts from annual rates to quarterly rates). There is only modest “indexation” in the price Phillips curve and none in the wage Phillips curve (η^p near 0.3 and η^w near 0). Finally, habits and adjustment costs are important (e.g., h near 0.7).

4 Sources of economic fluctuations

Table 4 presents the forecast-error-variance decomposition for growth of real GDP at various (quarterly) horizons, divided into the three broad categories. These statistics indicate how much of the variance in the forecast error for growth at each horizon is attributable to each category of shock. Similar decompositions for hours per capita and consumer price inflation are reported in tables 5 and 6.

For GDP, aggregate supply shocks and shifts in the IS curve are both important contributors to the forecast error variance at all frequencies (table 4). With regard to investment-specific technology shocks, these play only a relatively small role – for example, they contribute 19 percent and 11 percent to the forecast error variance at the 1 and 4 quarter horizons. The nonresidential IS curve shocks – the marginal efficiency of investment shock – is more significant in the aggregate reported for the IS curve column, accounting for 40 and 57 percent at the 1 and 4 quarter horizons.

For hours per capita, shifts in the IS curve dominate the cyclical movements. The

Table 3: Prior Distribution and Posterior Mode for Estimated Parameters

Parameter	Prior Dist.	Prior mean	Prior s.d.	Posterior mode	s.d.
h	N	0.000	0.3300	0.7094	0.0224
ν	G	2.000	1.0000	0.5039	0.1113
r_π	N	1.500	0.0625	1.3864	0.0585
r_y	N	1.000	0.1250	0.1124	0.0108
$r_{\Delta y}$	N	0.000	0.1250	0.4690	0.0552
χ^p	G	4.000	1.0000	1.6919	0.1410
χ^H	G	4.000	1.0000	4.1691	1.4586
χ^w	G	4.000	1.0000	0.5160	0.0695
χ^{nr}	G	4.000	1.0000	0.5348	0.0622
χ^{cd}	G	4.000	1.0000	0.4554	0.0629
χ^r	G	4.000	1.0000	9.3074	1.2096
η^p	N	0.000	0.5000	0.2926	0.1076
η^w	N	0.000	0.5000	-0.0446	0.1515
ρ_R	N	0.500	0.2500	0.6761	0.0257
ρ_{cnn}	N	0.000	0.3300	0.8678	0.0371
ρ_{nr}	N	0.000	0.3300	0.7367	0.0332
ρ_{cd}	N	0.000	0.3300	0.4943	0.0979
ρ_{HG}	B	0.500	0.0150	0.9323	0.0166
ρ_L	N	0.000	0.3300	0.4645	0.0565
ρ_r	N	0.000	0.3300	0.8409	0.0212
σ_{cnn}	I	1.000	2.0000	1.4727	0.1245
σ_{HG}	I	1.000	2.0000	1.2398	0.1818
σ_L	I	1.000	2.0000	3.6768	0.3741
σ_R	I	0.200	2.0000	0.1554	0.0126
$\sigma_{z, kb}$	I	0.250	2.0000	0.8659	0.1243
$\sigma_{z, m}$	I	0.250	2.0000	0.4599	0.0610
σ_{cbi}	I	0.200	2.0000	0.2253	0.0232
σ_{kb}	I	0.200	2.0000	0.3414	0.0644
σ_r	N	5.000	1.0000	3.5132	0.3468
σ_{cd}	N	5.000	1.0000	5.7528	0.5606
σ_{nr}	N	5.000	1.0000	5.1077	0.4202

Notes:

1. B denotes the Beta distribution; G denotes the Gamma distribution; I denotes the Inverted Gamma distribution; and N denotes the Normal distribution. For the Gamma distribution, hyperparameters are shown. The posterior standard deviations are based on the negative inverse hessian evaluated at the posterior mode.

Table 4: Forecast-Error-Variance Decomposition - Growth in Real GDP

Horizon	Type of Shock		
	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.41	0.47	0.12
Four Quarter	0.34	0.64	0.02
Twelve Quarter	0.79	0.21	0.00

Note: Each row contains the fraction of the forecast-error variance accounted for by each category of shock. Rows may not sum to 100 due to rounding.

nonresidential IS curve shocks – the marginal efficiency of investment shock – is more significant in the aggregate reported for the IS curve column, accounting for 54 and 66 percent at the 1 and 4 quarter horizons.

Aggregate supply shocks are a very important factor for fluctuations in consumer price inflation in the very short run, reflecting the role of markup shocks. Technology shocks are not very important in the aggregate supply column. At longer horizons, the IS curve shocks dominate – and again the nonresidential shock is very important, accounting for 32 percent and 55 percent at the 4 and 12 quarter horizons.

In summary, the EDO model implies a very significant role for IS curve shocks associated with nonresidential investment for business cycles and inflation. Investment-specific technology shocks are less important for most top-line macroeconomic aggregates.

5 What are IS curve shocks?

Our analyses, in this paper and previous research, has consistently pointed to shocks to “IS curves” as the important driver of business cycles. As a result, our earlier

Table 5: Forecast-Error-Variance Decomposition - Hours Per Capita

Horizon	Type of Shock		
	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.05	0.91	0.04
Four Quarter	0.05	0.92	0.03
Twelve Quarter	0.10	0.89	0.01

Note: Each row contains the fraction of the forecast-error variance accounted for by each category of shock. Rows may not sum to 100 due to rounding.

Table 6: Forecast-Error-Variance Decomposition - Consumer Price Inflation

Horizon	Type of Shock		
	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.85	0.13	0.02
Four Quarter	0.57	0.37	0.06
Twelve Quarter	0.25	0.72	0.03

Note: Each row contains the fraction of the forecast-error variance accounted for by each category of shock. Rows may not sum to 100 due to rounding.

work has suggested that future research should consider what types of frictions may generate these shocks, with a special emphasis on financial frictions (e.g., Edge, Kiley, and Laforge (2008a, 2008b)).

In this section, we explore these ideas more fully. In particular, IS-curve shocks are shocks that enter the equations for consumption smoothing given the assets available to agents in the economy – nonresidential capital, residential capital, and consumer durables. The intertemporal-optimality conditions/Euler equations/IS curves that determine these relationships, and that are shocked by our marginal efficiency of investment shocks and consumption preference shocks, are standard asset pricing relationships. In order to see whether more detailed modeling of financial markets may help understand why these shocks are important, we consider a detailed investigation similar to that considered on a small scale by Justiniani, Primiceri, and Tambalotti (2009).

Specifically, we examine the dynamic correlations between our IS curve shocks and financial market variables. We consider three financial market variables: the spread between a BBB bond yield and the ten-year Treasury yield; the spread between the dividend yield on household equity wealth (measured as dividend income from the National Income and Product Accounts divided by U.S. household equity holdings from the Flow of Funds Accounts) and the ten-year Treasury yield; and the spread between the 30-year fixed rate mortgage rate and the ten-year Treasury yield. These three indicators provide measures of financial market variables specific to the corporate bond market, household wealth, and mortgage markets, and the relationships of these variables with the IS curve shocks from our model may provide clues regarding fruitful research directions.

Figure 2 reports the covariance matrix (with correlations, t-statistics, and p-values) for the IS curve shocks and the financial market variables; all the data are detrended using the Hodrick-Prescott filter and a smoothing parameter of 1600. Two points are apparent. First, the correlations are high between all of the IS shocks and

Table 7: Granger causality from financial variables to IS curve processes

IS-curve Process	Financial Variable		
	BBB spread	Dividend yield spread	Mortgage spread
Bus. Inv. Shock	0.02	0.00	0.10
Nondurable C Shock	0.05	0.69	0.40
Durable C Shock	0.05	0.11	0.25
Res. Inv. Shock	0.18	0.03	0.02

Note: Each row contains the p-value associated with the null that the variable does not Granger cause the shock process in the row (Sample 1984q4-2008q4, with two lags).

the BBB spread and dividend yield. Second, the correlation of the mortgage spread is not very large or significant, except for the residential investment shock. Figures 3, 4, and 5 present the data, and the comovement between the series is very apparent. These correlations suggest important relationships between observable financial market variables and the IS shocks, which should be investigated in models with more explicit financial market channels of transmission. A recent effort on such a model is that of Christiano, Motto, and Rostagno (2007).

An interesting question is whether the exogenous IS curve processes are forecastable using financial market information. Such forecastability would clearly call for extensions of the model – as these processes are assumed to be exogenous in EDO (and many other DSGE models). Forecastability would also hint that these shocks are anticipated – as suggested by the “news” literature (e.g., Schmitt-Grohe and Uribe (2008)). Table 7 presents the p-values associated with Granger causality tests from the financial market indicators to the IS curve shock processes. (In this case, the data are not filtered).

The results are quite interesting. There is clear evidence of Granger causality,

especially for the BBB spread and for the dividend yield; the mortgage spread Granger causes the IS shock process most directly related to residential investment, suggesting important information in that one financial variable in the area where it most directly may affect expenditures. Overall, these results suggest some anticipation in financial markets, consistent with the “news” literature.

6 Conclusion

Our analysis reaches three conclusions:

- Intertemporal IS curve shocks, especially those related to nonresidential investment, are the dominant source of business cycles. Investment-specific technology shocks, while very important for long-run growth as we have previously emphasized (Edge, Kiley, and Laforge (2007, 2008a)), are not as important for the business cycle.
- Intertemporal IS curve shocks are highly correlated with financial variables, which may suggest a structural role for financial frictions as explored in Christiano, Motto, and Rostagno (2007).
- Financial variables predict our IS curve shock processes, suggesting that these shocks are (partly) anticipated as suggested in the “news” literature.

Future extensions our model will likely consider explicit models of financial markets. We think developments along these lines are important, for example, to improve the regular presentation of our model analyses to staff at the Federal Reserve and the Federal Open Market Committee (FOMC).

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Figure 1: Model Overview

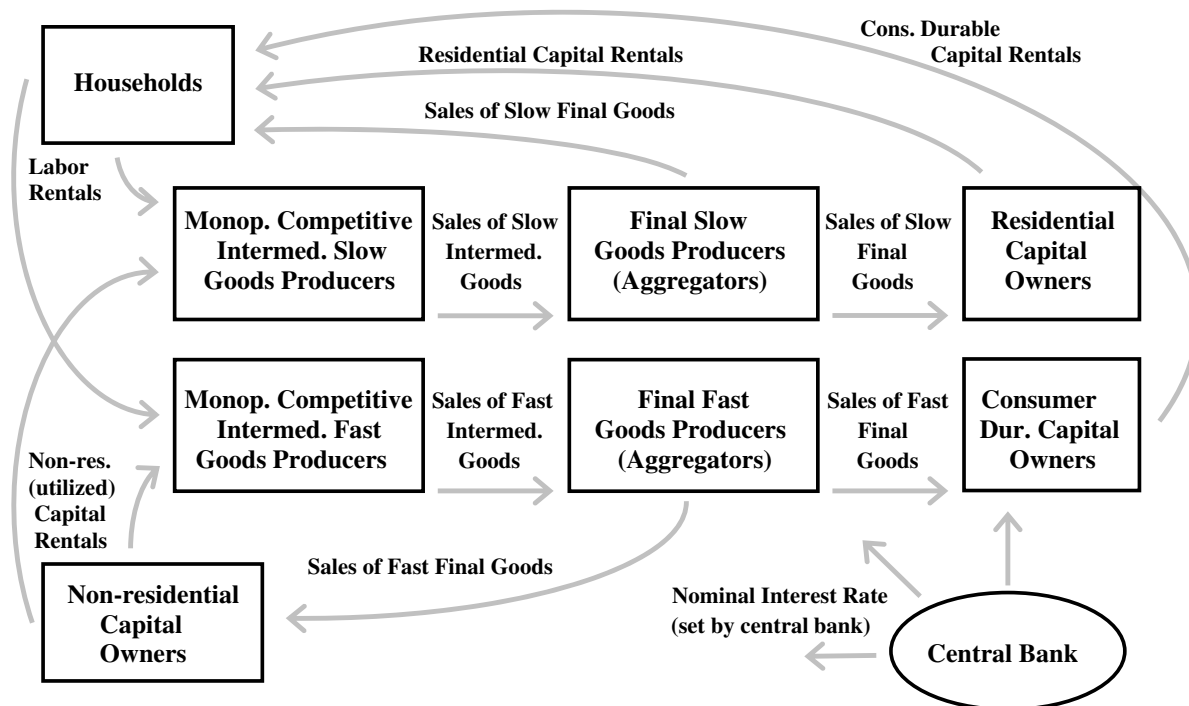


Figure 2: Covariance Matrix for Financial Market Variables and IS Shock Processes

Sample: 1984Q4 2008Q4
Included observations: 97

Covariance Correlation t-Statistic Probability	BBB spread	Dividend yield spread	Mortgage spread	Bus. Inv. Shock	Nondurable C Shock	Durable C Shock	Res. Inv. Shock
BBB spread	0.172641 1.000000 ----- -----						
Dividend yield spread	0.155390 0.550429 6.425959 0.0000	0.461637 1.000000 ----- -----					
Mortgage spread	0.037471 0.507311 5.737834 0.0000	0.030663 0.253876 2.558292 0.0121	0.031600 1.000000 ----- -----				
Bus. Inv. Shock	0.479886 0.289011 2.942498 0.0041	1.411895 0.519996 5.933599 0.0000	-0.050920 -0.071679 -0.700441 0.4854	15.96995 1.000000 ----- -----			
Nondurable C Shock	0.394789 0.553704 6.481023 0.0000	0.623460 0.534740 6.167932 0.0000	0.031970 0.104806 1.027178 0.3069	3.254476 0.474585 5.255209 0.0000	2.944627 1.000000 ----- -----		
Durable C Shock	0.628436 0.350736 3.650447 0.0004	0.853470 0.291292 2.967870 0.0038	-0.125247 -0.163385 -1.614174 0.1098	0.849320 0.049285 0.480950 0.6317	3.499134 0.472864 5.230650 0.0000	18.59593 1.000000 ----- -----	
Res. Inv. Shock	0.469654 0.384430 4.058863 0.0001	-0.112672 -0.056399 -0.550591 0.5832	0.101470 0.194134 1.928879 0.0567	-0.253129 -0.021543 -0.210022 0.8341	1.039714 0.206068 2.052551 0.0429	1.904495 0.150204 1.480808 0.1420	8.645259 1.000000 ----- -----

Figure 3: BBB bond yield spread and IS Shock Processes



Figure 4: Dividend yield spread and IS Shock Processes

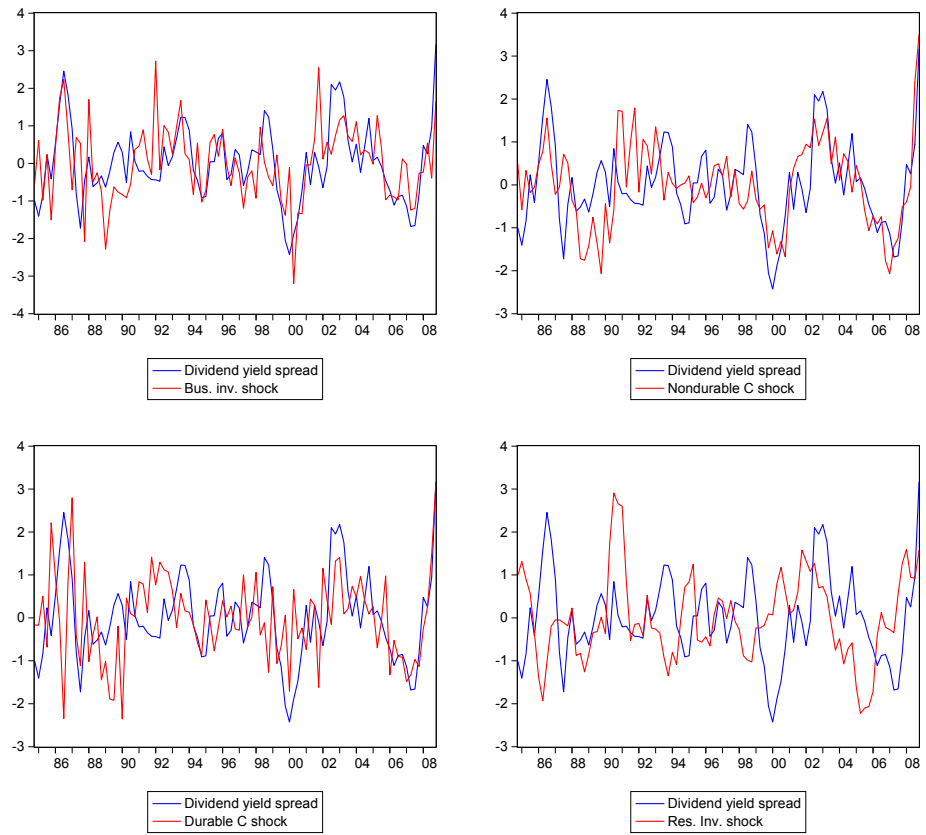


Figure 5: Mortgage rate spread and IS Shock Processes

