The Sources of Fluctuations in Residential Investment: A View from a Policy-Oriented DSGE Model of the U.S. Economy *

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Abstract

This paper analyzes fluctuations in residential investment using an estimated DSGE model of the U.S. economy, which is current used to analyze policy questions and to produce forecasts on a regular basis. Importantly, the model is more detailed in its treatment of domestic spending and production decisions than most other models, allowing consideration of questions related to the housing sector and other macroecnomic developments. Our analysis examines the importance of various structural factors in determining the course of residential investment in the United States over the past two decades. We focus especially on developments in the last ten years, and examine in detail the relationship between monetary policy actions and residential investment within our model.

JEL classification: C51; E32; E52; O41.

Keywords: Residential Investment, Housing, Monetary Policy

*We thank our colleagues for discussions on this topic. This project and the associated work on the FRB/Edo model has benefited substantial from the research assistance of Richard Windle. The views expressed herein are the authors and should not be attributed to the Board of Governors of the Federal Reserve System or other members of its staff.

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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 contribute to the forecast work at the Federal Reserve Board (Edge, Kiley, and Laforte (2007, 2008a, 2008b)). This research examines how our Estimated, Dynamic, Optimization-based model, FRB/EDO, interprets fluctuations in residential investment over the last two decades. We focus on three questions:

- What are the fundamental determinants of business-cycle fluctuations in residential investment?
- Are the sources of fluctuations in residential investment at business-cycle frequencies different, at least to some extent, than the sources of fluctuations in GDP and inflation?
- How important is monetary policy as a factor driving residential investment over the past two decades, as well as more recently?

We think each of these questions is particularly important in the current environment. Residential investment has contracted sharply over the past year-and-a-half. A decomposition of this decline into the separate influences of structural factors such as productivity movements, preference (e.g., demand) shifts, and interest rates provides information on the likely future course of the housing market and the setting of monetary policy. Moreover, our analysis sheds some light on the degree to which the strength of residential investment from 2002 to 2005 may have reflected monetary policy decisions, a topic of several recent pieces of research.

The Edo model is particularly well-suited to answer this set of questions. The models general equilibrium approach and rich sectoral detail allow consideration of movements in residential investment, broader measures of economic activity (such as GDP and aggregate hours), and inflation; 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 is relatively unique among existing DSGE models.

The remainder of this paper is divided into six 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 in residential investment according to Edo and compares these sources to those driving GDP and inflation. The fourth section examines the role of monetary policy innovations in accounting for the realized paths of key macroeconomic variables, both over the past two decades and during the recent run-up and subsequent decline in housing. A concluding section provides some thoughts for future research.

2 Related Research

A number of recent pieces have examined the rise and subsequent decline of residential investment in the United States over the past ten years. We highlight the previous studies most closely related to our focus.

Del Negro and Otrok (2005) and Fisher and Quayyam (2006) examine the impact of monetary policy innovations on house prices and residential investment, respectively, using plausible identifying restrictions in reduced-form vector-autoregression (VAR) models. Both studies attribute only a small portion of the run-up in these housing market indicators through 2005 to monetary policy. Our use of a structural model allows us to widen our study to examine the broader economic implications of monetary policy in both the early 1990s and early 2000s. We are also able to extend our analysis through the first half of 2007.

Iacoviello and Neri (2007) consider similar questions in a dynamic, stochastic, general equilibrium model with many features that are similar to the Edo model. Their model contains a collateral channel for housing wealth that is absent from Edo; they also model house prices. However, their model contains less detail on other components of expenditure (e.g., consumer durables are lumped with other components of consumption, and their measure of GDP ignores inventory investment, government expenditure, and net exports); they also model less detail on inflation (e.g., our model contains measures of consumer expenditure inflation, capital goods inflation, and GDP inflation, whereas their model considers only nonfarm business inflation). We suspect that a fairly detailed treatment of inflation and GDP is most appropriate for questions analyzing monetary policy, as policymakers appear concerned with economic activity overall not the subset of activity that is both modeled and measured by Iacoviello and Neri (2007).

With respect to findings, Iacoviello and Neri (2007) attribute a sizeable portion of the run-up in residential investment following 2002 to monetary policy shocks. However, this finding appears to reflect, in part, their estimation strategy. In particular, they estimate their model over the period from 1965 to the present. As a result, their model views monetary policy as more erratic and hence as a larger contributor to the business cycle than would modesl that focus on the U.S. economy since the early 1980s, as does Edo. (We estimate the Edo model from late 1984 to the present, arguably a period with a more stable monetary policy; other aspects of the economy may have also been more stable during our sample period).

Leamer (2007) suggests that monetary policy contributed significantly to housing fluctuations recently. His analysis is neither based on a structural model nor on transparent identification assumptions (a hallmark of the other research discussed previously). He suggests that monetary policy performed very poorly recently but well in the early 1990s.

Taylor (2007) also suggests that monetary policy did not perform especially well in the most recent period. But his analysis is much more impressionistic that that of the other research we have reviewed, except perhaps that of Leamer (2007). Nonetheless, two points are worth highlighting. First, Taylor calls for analysis using a structural model with firm microeconomic foundations, but follows a reduced-form approach in his own analysis; our research addresses his call for a structural approach. Second, Taylor views the path of the federal funds rate from 2002 through 2005 as very large. We will find smaller deviations in our examination in section 5. It is important to note that this view of Taylors is simply assumed; it is not based on an estimated rule consistent with FOMC behavior over the past two decades. The policy rule in Edo is estimated and tracks the federal funds rate data very well.

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 Laforte (2007, 2008a).

Figure 1 provides a graphical overview of the economy described by our model. 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 canonical DSGE models of Christiano et al. [2005] and Smets and Wouters [2004b] did not address differences in trend growth rates between investment and consumption spending aggregates and trending relative price measures that drive our choice of a two-sector structure, although an earlier literature—less closely tied to business cycle fluctuations in the data—did explore the multi-sector structure underlying U.S. growth and fluctuations.[1] Subsequent richly-specified models with close ties to the data have adopted a multi-sector growth structure, including Altig et al. [2004], Edge, Laubach, and Williams [2003], and DiCecio [2005]; our model shares features with the latter two of these models.

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 residential investment. Many previous models have lumped residential investment with other types of investment. Of course, important exceptions exist – most notably Iacoveillo and Neri (2007), as discussed earlier.

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.

[1] See for examples, Greenwood et. al [1997], Greenwood et. al [2000], Whelan [2003], and Fisher [2006].

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:

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

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

$$\theta_t^{x,s} = \epsilon_t^{\theta,x,s}, \text{ for } s = cbi, kb, \tag{2}$$

where $\epsilon_t^{\theta,x,s}$ 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:

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

The term Θ_t^l is the stochastic elasticity of substitution between the differentiated labor inputs. Letting $\theta_t^l \equiv \ln \Theta_t^l - \ln \Theta_*^l$ denote the log-deviation of Θ_t^l from its steady-state value of Θ_*^l, we assume that

$$\theta_t^l = \epsilon_t^{\theta,l} \tag{4}$$

where $\epsilon_t^{\theta,l}$ is an i.i.d. shock process.

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:

$$\min_{\left\{L_t^s(j), K_t^{u,nr,s}(j)\right\}} W_t^s L_t^s(j) + R_t^{nr,s} K_t^{u,nr,s}(j)$$
$$\text{subject to } \left(Z_t^m Z_t^s L_t^s(j)\right)^{1-\alpha} \left(K_t^{u,nr,s}(j)\right)^{\alpha} \geq X_t^s(j), \text{ for } s = cbi, kb, \text{ but } Z_t^{cbi} \equiv 1. \tag{5}$$

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

$$\ln Z_t^n - \ln Z_{t-1}^n = \ln \Gamma_t^{z,n} = \ln\left(\Gamma_*^{z,n} \cdot \exp[\gamma_t^{z,n}]\right) = \ln \Gamma_*^{z,n} + \gamma_t^{z,n},\ \ n = kb, m \tag{6}$$

where $\Gamma_*^{z,n}$ and $\gamma_t^{z,n}$ are the steady-state and stochastic components of $\Gamma_t^{z,n}$. The stochastic component $\gamma_t^{z,n}$ is assumed to evolve according to

$$\gamma_t^{z,n} = \rho^{z,n}\gamma_{t-1}^{z,n} + \epsilon_t^{z,n},\ \ n = kb, m. \tag{7}$$

where $\epsilon_t^{z,n}$ is an i.i.d shock process, and $\rho^{z,n}$ represents the persistence of $\gamma_t^{z,n}$ to a shock. 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:

$$\begin{aligned} \max_{\{P_t^s(j), X_t^s(j), X_t^s(j)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \Bigg\{ & P_t^s(j) X_t^s(j) - MC_t^s(j) X_t^s(j) \\ & - \frac{100 \cdot \chi^p}{2} \left(\frac{P_t^s(j)}{P_{t-1}^s(j)} - \eta^p \Pi_{t-1}^{p,s} - (1-\eta^p)\Pi_*^{p,s} \right)^2 P_t^s X_t^s \Bigg\} \end{aligned}$$

$$\text{subject to } X_\tau^s(j) = \left(P_\tau^s(j)/P_\tau^s\right)^{-\Theta_\tau^{x,s}} X_\tau^s \text{ for } \tau = 0, 1, ..., \infty \text{ and } s = cbi, kb. \tag{8}$$

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 5 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, $\Lambda_t^{cnn}/P_t^{cbi}$):

$$\max_{\{E_t^{nr}(k),K_{t+1}^{nr}(k),K_t^{nr,cbi}(k),K_t^{nr,kb}(k)U_t^{cbi}(k),U_t^{kb}(k)\}_{t=0}^{\infty}}$$

$$\mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \Big\{ R_t^{nr} U_t^{cbi}(k) K_t^{nr,cbi}(k) + R_t^{nr} U_t^{kb}(k) K_t^{nr,kb}(k) - P_t^{kb} E_t^{nr}(k)$$
$$- \kappa \left(\frac{U_t^{cbi}(k)^{1+\psi} - 1}{1+\psi} \right) P_t^{kb} K_t^{nr,cbi} - \kappa \left(\frac{U_t^{kb}(k)^{1+\psi} - 1}{1+\psi} \right) P_t^{kb} K_t^{nr,kb} \Big\}$$

subject to

$$K_{\tau+1}^{nr}(k) = (1-\delta^{nr}) K_\tau^{nr}(k) + A_\tau^{nr} E_\tau^{nr}(k) - \frac{100 \cdot \chi^{nr}}{2} \left(\frac{E_\tau^{nr}(k) - E_{\tau-1}^{nr}(k) \Gamma_t^{y,kb}}{K_\tau^{nr}} \right)^2 K_\tau^{nr} \text{ and}$$
$$K_\tau^{nr,cbi}(k) + K_\tau^{nr,kb}(k) = K_\tau^{nr}(k) \text{ for } \tau = 0, 1, ..., \infty. \tag{9}$$

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 $(E^{nr}_{\tau}(k) - E^{nr}_{\tau-1}(k)\Gamma^{y,kb}_{t})$ rises above zero. The variable A^{nr}_t is a stochastic element affecting the efficiency of non-residential investment in the capital-accumulation process. Letting $a^{nr}_t \equiv \ln A^{nr}_t$ denote the log-deviation of A^{nr}_t from its steady-state value of unity, we assume that:

$$a^{nr}_t = \rho^{a,nr} a^{nr}_{t-1} + \epsilon^{a,nr}_t. \tag{10}$$

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^{cd}_t, the price of consumer-durable goods, P^{kb}_t, and households' valuation of nominal capital income, $\Lambda^{cnn}_t/P^{cbi}_t$, the capital owner chooses investment in consumer durables, I^{cd}_t, and its implied capital stock, K^{cd}_t, to solve:

$$\max_{\{E^{cd}_t(k),K^{cd}_{t+1}(k)\}^{\infty}_{t=0}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda^{cnn}_t}{P^{cbi}_t} \left\{ R^{cd}_t K^{cd}_t(k) - P^{kb}_t E^{cd}_t(k) \right\}$$

subject to

$$K^{cd}_{\tau+1}(k) = (1-\delta^{cd})K^{cd}_{\tau}(k) + A^{cd}_{\tau} E^{cd}_{\tau}(k) - \frac{100 \cdot \chi^{cd}}{2} \left(\frac{E^{cd}_{\tau}(k) - E^{cd}_{\tau-1}(k)\Gamma^{x,kb}_{\tau}}{K^{cd}_{\tau}} \right)^2 K^{cd}_{\tau}$$

for $\tau = 0, 1, ..., \infty$. (11)

The residential capital owner's decision is analogous:

$$\max_{\{E^{r}_t(k),K^{r}_{t+1}(k)\}^{\infty}_{t=0}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda^{cnn}_t}{P^{cbi}_t} \left\{ R^{r}_t K^{r}_t(k) - P^{cbi}_t E^{r}_t(k) \right\}$$

subject to

$$K^{r}_{\tau+1}(k) = (1-\delta^{r})K^{r}_{\tau}(k) + A^{r}_{\tau} E^{r}_{\tau}(k) - \frac{100 \cdot \chi^{r}}{2} \left(\frac{E^{r}_{\tau}(k) - E^{r}_{\tau-1}(k)\Gamma^{x,cbi}_{\tau}}{K^{cd}_{\tau}} \right)^2 K^{cd}_{\tau}$$

for $\tau = 0, 1, ..., \infty$. (12)

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 (10).

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^{cnn} 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 ith household solves:

$$\max_{\left\{E_t^{cnn}(i),K_t^{cd}(i),K_t^{r}(i),\{W_t^s(i),L_t^s(i)\}_{s=cbi,kb},B_{t+1}(i)\right\}_{t=0}^{\infty}}$$

$$\mathcal{E}_0\sum_{t=0}^{\infty}\beta^t\Big\{\varsigma^{cnn}\Xi_t^{cnn}\ln(E_t^{cnn}(i)-h^{cnn}E_{t-1}^{cnn}(i))+\varsigma^{cd}\Xi_t^{cd}\ln(K_t^{cd}(i)-h^{cd}K_{t-1}^{cd}(i))$$

$$+\varsigma^{r}\Xi_t^{r}\ln(K_t^{r}(i)-h^{r}K_{t-1}^{r}(i))-\varsigma^{l}\Xi_t^{l}\frac{(L_t^{cbi}(i)+L_t^{kb}(i))^{1+\nu}}{1+\nu}\Big\}.$$

subject to

$$R_\tau^{-1}B_{\tau+1}(i)=B_\tau(i)+\sum_{s=cbi,kb}W_\tau^s(i)L_\tau^s(i)+\textit{Capital and Profits Income}_\tau(i)-P_\tau^{cbi}E_\tau^{cnn}(i)$$

$$-R_\tau^{cd}K_\tau^{cd}(i)-R_\tau^{r}K_\tau^{r}(i)-\sum_{s=cbi,kb}\frac{100\cdot\chi^w}{2}\left(\frac{W_\tau^s(j)}{W_{\tau-1}^s(j)}-\eta^w\Pi_{\tau-1}^{w,s}-(1-\eta^w)\Pi_*^w\right)^2W_\tau^sL_\tau^s$$

$$-\frac{100\cdot\chi^l}{2}\left(\frac{L_*^{cbi}\cdot W_\tau^{cbi}}{L_*^{cbi}+L_*^{kb}}+\frac{L_*^{kb}\cdot W_\tau^{kb}}{L_*^{cbi}+L_*^{kb}}\right)\left(\frac{L_\tau^{cbi}(i)}{L_\tau^{kb}(i)}-\eta^l\frac{L_{\tau-1}^{cbi}}{L_{\tau-1}^{kb}}-(1-\eta^l)\frac{L_*^{cbi}}{L_*^{kb}}\right)^2\frac{L_\tau^{kb}}{L_\tau^{cbi}}.$$

$$L_\tau^{cbi}(i)=\left(W_\tau^{cbi}(i)/W_\tau^{cbi}\right)^{-\Theta_\tau^{l,cbi}}L_\tau^{cbi},\text{ and }L_\tau^{kb}(i)=\left(W_\tau^{kb}(i)/W_\tau^{kb}\right)^{-\Theta_\tau^{l,kb}}L_\tau^{kb},$$

$$\text{for }\tau=0,1,...,\infty. \tag{13}$$

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}, Ξ_t^{cd}, Ξ_t^{r}, and Ξ_t^{l} represent aggregate shocks to the household's utility of its consumption components 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

$$\xi_t^x=\rho^{\xi,x}\xi_{t-1}^x+\epsilon_t^{\xi,x},\qquad x=cnn,cd,r,l. \tag{14}$$

The variable $\epsilon_t^{\xi,x}$ is an i.i.d. shock process, and $\rho^{\xi,x}$ represents the persistence of Ξ_t^x away from steady-state following a shock to equation (14). 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, a point we briefly return to when discussing our parameter estimates.

3.5 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 $\bar{R}_t$

$$R_t = (R_{t-1})^{\phi^r} \left(\bar{R}_t\right)^{1-\phi^r} \exp\left[\epsilon_t^r\right], \tag{15}$$

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 on GDP growth relative to steady-state growth, H_t^{gdp}/H_*^{gdp}, the acceleration of GDP growth, H_t^{gdp}/H_{t-1}^{gdp}, GDP inflation relative to target, $\Pi_*^{p,gdp}/\Pi_t^{p,gdp}$, and the acceleration of GDP inflation, $\Pi_t^{p,gdp}/\Pi_{t-1}^{p,gdp}$:

$$\bar{R}_t = \left(\frac{H_t^{gdp}}{H_*^{gdp}}\right)^{\phi^{h,gdp}} \left(\frac{H_t^{gdp}}{H_{t-1}^{gdp}}\right)^{\phi^{\Delta h,gdp}} \left(\frac{\Pi_t^{p,gdp}}{\Pi_*^{p,gdp}}\right)^{\phi^{\pi,gdp}} \left(\frac{\Pi_t^{p,gdp}}{\Pi_{t-1}^{p,gdp}}\right)^{\phi^{\Delta\pi,gdp}} R_*. \tag{16}$$

In equation (16), R_* denotes the economy's steady-state nominal interest rate and $\phi^{h,gdp}$, $\phi^{\Delta h,gdp}$, $\phi^{\pi,gdp}$, and $\phi^{\Delta\pi,gdp}$ denote the weights in the feedback rule.

GDP growth has not yet been discussed. It equals the Divisia (share-weighted) aggregate of final spending in the economy, as given by the identity:

$$H_t^{gdp} = \left(\left(\frac{X_t^{cbi}}{X_{t-1}^{cbi}}\right)^{P_*^{cbi}X_*^{cbi}} \left(\frac{X_t^{kb}}{X_{t-1}^{kb}}\right)^{P_*^{kb}X_*^{kb}} \left(\frac{\Gamma_t^{x,cbi} \cdot \widetilde{X}_t^{gf}}{\widetilde{X}_{t-1}^{gf}}\right)^{P_*^{cbi}X_*^{gf}}\right)^{\frac{1}{P_*^{cbi}X_*^{cbi}+P_*^{kb}X_*^{kb}+P_*^{cbi}X_*^{gf}}}. \tag{17}$$

In equation (17), $\widetilde{X}_t^{gf}$ represent stationary un-modeled output (that is, GDP other than 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:

$$\ln \widetilde{X}_t^{gf} - \ln \widetilde{X}_*^{gf} = \rho^{x,gf} \left(\ln \widetilde{X}_t^{gf} - \ln \widetilde{X}_*^{gf} \right) + \epsilon^{x,gf}.$$

The inflation rate of the GDP deflator, represented by $\Pi_t^{p,gdp}$, is defined implicitly by:

$$\Pi_t^{p,gdp} H_t^{gdp} = \frac{P_t^{gdp} X_t^{gdp}}{P_{t-1}^{gdp} X_{t-1}^{gdp}} = \frac{P_t^{cbi} X_t^{cbi} + P_t^{kb} X_t^{kb} + P_t^{cbi} X_t^{gf}}{P_t^{cbi} X_{t-1}^{cbi} + P_{t-1}^{kb} X_{t-1}^{kb} + P_t^{cbi} X_{t-1}^{gf}}.$$

3.6 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]

3.7 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.

[2]Interestingly, a common criticism of large econometric models like 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.

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 12 data series. The series, each from the Bureau of Economic Analysis's National Income and Product Accounts except where noted, are: Nominal gross domestic product; Nominal consumption expenditure on non-durables and services excluding housing services; Nominal consumption expenditure on durables; Nominal residential investment expenditure; Nominal business investment expenditure, which equals nominal gross private domestic investment minus nominal residential investment; GDP price inflation; Inflation for consumer non-durables and non-housing services; Inflation for consumer durables; Hours, which equals hours of all persons in the non-farm business sector from the Bureau of Labor Statistics;[3] Wage inflation, which equals compensation per hour in the non-farm business sector from the Bureau of Labor Statistics; the federal funds rate, from the Federal Reserve Board; and the nominal yield on the Ten-Year Treasury Note, our measure of the long-term interest 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 companion piece presents estimates of the model's parameters and properties in detail.

4 Sources of fluctuations in residential investment

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

[3]We 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.

- 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 and capital accumulation technologies (both if which affect the intertemporal Euler equations for the components of household and business demand), autonomous demand, and the slope of the term structure.
- A monetary policy shock

This classification maps (indirectly) the 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.

Table 1 presents the forecast-error-variance decomposition for growth of residential investment 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. It is clear from the table that fluctuations in residential investment are overwhelmingly driven by shifts in the IS curve (column 2); aggregate supply shocks contribute at most one-quarter of the forecast error variance even at medium-to-long horizons (column 1). Within the IS curve category, the most important shock contributing to the forecast error variance at medium-term horizons is the shock to the efficiency of business investment (not shown).

Figures 2 and 3 provide a historical decomposition of the percent change in residential investment from a year earlier relative to its trend; the decomposition attributes deviations from trend to the structural shocks. As shown in figure 2, the downturn in residential investment in the early 1990s and recently are entirely declines relative to the long-run trend. According to figure 3, nearly all of the fluctuations relative to trend come from shifts in the IS curve (the middle panel). Aggregate supply shocks

Table 1: Forecast-Error-Variance Decomposition - Growth in Residential Investment

	Type of Shock		
Horizon	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.08	0.90	0.01
Four Quarter	0.13	0.84	0.03
Eight Quarter	0.24	0.73	0.02

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.

(the upper panel) generate lower-frequency fluctuations. In particular, aggregate supply shocks hold down growth in residential investment in the first half of the sample and then boost residential investment growth in the second half; this occurs because productivity growth and hence growth in technology is lower in the 1985-1995 period than in the later period. Finally, monetary policy shocks the lower panel contribute relatively little to the wide swings in the growth of residential investment. We will return to the role of monetary policy in the third section.

The role of our structural shocks in driving residential investment is a bit hard to interpret out-of-context. We provide similar decompositions for real GDP growth and GDP price inflation for comparison purposes in tables 2 and 3 and in figures 4 to 7.

For GDP, shifts in the IS curve are the most important contributor to the forecast error variance at medium-run frequencies (table 2, column 2). This is also apparent in the sources of deviations of GDP growth from trend in figure 5; of particular note is the sharp drag on GDP growth exhibited by shifts in the IS curve at the start of the 1990s and 2000s that is, at the start of the two recessions in our sample period. Table 2 and figure 5 also make it clear that aggregate supply and monetary policy shocks

Table 2: Forecast-Error-Variance Decomposition - Growth in Real GDP

	Type of Shock		
Horizon	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.25	0.69	0.06
Four Quarter	0.21	0.75	0.05
Eight Quarter	0.26	0.73	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.

play a larger role in the fluctuations in GDP growth than for growth of residential investment.

In contrast to the results for residential investment and GDP, aggregate supply shocks are a very important factor for fluctuations in GDP price inflation (table 3, column 1 and figures 6 and 7). The bottom two panels of figure 7 reveal only a slow-moving and persistent effect of shifts in the IS curve and monetary policy shocks on inflation; this is consistent with a relatively flat Phillips curve effect in response to these shocks.

5 The role of monetary policy

The variance decompositions and decomposition of historical fluctuations in residential investment do not suggest a large role for monetary policy. This finding seems to conflict with arguments by some economists that monetary policy was an important factor recent fluctuations in residential investment.

In this section, we examine the interaction between monetary policy and residential investment in more detail. In the first subsection, we take the estimated rule in

Table 3: Forecast-Error-Variance Decomposition - GDP Price Inflation

	Type of Shock		
Horizon	Aggregate supply	Intertemporal IS curve	Monetary policy
One Quarter	0.97	0.00	0.01
Four Quarter	0.80	0.09	0.11
Eight Quarter	0.61	0.20	0.19

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.

the FRB/EDO model as given, and examine how shocks to monetary policy have influenced residential investment and the economy more generally; this analysis is very similar to some of the previous research summarized in section 1. The next subsection considers how residential investment, and the economy more generally, may have behaved over the past two decades if monetary policy actions had acted optimally (according to various criteria) given the structure of the FRB/EDO model.

5.1 Monetary policy shocks

Figure 8 provides some perspective on the role of monetary policy in fluctuations of residential investment. The upper panel presents the contribution of monetary policy to the four-quarter change in residential investment (the dotted blue line) the same information shown on the lower panel of figure 3, but without the data on residential investment. The primary change from figure 3 is a change in scale a change that makes it apparent that monetary policy shocks have played a role in housing fluctuations, albeit a modest one relative to the overall size of movements in residential investment. Most recently, monetary policy the set the federal fudns rate below the level implied by the estimated rule from 2002 to 2004 contributed to growth rates of residential investment several percentage points above trend an effect that cumulates to a peak of about 10 percent of the level of residential investment (not shown). Given the size of swings in residential investment, this contribution to the rise in residential investment from 2002 is pretty small, albeit economically significant.

Despite the small size of this estimated contribution, it does illustrate that, according to Edo, monetary policy was a factor in the rise and subsequent decline in residential investment; a similar influence of monetary policy can been seen in the early 1990s.

However, an examination of residential investment in isolation does not provide any context. In particular, the idea that a monetary policy settings for the federal funds rate below the presciptions of the estimated rule over 2002-2004 contributed to a rise in residential construction begs the question of why monetary policy may have been more accomodative than expected by the estimated rule over that period. Edo provides a coherent framework for considering this question, as its detailed general-equilibrium structure allows analysis of residential investment, GDP, inflation, the labor market, and monetary policy within a single model based on clear micro-foundations.

Within Edo, monetary policy is governed by an estimated nominal interest rate rule linking the federal funds rate to its own lag and current and lagged readings on GDP growth and GDP price inflation. The second panel of figure 8 presents the data on the federal funds rate (solid, black line) and the simulated value that would have prevailed with no monetary policy shocks (the dashed, red line). The model explains movements in the federal funds rate quite well, and only two periods show persistent deviations from the value prescribed by the rule: the early 1990s and the middle of 2001 through early 2005. Both of these periods included recessions in economic activity and downward pressure on inflation. This suggests that monetary policy may have been accomodative during these periods in order to combat a deterioration in the labor market and/or downward pressure on inflation.

The bottom two panels offer some support to this interpretation. As shown in the inflation panel, Edo suggests that inflation would have fallen to about 1 percent in the early 1990s and from the middle of 2002 through 2003 in the absence of stimulative monetary policy. In the event, stimulative monetary prevented these declines in inflation. We view this characterization of policy actions during this period as plausible: For example, the FOMC explicitly noted the idea of a possible unwelcome fall in inflation during the recent period as a motivation for accomodative monetary policy.

The bottom panel turns to the labor market, which are summarized in Edo by the behavior of hours per capita. During both the early 1990s and the recent recession/early recovery period, Edo indicates that aggressive monetary easing trimmed the deterioration in the labor market. For example, hours per capita would have fallen to a level twice as far below trend as the amount they actually did fall by 2004 in the absence of monetary easing (relative to the policy rule). To put this counterfactual decline in hours in perspective, it would have been consistent with an unemployment rate peaking at a value near or above 7 percent, in contrast to the $6\frac{1}{4}$ percent peak that actually occurred. This interpretation of history by Edo is consistent with the notion that policymakers may have eased policy substantially in the early 1990s and the most recent recession in order to forestall a more significant decline in employment. This is perhaps consistent with the widespread notion that both periods were times of jobless recoveries suggesting that the path of GDP (the variable in the Edo policy rule) may not have been as good an indicator of overall economic activity at these times as it has been during other periods.

In sum, the decomposition of fluctuations in residential investment, the federal funds rate, inflation, and the labor market by Edo is consistent with the idea that aggressive monetary policy easing boosted residential investment notably in the most recent two recessions/early recovery periods, and that this boost may have been part of a strategy designed to prevent both declines in employment and inflation during those periods. In broad terms, the experience of the early 1990s and early 2000s look very similar. This conclusion is different than that of Leamer (2007) and Taylor (2007), who view the early 1990s as a monetary policy success but who are more critical of recent policy actions.

5.2 Optimal Monetary Policy

To be completed.

6 Conclusions

Our discussion has skipped over several important details that deserve further study.

We have focused on monetary policy shocks and have not considered in detail the systematic component of monetary policy. Edos nominal interest rate rule called for substantial declines in the federal funds rate in the early 1990s and early 2000s, and this systematic aspect of policy actions has important effects on the dynamic behavior of the economy that could be examined in more detail.

We have suggested that the stimulus to residential investment from accomodative monetary policy in the early 1990s and early 2000s may have been related to efforts by the FOMC to fulfill its objectives of price stability and full employment. Edo contains an explicit, utility-based welfare criterion, and it is possible to consider whether the nature of policy actions during these periods was welfare enhancing according to this metric. However, we do have some reservations about these types of welfare calculations. In particular, Edo contains a very rich description of economic dynamics, but only a partial description of the wide range of factors the lead to important welfare effects of fluctuations in inflation and activity; as a result, its welfare calculations may miss important interactions between features that are included in Edo and those that are excluded.

Finally, we have only provided a cursory description of the nature of the intertemporal IS curve shocks that are very important in Edo. A fuller description of the nature of these shocks may supply good clues regarding future model enhancements that may allow us to more fully understand these sources of fluctuations. One likely source of IS curve shocks is developments in financial markets. This area that is very difficult to model in a micro-founded, general-equilibrium manner, but we consider future research in this area to be very important.

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Figure 1: Model Overview

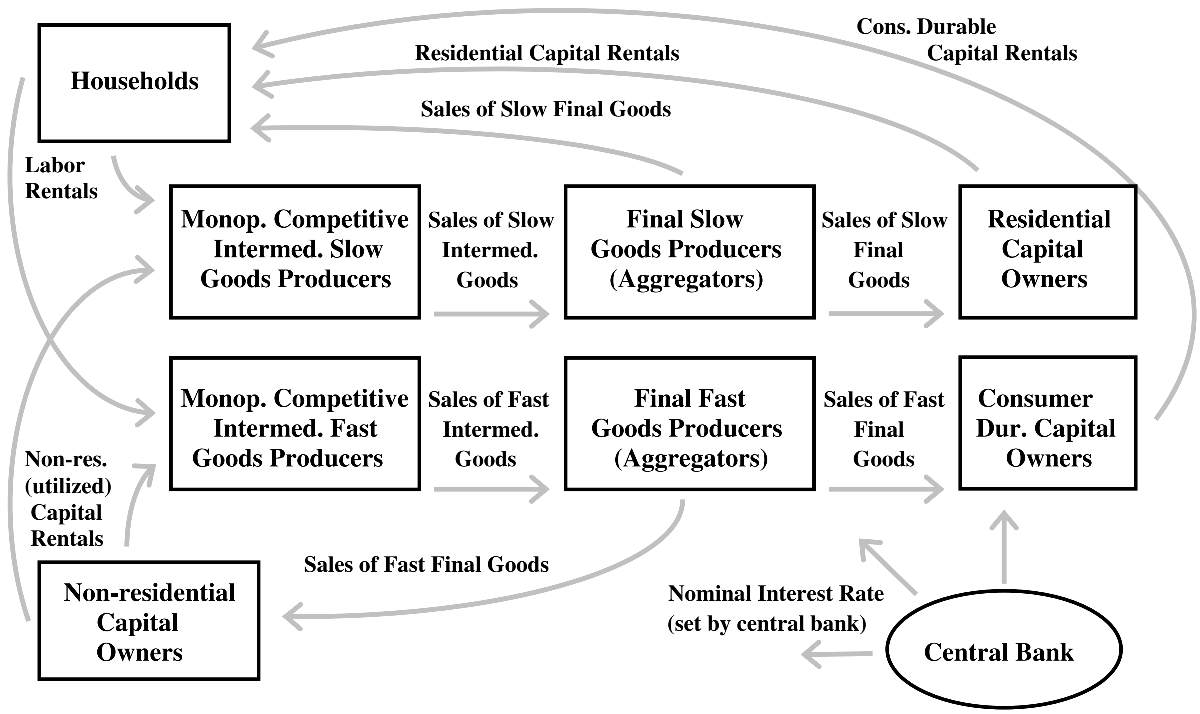
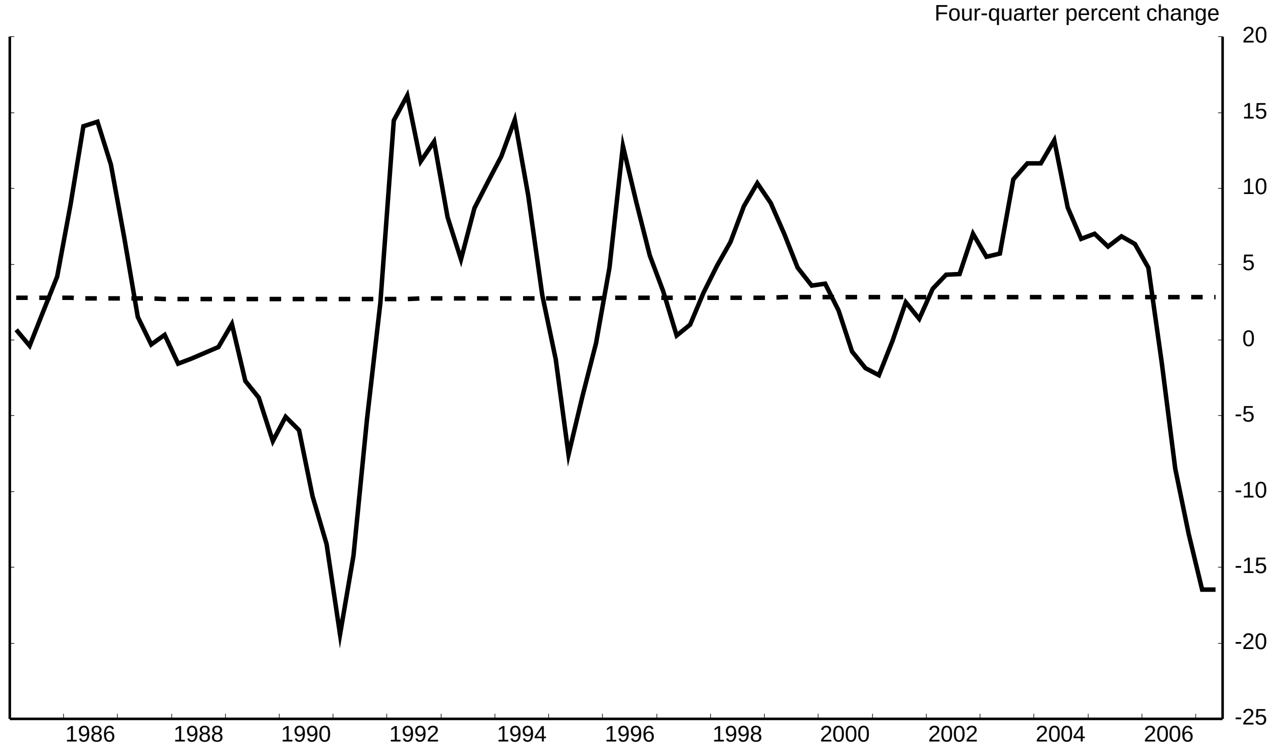


Figure 2
Residential Investment (in chain-weighted 2000 dollars)

Growth of residential investment (solid) and trend (dashed)



Deviations of residential investment growth from trend

Figure 3
Sources of fluctuations in residential investment

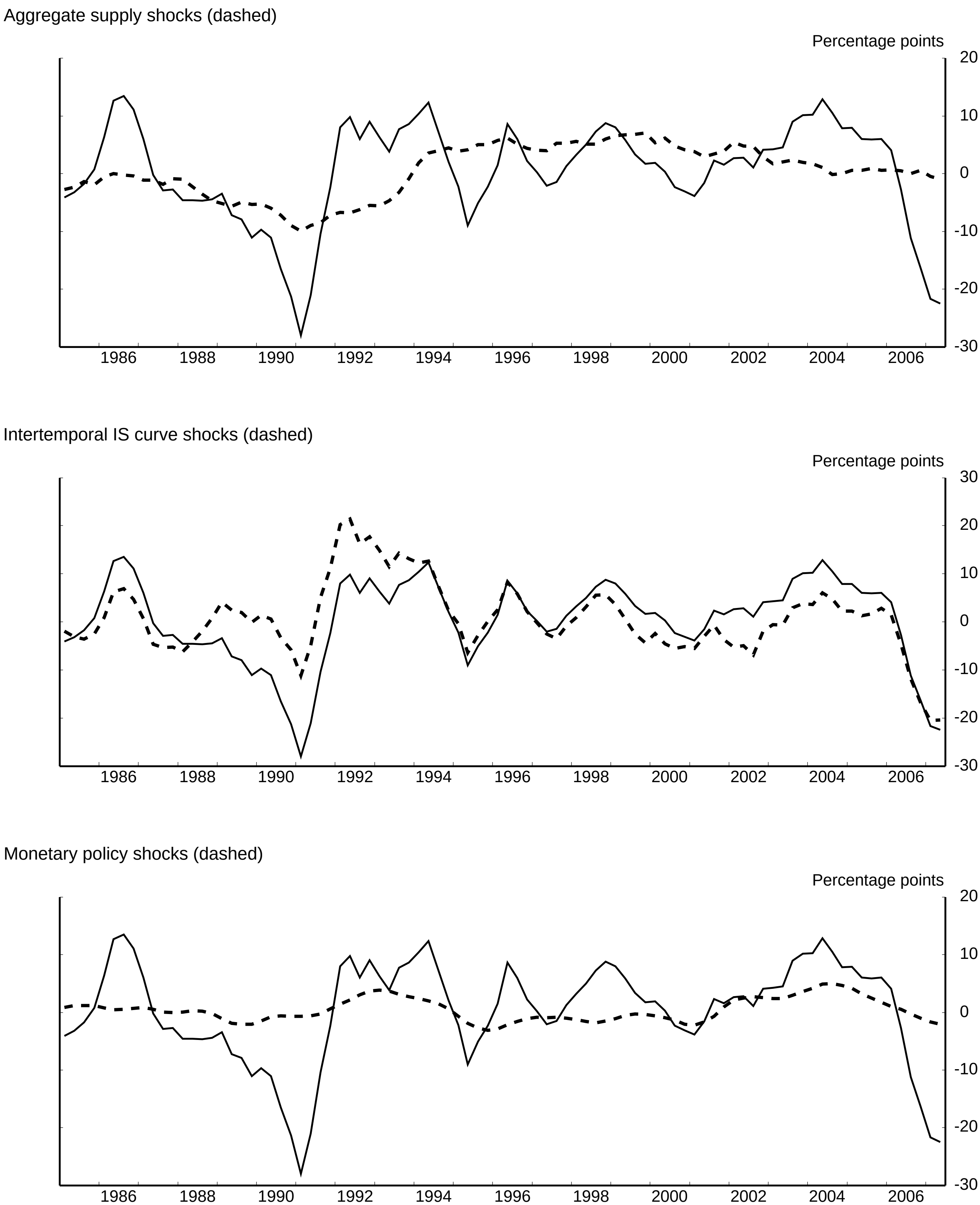
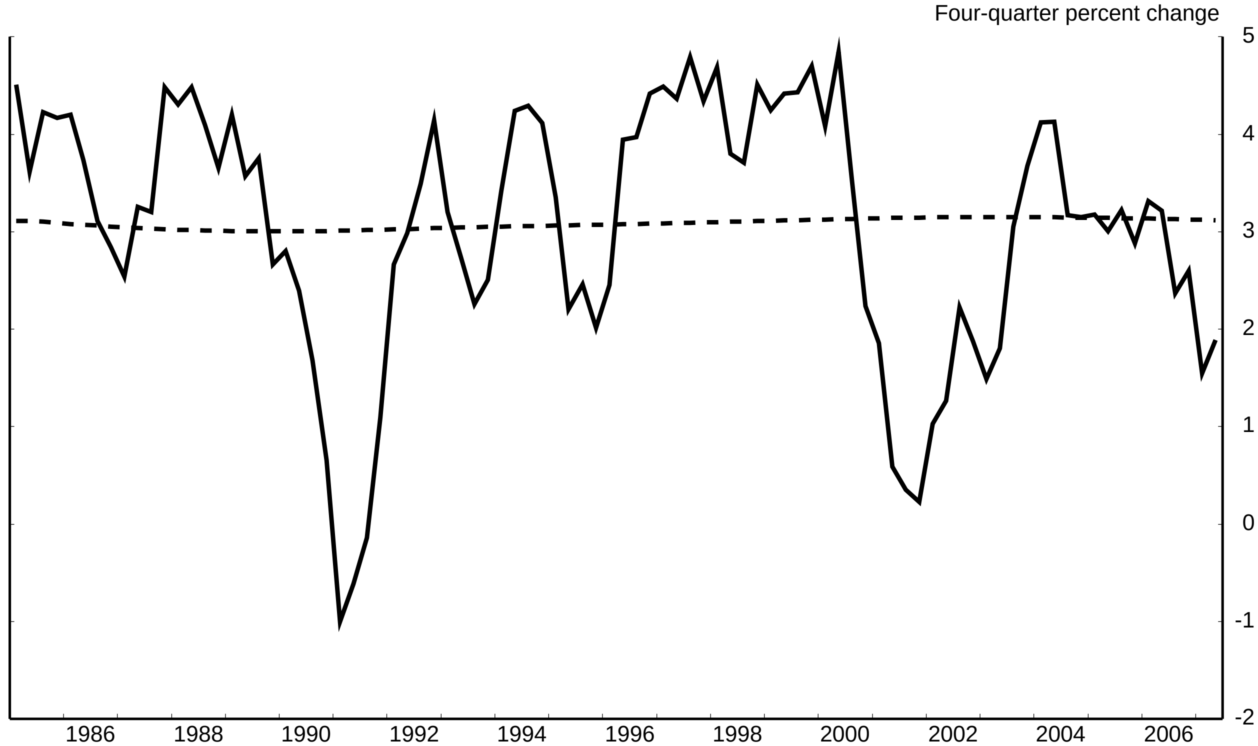


Figure 4
Gross domestic product (GDP, in chain-weighted 2000 dollars)

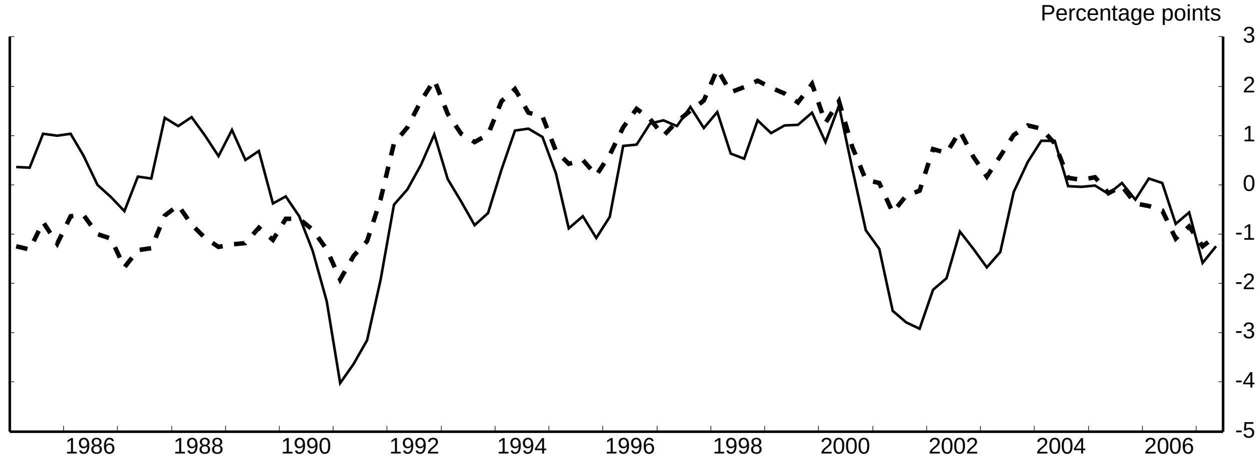
GDP growth (solid) and trend (dashed)



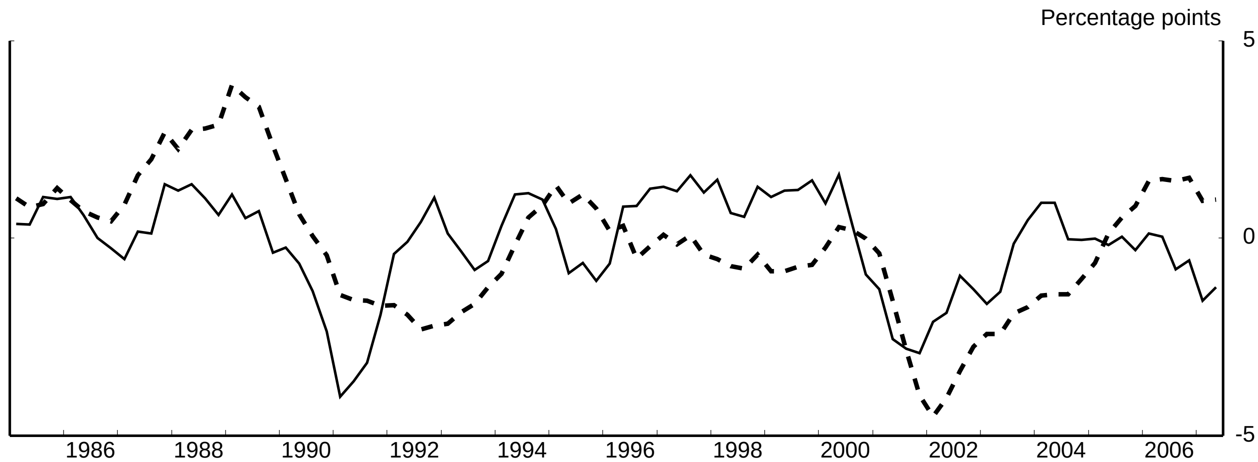
Deviations of GDP growth from trend

Figure 5
Sources of fluctuations in GDP

Aggregate supply shocks (dashed)



Intertemporal IS curve shocks (dashed)



Monetary policy shocks (dashed)

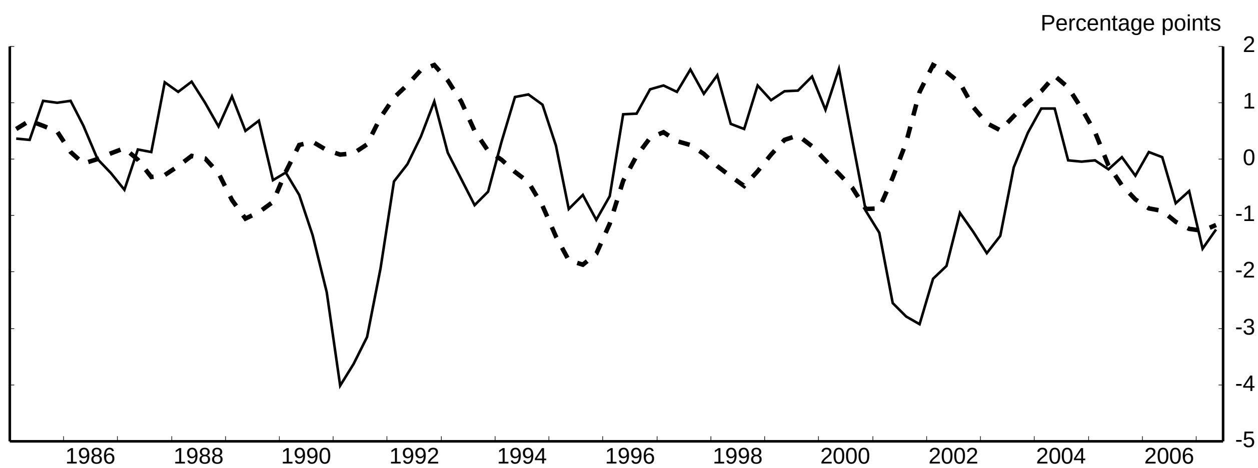
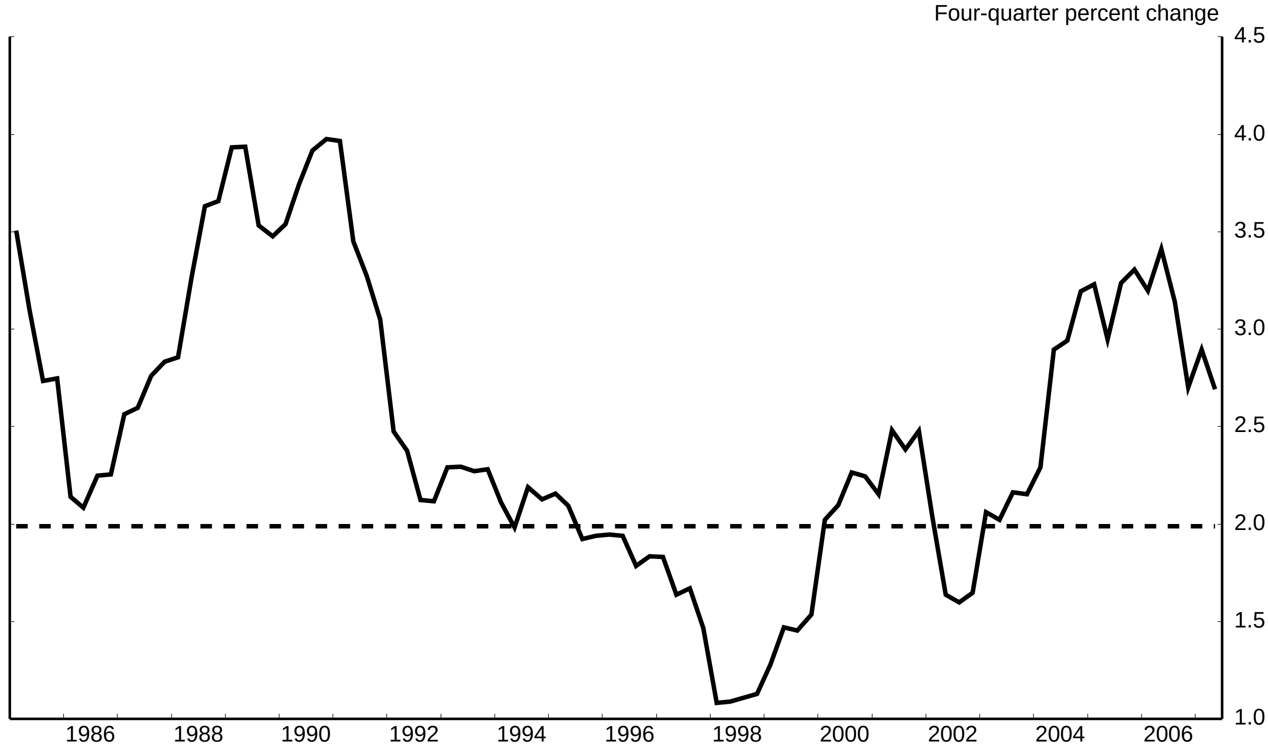


Figure 6
Inflation (GDP price index)

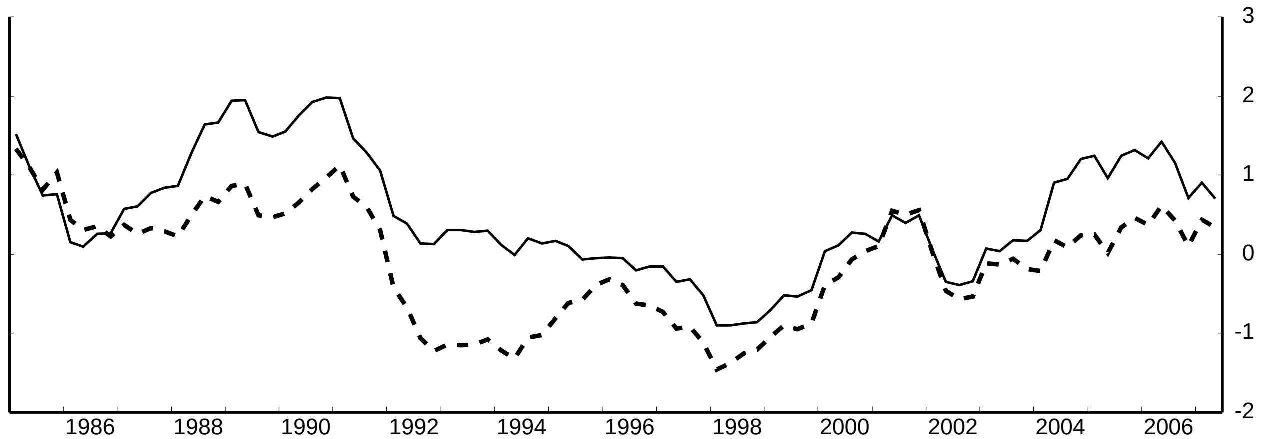
GDP inflation (solid) and trend (dashed)



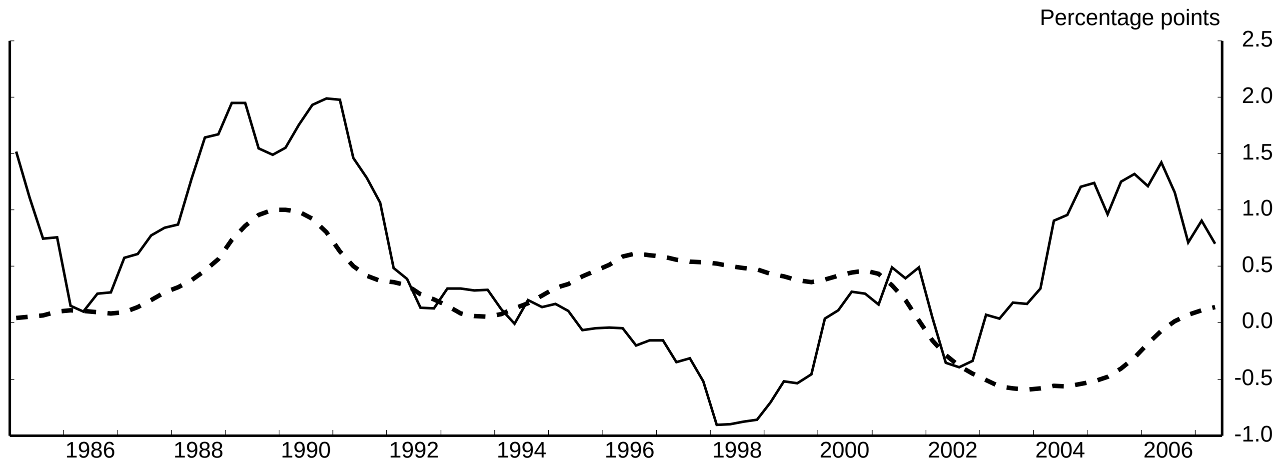
Deviations of GDP price inflation from trend (four-quarter percent change)

Figure 7
Sources of fluctuations in GDP price inflation

Aggregate supply shocks (dashed)



Intertemporal IS curve shocks (dashed)



Monetary policy shocks (dashed)

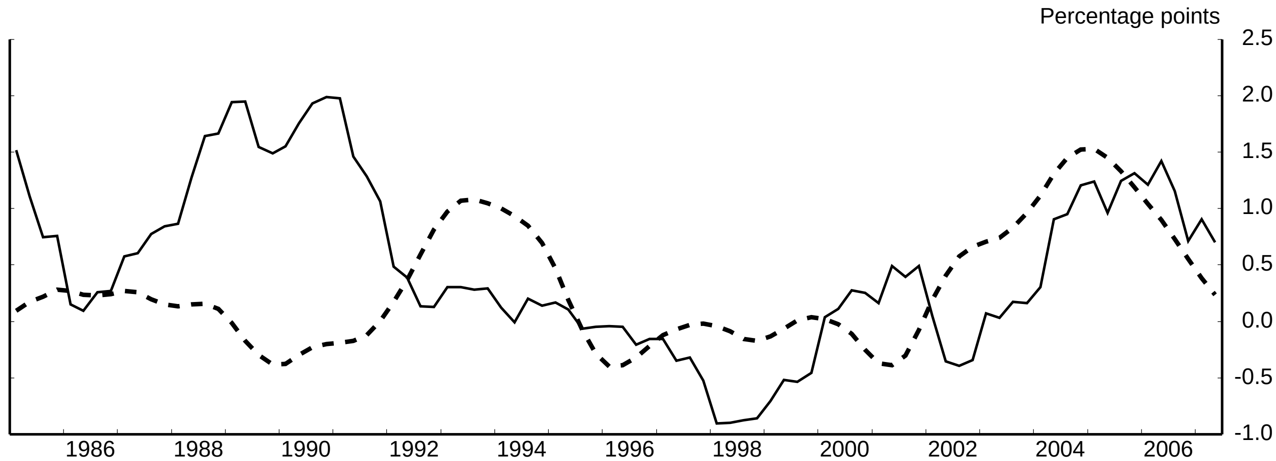


Figure 8: Effects of Monetary Policy Innovations