Shocks, Structures or Monetary Policies? The EA and US After 2001*

Lawrence Christiano†, Roberto Motto‡, and Massimo Rostagno§

February 13, 2007

Abstract

We describe a model we have estimated using US and Euro Area data, and use it to address a recent controversy. The US Federal Reserve cut interest rates much more vigorously in the recent recession than the European Central Bank did. By comparison with the Fed, it is claimed, the ECB stood by passively as the EA economy slumped. We argue that ECB passivity is not a useful explanation of the different policy outcomes in the EA and the US. First, we find that - because there is greater inertia in the ECB's policy rule - the policy actions of the ECB actually had a greater stabilizing effect than did those of the Fed. The ECB converted what would have been a severe recession in the EA into what turned out to be only an economic growth slowdown, without compromising its inflation objective. A second reason that policy outcomes in the EA and the US were different is that the two economic regions were hit by different shocks.

*This paper expresses the views of the authors and not necessarily those of the European Central Bank. We are grateful for the comments of Mark Gertler and for reactions of participants at the conference organized by the International Research Forum on Monetary Policy, Federal Reserve Board of Governors, December 1-2, 2005. The first author is grateful to the National Science Foundation for financial support.

†Northwestern University and National Bureau of Economic Research

‡European Central Bank

§European Central Bank

1 Introduction

The European Central Bank (ECB) has recently experienced its first recession. The ECB's performance did not earn high marks from everyone. According to critics, the ECB did poorly in comparison with the US Federal Reserve (Fed). Critics argue that the Fed's move to abruptly cut the Federal Funds rate in 2001 spared the US from a deep recession and laid the groundwork for a strong recovery (see Figure 1a). They note that the ECB cut its policy rate by much less (Figure 1a). The critics argue that, in effect, the ECB dithered as the Euro area (EA) economy languished, while the Fed showed skill in simultaneously keeping down inflation while acting vigorously to protect real economic activity. They argue that the ECB needs to learn to be less passive and more responsive to the state of economic activity.

We argue that the critics have got it wrong for two reasons. First, it is misleading to measure the degree of central bank activism by how much the interest rate moves. A central bank that moves its policy rate sharply in response to each twist and turn in the data would under this measure be viewed as activist. Yet, such a central bank would have only a limited impact on economic activity. This is because policy shifts that lack persistence have little impact on longer-term interest rates.[1]

According to our estimates ECB policy is characterized by greater persistence than Fed policy is. As a result, to achieve a given economic effect the ECB must move its policy rate by much less than the Fed must. This is why we find that interest rate actions by the ECB had a greater stabilizing effect on output than the Fed interest rate actions did, even though the latter were bigger. The slowdown in economic activity after 2000 in the EA was so mild that it technically does not even meet the definition of a recession (see log, per capita real GDP in the EA and the US in Figure 1b).[2] We estimate that, had it not been for the supportive monetary policy shocks implemented by the ECB, the EA growth slowdown after 2000 would instead have been a substantial recession. This is the first reason for our conclusion that the critics have it wrong when they maintain that the ECB stood by passively as the EA economy fell into a slump.

A second reason the critics got it wrong is that they do not take into account that the US and EA were hit by different shocks. For example, it is true that the Fed's response to the 2001 recession was very aggressive. Indeed, we find that the Fed's reaction was greater than what one would have predicted on the basis of its past behavior in recessions. It is true that the ECB did not spring into action at the same time and with the same abruptness as the Fed. But, that is because the shocks that produced the EA recession did not occur until later (see Figure 1b). There was nothing for the ECB to respond to at the time the Fed made the interest rate moves that so grabbed the critics' attention. When the bad shocks

[1] This principle has been analyzed extensively by Rotemberg and Woodford (1999), and Woodford (1999,2003).

[2] We never see two consecutive quarters of negative growth.

that produced the EA slowdown finally did strike one year later, the ECB reacted like the Fed, by deviating from past patterns. The ECB continued to keep rates low longer than the Fed did, because bad shocks lingered longer in the EA than in the US (see Figure 1a). The ECB was able to provide support to economic activity, without violating its inflation objective (see Figure 1c).

The critics' idea that output would have been stronger without sacrificing inflation objectives in the EA if the ECB had imitated the Fed suggests a simple test. We simulated the post 2000 period in the EA, replacing the ECB monetary policy rule by the Fed's policy rule. To our initial surprise, we found that inflation would have been substantially higher and output would have been lower in the EA, if the ECB had adopted the Fed's monetary policy.[3]

Our analysis requires disentangling the part of the data which reflects exogenous shocks from the part that reflects central bank policy reactions. In addition, we are interested in counterfactual questions, like 'what would have happened if the ECB had adopted the Fed's monetary policy strategy in the 2001 recession?' The formal tools we use in this paper are designed to address issues like this. We use models that have been estimated using EA and US data in Christiano, Motto and Rostagno (2007). The estimation exercise provides us with estimates of the shocks driving the two economies, as well as parameter values for their economic structures and monetary policy rules.

The models we use must be fairly elaborate if the set of shocks that we identify is to be credible. We want to include standard shocks such as disturbances to technology, government consumption, household preferences and monetary policy. In addition, the substantial volatility observed in financial markets in recent times suggests that it is important to allow for the possibility that financial factors play an important role in dynamics. Thus, we allow for the possibility that financial markets are a source of shocks, and for the possibility that financial markets play an important role in the propagation of non-financial market shocks. Our estimated models are a variant of one we used to understand another period when financial market volatility played an important role, the US Great Depression (see Chris-

[3]It is useful to differentiate the question we study from an alternative question: "what would have happened if the Fed had been in charge of the ECB?" Because the US and EA economies have somewhat different structures and shocks, it is possible that if the Fed were literally in charge of the ECB, it might not have applied the same monetary policy strategy that it uses in the US. To answer the alternative question would require identifying the Fed's objective function and then computing the monetary policy rule that optimizes it, conditional on the economy corresponding to the estimated EA economy. The question of what the Fed would have done, had it been in charge of the ECB, would be answered by simulating our EA model economy with the optimized policy rule. We did not do this. When we investigate what the Fed would have done, had it been in charge of the ECB, we simulate the monetary policy rule that we estimated the Fed to have used in the US.

tiano, Motto and Rostagno (2003)). This model builds on the basic structure of Christiano, Eichenbaum and Evans (2005) by incorporating sticky wages and prices, adjustment costs in investment, habit persistence in preferences and variable capital utilization. Regarding financial markets, the model integrates the neoclassical banking model of Chari, Christiano and Eichenbaum (1995). In addition, the model integrates the model of financing frictions built by Bernanke, Gertler and Gilchrist (1999). Finally, our analysis proceeds in the spirit of Smets and Wouters (2003) by including a relatively large range of shocks and by using Bayesian methods for model estimation and for evaluation of model fit.

The details of the estimation results for our model are reported in a separate paper (Christiano, Motto and Rostagno (2007)). In this paper we provide an overview of the model, followed by our analysis.

2 The Model

We describe the model structure in this section, as well as the shocks. The model is composed of households, firms, capital producers, entrepreneurs, banks and a monetary authority. At the beginning of the period, households supply labor and entrepreneurs supply capital to homogeneous factor markets. In addition, households divide their high-powered money into currency and bank deposits. Currency pays no interest, and is held for the transactions services it generates. All transactions services are modeled by placing the associated monetary asset in the utility function. Bank deposits pay interest and also generate transactions services. Banks use household deposits to fund working capital loans to firms. Firms use working capital to pay the wage bill and rent on capital. Firms and banks use labor and capital to produce output and transactions services, respectively.

The output produced by firms is converted into consumption goods, investment goods and goods used up in capital utilization. Capital producers combine investment goods with used capital purchased from entrepreneurs to produce new capital. This new capital is then purchased by entrepreneurs, using a combination of their own net worth and loans from banks. Agency costs introduce financial frictions into the entrepreneur-bank relationship. Banks obtain the funds to lend to entrepreneurs by issuing two types of liabilities to households.

The monetary authority conducts monetary policy according to a standard Taylor rule. It is able to do this, because it controls the quantity of high-powered money.

2.1 Goods Production

We adopt the standard Dixit-Stiglitz framework for final goods production. Final output, Y_t, is produced by a perfectly competitive, representative firm. It does so by combining a continuum of intermediate goods, indexed by $j \in [0,1]$, using the technology

$$Y_t = \left[\int_0^1 Y_{jt}{}^{\frac{1}{\lambda_{f,t}}} dj \right]^{\lambda_{f,t}}, \ 1 \leq \lambda_{f,t} < \infty, \tag{1}$$

where Y_{jt} denotes the time-t input of intermediate good j and $\lambda_{f,t}$ is a shock. The time series representations of this and all other stochastic processes in the model will be discussed below. Let P_t and P_{jt} denote the time-t price of the consumption good and intermediate good j, respectively. The firm chooses Y_{jt} and Y_t to maximize profits, taking prices as given.

We assume that final output can be converted into consumption goods one-for-one. One unit of final output can be converted into $\mu_{\Upsilon,t}\Upsilon^t$ investment goods, where $\Upsilon > 1$ is the trend rate of investment-specific technical change, and $\mu_{\Upsilon,t}$ is a stationary stochastic process. Because firms that produce consumption and investment goods using final output are assumed to be perfectly competitive, the date t equilibrium price of consumption and investment goods are P_t and $P_t/\left(\mu_{\Upsilon,t}\Upsilon^t\right)$, respectively.

The j^{th} intermediate good used in (1) is produced by a monopolist using the following production function:

$$Y_{jt} = \begin{cases} \epsilon_t K_{jt}^{\alpha} \left(z_t l_{jt}\right)^{1-\alpha} - \Phi z_t^* & \text{if } \epsilon_t K_{jt}^{\alpha} \left(z_t l_{jt}\right)^{1-\alpha} > \Phi z_t^* \\ 0, & \text{otherwise} \end{cases}, \ 0 < \alpha < 1, \tag{2}$$

where Φz_t^* is a fixed cost and K_{jt} and l_{jt} denote the services of capital and homogeneous labor. Fixed costs are modeled as growing with the exogenous variable, z_t^* :

$$z_t^* = z_t \Upsilon^{\left(\frac{\alpha}{1-\alpha} t\right)}, \ \Upsilon > 1, \tag{3}$$

where the growth rate of z_t^* corresponds to the growth rate of output in steady state. We suppose that fixed costs grow at this rate to ensure that they remain relevant along the equilibrium growth path, and to be consistent with balanced growth.

In (2), the persistent shock to technology, z_t, has the following time series representation:

$$z_t = \mu_{z,t} z_{t-1},$$

where $\mu_{z,t}$ is a stochastic process. The variable, ϵ_t, is a stationary shock to technology.

The homogeneous labor employed by firms in (2) and the differentiated labor supplied by individual households are related as follows:

$$l_t = \left[\int_0^1 \left(h_{t,i}\right)^{\frac{1}{\lambda_w}} di \right]^{\lambda_w}, \ 1 \leq \lambda_w. \tag{4}$$

Below, we discuss how $h_{t,i}$ is determined.

Intermediate-goods firms are competitive in factor markets, where they confront a rental rate, $P_t\tilde{r}_t^k$, on capital services and a wage rate, W_t, on labor services. Each of these is expressed in units of money. Also, each firm must finance a fraction, ψ_k, of its capital services expenses in advance. Similarly, it must finance a fraction, ψ_l, of its labor services in advance. The gross rate of interest it faces for this type of working-capital loan is R_t.

We adopt a variant of Calvo sticky prices. In each period, t, a fraction of intermediate-goods firms, $1-\xi_p$, can reoptimize their price. If the i^{th} firm in period t cannot reoptimize, then it sets price according to:

$$P_{it} = \tilde{\pi}_t P_{i,t-1},$$

where

$$\tilde{\pi}_t = \left(\pi_t^{target}\right)^{\iota_1} \left(\pi_{t-1}\right)^{1-\iota_1}, \tag{5}$$

where ι_1 controls the degree of indexation to the monetary authority's inflation target, π_t^{target}, which we discuss below. Initially, we also included steady state inflation in (5), in a way that preserved linear homogeneity. However, the value of the power on steady state inflation went to a corner of zero during estimation on both the EA and US data, and so we simply impose this estimation result here in the description of the model. The i^{th} firm that can optimize its price at time t chooses $P_{i,t} = \tilde{P}_t$ to optimize discounted profits:

$$E_t \sum_{j=0}^{\infty} \left(\beta\xi_p\right)^j \lambda_{t+j} \left[P_{i,t+j}Y_{i,t+j} - P_{t+j}s_{t+j}\left(Y_{i,t+j} + \Phi z_{t+j}^*\right)\right]. \tag{6}$$

Here, λ_{t+j} is the multiplier on firm profits in the household's budget constraint. Also, $P_{i,t+j}$, $j > 0$ denotes the price of a firm that sets $P_{i,t} = \tilde{P}_t$ and does not reoptimize between $t+1, ..., t+j$.

2.2 Capital Producers

At the end of period t, capital producers purchase investment goods, I_t, and installed physical capital, x, that has been used in period t. Capital producers use these inputs to produce new installed capital, x', that can be used starting period $t+1$. In producing capital goods, capital producers face adjustment costs. In our baseline specification, these costs are expressed in terms of I_t/I_{t-1} :

$$x' = x + \left(1 - S(\zeta_{i,t}\, I_t/I_{t-1})\right) I_t.$$

Here, S is a function with the property that in steady state, $S = S' = 0$, and $S'' > 0$. Also, $\zeta_{i,t}$ is a shock to the marginal efficiency of investment. Since the marginal rate of transformation from previously installed capital (after it has depreciated by $1-\delta$) to new capital is unity, the price of new and used capital is the same, and we denote this by $Q_{\bar{K}',t}$. The firm's time-t profits are:

$$\Pi_t^k = Q_{\bar{K}',t}\left[x + \left(1 - S(\zeta_{i,t} I_t/I_{t-1})\right) I_t\right] - Q_{\bar{K}',t}x - \frac{P_t}{\Upsilon^t \mu_{\Upsilon,t}} I_t.$$

The capital producer's problem is dynamic because of the adjustment costs. It solves:

$$\max_{\{I_{t+j},x_{t+j}\}} E_t \left\{ \sum_{j=0}^{\infty} \beta^j \lambda_{t+j} \Pi_{t+j}^k \right\},$$

where E_t is the expectation conditional on the time-t information set, which includes all time-t shocks.

Let $\bar{K}_{t+j}$ denote the beginning-of-time $t+j$ physical stock of capital in the economy, and let δ denote the depreciation parameter. From the capital producer's problem it is evident that any value of x_{t+j} whatsoever is profit maximizing. Thus, setting $x_{t+j} = (1-\delta)\bar{K}_{t+j}$ is consistent with profit maximization and market clearing. The aggregate stock of physical capital evolves as follows

$$\bar{K}_{t+1} = (1-\delta)\bar{K}_t + \left(1 - S(\zeta_{i,t}\, I_t/I_{t-1})\right) I_t.$$

2.3 Entrepreneurs

The situation of the entrepreneur is depicted in Figure 2. At the end of period t, the entrepreneur uses his net worth, N_{t+1}, plus a loan from a bank to purchase the new, installed physical capital, $\bar{K}_{t+1}$, from capital producers. The entrepreneur then experiences an idiosyncratic productivity shock: the purchased capital, $\bar{K}_{t+1}$, becomes $\bar{K}_{t+1}\omega$, where ω is a unit mean, lognormally distributed random variable across all entrepreneurs. The object, $\log\omega$ has a variance of σ_t^2, where the t subscript indicates that σ_t is itself the realization of a random variable. The random variable, ω, is drawn independently across entrepreneurs and over time from a cumulative distribution function which we denote by F. In period $t+1$, after observing the period $t+1$ shocks, the entrepreneur determines the utilization rate of capital, and then rents it out in competitive markets at nominal rental rate, $P_{t+1}\tilde{r}_{t+1}^k$. In choosing the capital utilization rate, the entrepreneur takes into account the utilization cost function:

$$P_{t+1}\Upsilon^{-(t+1)}\tau_{t+1}^{oil} a(u_{t+1})\omega\bar{K}_{t+1},$$

where a is an increasing and convex function, and τ_{t+1}^{oil} is a shock which we identify with the real price of oil. After determining the utilization rate of capital and earning rent (net of utilization costs) on it, the entrepreneur sells the undepreciated part of its capital to the capital producers. At this point, the entrepreneur's after tax rate of return on capital is defined as:

$$1+R_{t+1}^{k}=\frac{(1-\tau^{k})\left[u_{t+1}\tilde{r}_{t+1}^{k}-\Upsilon^{-(t+1)}\tau_{t+1}^{oil}a(u_{t+1})\right]P_{t+1}+(1-\delta)Q_{\bar{K}',t+1}+\tau^{k}\delta Q_{\bar{K}',t}}{Q_{\bar{K}',t}},$$

where τ^k is the tax rate on capital income. After this, entrepreneurs settle their bank loans. Entrepreneurs with a large enough ω (bigger than a variable we denote by $\bar{\omega}_t$) pay interest, Z_{t+1}, on their bank loan. Entrepreneurs who declare that $\omega < \bar{\omega}_t$ cannot fully repay their bank loan are monitored, and they must turn over everything they have to the bank. The monitoring cost to the bank is a proportion, μ, of the entrepreneur's total gross revenues. The interest rate, Z_{t+1}, and loan amount to entrepreneurs are determined as in a standard debt contract. In particular, the loan amount and interest rate maximize the entrepreneur's expected state at the end of the loan contract, subject to a zero profit condition on the bank. The bank's zero profit condition reflects the assumption that there is perfect competition in banking.[4]

After the entrepreneur has settled his debt with the bank in period $t+1$, and his capital has been sold to capital producers, the entrepreneur's period $t+1$ net worth is determined. At this point, the entrepreneur exits the economy with probability $1-\gamma_{t+1}$, and survives to continue another period with probability γ_{t+1}. The probability, γ_{t+1}, is the realization of a stochastic process.

Each period, new entrepreneurs are born in sufficient numbers so that the population of entrepreneurs remains constant. New entrepreneurs born in period $t+1$ receive a transfer of net worth, W_{t+1}^{e}. Because W_{t+1}^{e} is relatively small, this birth and death process helps to ensure that entrepreneurs do not accumulate so much net worth, that they become independent of banks. Entrepreneurs selected to exit consume a fraction, Θ, of their net worth, V_t, in the period that they are selected to exit the economy. The complementary fraction of V_t is transferred in the form of a lump-sum payment to households.[5]

We interpret the random variable, γ_t, as a reduced form way to capture an 'asset price bubble' or 'irrational exuberance'. In informal discussions these phrases are often used to refer to changes in stock market wealth that are not clearly linked to shifts in preferences or technology. This is literally the case in our model when γ_t jumps. The random variable, σ_t, is a way to capture the notion that the riskiness of entrepreneurs' activities varies over time.

[4] In addition, as we note below, the nature of the zero profit condition also reflects the assumption that banks do not have access to complete, state-contingent markets.

[5] There are two objects we call 'net worth' in this section, N_{t+1} and V_t. The former is the average net worth of entrepreneurs in period t after a fraction of entrepreneurs is selected to leave and after all transfers have been received. The object, V_t, is the period t average net worth of all entrepreneurs who were present in period $t-1$.

The details of our model of entrepreneurs follows the specification in Christiano, Motto and Rostagno (2003). With one exception, that model is taken from Bernanke, et al (1999). The exception has to do with restriction that the return received by households is nominally non-state contingent. This nominal restriction allows the model to articulate Fisher's (1933) "debt deflation" hypothesis. According to this, when there is an unexpected drop in the price level, the total real resources transferred from entrepreneurs to households is increased. Another difference with Bernanke et al (1999) is that we specify idiosyncratic uncertainty, σ_t, and the entrepreneur's wealth shock, γ_t, to be random variables.

2.4 Banking

There is a representative, competitive bank. The bank intermediates loans between households and firms, and it produces transaction services using capital, labor and reserves.

In period t, banks make working capital loans, S_t^w, to intermediate goods producers and other banks. Working capital loans are for the purpose of financing wage payments and capital rental costs:

$$S_t^w = \psi_l W_t l_t + \psi_k P_t \tilde{r}_t^k K_t.$$

Here, ψ_l and ψ_k are the fraction of the wage and capital rental bills, respectively, that must be financed in advance. Note that these apply to all homogeneous labor, l_t, and capital services, K_t, reflecting our assumption that both intermediate goods producing firms and banks must finance their period t variable input costs at the beginning of period t. The funds for working capital loans are obtained by issuing demand deposit liabilities to households.

In period t, banks make loans to entrepreneurs, B_{t+1}, to purchase capital. Banks obtain funds for these types of loans by issuing two types of liabilities to households - savings deposits, D_{t+1}^m, and time deposits, T_t - subject to:

$$D_{t+1}^m + T_t \geq B_{t+1}. \tag{7}$$

Household savings deposits pay interest, R_{t+1}^m, in period $t+1$ and also generate some transactions services. Time deposits generate interest, R_{t+1}^T, in period $t+1$ but they provide no transactions services.

Our model has implications for various monetary aggregates: currency, M_1 (currency plus demand deposits), M_3 (M_1 plus savings deposits), high powered money (currency plus bank reserves) and bank reserves. The reason we assume banks finance loans to entrepreneurs by issuing two types of liabilities rather than one, is that this allows us to match the observed velocity of M_3.[6] If banks only issued one type of liability, and this liability were included in

[6] In Christiano, Motto and Rostagno (2003), banks finance entrepreneurial loans with only one type of liability.

M_3, then the velocity of M_3 would be counterfactually low. This is because, as in the data, the quantity of debt to entrepreneurs is high in our model.

In period $t+1$ the bank earns a return, R^e_{t+1}, on B_{t+1}. It passes this on to households in the form of interest, R^T_{t+1}, on T_t and interest, R^m_{t+1}, on D^m_{t+1} (see Figure 3). For the reasons indicated in the previous subsection, we suppose that R^e_{t+1} is a function of information available at and before period t only. We suppose the same is true of R^T_{t+1} and R^m_{t+1}. Following Bernanke, et al (1999), we suppose that banks in period t do not have access to period $t+1$-contingent markets. As a result, they face the following 'no blood from stone' constraint, which states that payments made to households cannot exceed payments received from entrepreneurs:

$$\left(1+R^e_{t+1}\right) B_{t+1} \geq \left(1+R^T_{t+1}\right) T_t + \left(1+R^m_{t+1}\right) D^m_{t+1}. \tag{8}$$

The maturity period of loans to entrepreneurs coincides with the maturity period of household savings and time deposits. The loans are issued at the time new, installed capital is sold after the goods market closes and they are repaid at the same time next period. The timing of entrepreneurial lending activity and the associated liabilities is illustrated in Figure 4.

To finance working capital loans, S^w_t, the bank issues demand deposit liabilities, D^h_t, to households. These liabilities are issued in exchange for receiving A_t units of high-powered money from the households, so that

$$D^h_t = A_t. \tag{9}$$

Working capital loans are made in the form of demand deposits, D^f_t, to firms, so that

$$D^f_t = S^w_t. \tag{10}$$

Total demand deposits, D_t, are:

$$D_t = D^h_t + D^f_t. \tag{11}$$

Demand deposits pay interest, R^a_t. We suppose that the interest on demand deposits that are created when firms and banks receive working capital loans are paid to the recipient of the loans. Firms and banks hold these demand deposits until the wage bill is paid in a settlement period that occurs after the goods market.

Interest paid by firms on working capital loans is $R_t + R^a_t$. Since firms receive interest payments on deposits, net interest on working capital loans is R_t. The maturity period of time t working capital loans to firms and banks and the maturity period of demand deposits coincide. A period t working capital loan is extended just prior to production in period t, and then paid off after production. The household deposits funds into the bank just prior to production in period t and then liquidates the deposit after production (see Figure 4).

Demand and savings deposits are associated with transactions services. The bank has a technology for converting homogeneous labor, l_t^b, capital services, K_t^b, and excess reserves, E_t^r, into transactions services:

$$\frac{D_t + \varsigma D_t^m}{P_t} = a^b x_t^b \left(\left(K_t^b\right)^\alpha \left(z_t l_t^b\right)^{1-\alpha} \right)^\xi \left(\frac{E_t^r}{P_t} \right)^{1-\xi}, \; 0 < \xi < 1. \tag{12}$$

Here a^b and ς are positive scalars, and $0 < \alpha < 1$. Also, x_t^b is a unit-mean technology shock that is specific to the banking sector. We include excess reserves as an input to the production of demand deposit services as a reduced form way to capture the precautionary motive of a bank concerned about the possibility of unexpected withdrawals. Excess reserves are defined as follows:

$$E_t^r = A_t + F_t - \tau D_t, \tag{13}$$

where τ denotes required reserves. Here, F_t represents reserves borrowed from other banks on an interbank loan market. In the market, a bank can augment its reserves by borrowing F_t and then at the end of the period it must pay back $\left(1 + R_t^b\right) F_t$. Since all the banks are identical, we will have $F_t = 0$ in equilibrium. Our purpose in introducing this market is to be in a position to define the rate of interest on interbank loans.

At the end of the goods market, the bank settles claims for transactions that occurred in the goods market and that arose from its activities in the previous period's entrepreneurial loan and time deposit market. The bank's sources of funds at this time are: interest and principal on working capital loans, $(1 + R_t + R_t^a)S_t^w$, plus interest and principal on entrepreneurial loans extended in the previous period, $(1 + R_t^e)B_t$, plus the reserves it received from households at the start of the period, A_t, plus newly created time and savings deposits, $T_t + D_{t+1}^m$, plus loans on the interbank loan market, F_t. Its uses of funds include new loans, B_{t+1}, extended to entrepreneurs, plus principal and interest payments on demand deposits, $(1 + R_t^a)D_t$, plus interest and principal on saving deposits, $(1 + R_t^m)D_t^m$, plus principal and interest on time deposits, $\left(1 + R_t^T\right) T_{t-1}$, plus gross expenses on labor and capital services, plus principal and interest, $\left(1 + R_t^b\right) F_t$, on interbank loans. Thus, the bank's net source of funds at the end of the period, Π_t^b, is:

$$\begin{aligned}\Pi_t^b = {} & (1 + R_t + R_t^a)S_t^w + (1 + R_t^e) B_t + A_t + T_t + D_{t+1}^m + F_t - B_{t+1} - (1 + R_t^a)D_t \\ & - (1 + R_t^m)D_t^m - \left(1 + R_t^T\right) T_{t-1} - \left[(1 + \psi_k R_t) P_t \tilde{r}_t^k K_t^b\right] - \left[(1 + \psi_l R_t) W_t l_t^b\right] - \left(1 + R_t^b\right) F_t.\end{aligned}$$

Taking into account (9), (10) and (11), and rearranging, this reduces to:

$$\begin{aligned}\Pi_t^b = {} & R_t S_t^w + \left[(1 + R_t^e) B_t - (1 + R_t^m)D_t^m - \left(1 + R_t^T\right) T_{t-1}\right] - \left[B_{t+1} - T_t - D_{t+1}^m\right] \\ & - R_t^a A_t - (1 + \psi_k R_t) P_t \tilde{r}_t^k K_t^b - (1 + \psi_l R_t) W_t l_t^b - R_t^b F_t.\end{aligned} \tag{14}$$

In solving its problem, the bank takes rates of return and factor prices as given. In addition, B_{t+1} is determined by the considerations spelled out in the previous subsection, and so here $\{B_{t+1}\}$ is also taken as given as well. At date t, the bank takes D_t^m, T_{t-1} as given, and chooses S_t^w, D_{t+1}^m, T_t, A_t, K_t^b, l_t^b, F_t, E_t^r. The constraints are (7), (8), (9), (10), (11), (12) and (13).

2.5 Households

There is a continuum of households, indexed by $j \in (0,1)$. Households consume, save and supply a differentiated labor input. They set their wages using the variant of the Calvo (1983) frictions described in Erceg, Henderson and Levin (2000). We first describe the household utility function and budget constraint. We then discuss the household's wage setting problem.

The sequence of decisions by the j^{th} household during a period are as follows. First, the current period aggregate shocks are realized. Second, the household purchases state-contingent securities whose payoff is contingent upon whether it can reoptimize its wage decision. Third, it sets its wage rate after finding out whether it can reoptimize or not. Fourth, the household supplies the labor that is demanded at its posted wage rate. In addition, the household makes its consumption and portfolio decisions. In the analysis below, we do not index the consumption and portfolio decisions by j, because the state contingent securities guarantee that, in equilibrium these decisions are the same for all households (see Erceg, Henderson and Levin (2000).)

The preferences of the j^{th} household are given by:

$$E_t^j \sum_{l=0}^{\infty} \beta^{l-t} \zeta_{c,t+l} \{ u(C_{t+l} - bC_{t+l-1}) - z(h_{j,t+l}) \tag{15}$$
$$- \upsilon \frac{\left[\left(\frac{(1+\tau^c) P_{t+l} C_{t+l}}{M_{t+l}} \right)^{(1-\chi_{t+l})\theta} \left(\frac{(1+\tau^c) P_{t+l} C_{t+l}}{D_{t+l}^h} \right)^{(1-\chi_{t+l})(1-\theta)} \left(\frac{(1+\tau^c) P_{t+l} C_{t+l}}{D_{t+l}^m} \right)^{\chi_{t+l}} \right]^{1-\sigma_q}}{1-\sigma_q} \},$$

where E_t^j is the expectation operator, conditional on aggregate and household j idiosyncratic information up to, and including, time t; C_t denotes time t consumption; and h_{jt} denotes time t hours worked; τ^c is a tax on consumption; $\zeta_{c,t}$ is an exogenous shock to time t preferences; and χ_t is a money demand shock. In order to help assure that our model has a balanced growth path, we specify that u is the natural logarithm. When $b > 0$, (15) allows for habit formation in consumption preferences. The term in square brackets captures the notion that currency, M_t, savings deposits, D_t^m, and household demand deposits, D_t^h, contribute to utility by providing transactions services. The value of those services are an increasing function of the level of consumption expenditures (inclusive of consumption tax, τ^c). Finally, we employ the following functional form for $z(h_t)$:

$$z(h_t) = \psi_L \frac{h_t^{1+\sigma_L}}{1+\sigma_L}$$

We now discuss the household's period t uses and sources of funds. The household begins the period holding the monetary base, M_t^b. It divides this between currency, M_t, and deposits at the bank, A_t subject to:

$$M_t^b - (M_t + A_t) \geq 0. \tag{16}$$

In exchange for A_t, the household receives a demand deposit, D_t^h, from the bank. Thus, $D_t^h = A_t$. Demand deposits pay R_t^a and also offer transactions services.

The period t money injection is X_t. This is transferred to the household, so that by the end of the period the household is in possession of $M_t + X_t$ units of currency. We assume that the household's period t currency transactions services are a function of M_t only, and not X_t, because X_t arrives 'too late' to be useful in current period transactions. In this way, this timing assumption resembles the 'cash in advance' assumption emphasized by Carlstrom and Fuerst (1997). We make a similar assumption about demand deposits. At some point later in the period, the household is in possession of not just D_t^h, but also the deposits that it receives from wage payments. We assume that the household only enjoys transactions services on D_t^h, and that the other deposits come in 'too late' to generate transactions services for the household.

The household also can acquire savings and time deposits, D_{t+1}^m and T_t, respectively. These can be acquired at the end of the period t goods market and pay rates of return, $1 + R_{t+1}^m$ and $1 + R_{t+1}^T$ at the end of the period $t+1$ goods market. The household can use its funds to pay for consumption goods, $(1+\tau^c) P_t C_t$ and to acquire high powered money, M_{t+1}^b, for use in the following period.

Sources of funds include after-tax wage payments, $\left(1-\tau^l\right) W_{j,t} h_{j,t}$, where $W_{j,t}$ is the household's wage rate; profits, Π, from producers of capital, banks and intermediate good firms; and $A_{j,t}$. The latter is the net payoff on the state contingent securities that the household purchases to insulate itself from uncertainty associated with being able to reoptimize its wage rate. In addition, households receive lump-sum transfers, $1-\Theta$, corresponding to the net worth of the $1-\gamma_t$ entrepreneurs who exit the economy the current period. Also, the household pays a lump-sum tax, W_t^e, to finance the transfer payments made to the γ_t entrepreneurs that survive and to the $1-\gamma_t$ newly born entrepreneurs. Finally, the household pays other lump-sum taxes, $Lump_t$. These observations are summarized in the following asset accumulation equation:

$$\begin{aligned}(1+R_t^a)\left(M_t^b-M_t\right)+X_t-T_t-D_{t+1}^m \\ -(1+\tau^c)P_tC_t+(1-\Theta)(1-\gamma_t)V_t-W_t^e+Lump_t \\ +\left(1+R_t^T\right)T_{t-1}+(1+R_t^m)D_t^m \\ +\left(1-\tau^l\right)W_{j,t}h_{j,t}+M_t+\Pi_t+A_{j,t}-M_{t+1}^b\geq 0.\end{aligned} \tag{17}$$

The j^{th} household faces the following demand for its labor:

$$h_{j,t}=\left(\frac{W_{j,t}}{W_t}\right)^{\frac{\lambda_w}{1-\lambda_w}}l_t,\ 1\leq\lambda_w, \tag{18}$$

where l_t is the quantity of homogeneous labor employed by goods-producing intermediate good firms and banks, W_t is the wage rate of homogeneous labor, and $W_{j,t}$ is the j^{th} household's wage. Homogeneous labor is thought of as being provided by competitive labor contractors who use the production function, (4). The j^{th} household is the monopoly supplier of differentiated labor of type $h_{j,t}$. In a given period the j^{th} household can optimize its wage rate, $W_{j,t}$, with probability, $1-\xi_w$. With probability ξ_w it cannot reoptimize, in which case it sets its wage rate as follows:

$$W_{j,t}=\tilde{\pi}_{w,t}\left(\mu_{z^*}\right)^{1-\vartheta}\left(\mu_{z^*,t}\right)^{\vartheta}W_{j,t-1},$$

where $0\leq\vartheta\leq 1$ and

$$\tilde{\pi}_{w,t}\equiv\left(\pi_t^{target}\right)^{\iota_{w,1}}\left(\pi_{t-1}\right)^{\iota_{w,2}}\bar{\pi}^{1-\iota_{w,1}-\iota_{w,2}}. \tag{19}$$

Here, π_t^{target} is the target inflation rate of the monetary authority and $\bar{\pi}$ is a constant which is sometimes set to the steady state inflation rate. The parameters in this equation satisfy

$$0\leq\iota_{w,1},\iota_{w,2},\ 1-\iota_{w,1}-\iota_{w,2}\leq 1.$$

The household's problem is to maximize (15) subject to the various non-negativity, the demand for labor, the Calvo wage-setting frictions, and (17). The equilibrium conditions associated with the household problem are derived in the appendix.

2.6 Monetary Policy

The monetary policy rule is:

$$R_t^e=\rho_iR_{t-1}^e+(1-\rho_i)\left\{\pi_t^*+\alpha_\pi\left[E_t\left(\pi_{t+1}\right)-\pi_t^*\right]+\alpha_y\hat{y}_t+\alpha_Mg_{3t}\right\}+\varepsilon_t, \tag{20}$$

where the constant term has been deleted. The monetary authority's target inflation rate, π_t^*, is defined as follows:

$$\pi_t^* = \pi_{t+1}^{target} - \pi.$$

We model the inflation target as a stochastic process with high persistence. The notion that the inflation target is a slowly-moving variable is consistent with the findings of several recent empirical analyses of monetary policy.[7]

In (20), $\hat{y}_t$ denotes the log deviation from steady state of aggregate GDP, y_t, defined in the usual way as the sum of consumption, investment and government spending. Also, g_{3t} is the growth rate of $M3_t$. Finally, ε_t in (20) denotes a monetary policy shock, which we assume is uncorrelated over time.

2.7 Resource Constraint

We now develop the aggregate resource constraint for our model economy. Clearing in the market for final goods implies:

$$\mu \int_0^{\bar{\omega}_t} \omega dF(\omega) \left(1 + R_t^k\right) \frac{Q_{\bar{K}',t-1}\bar{K}_t}{P_t} + \frac{\tau_t^{oil} a(u_t)}{\Upsilon^t} \bar{K}_t + \frac{\Theta(1-\gamma_t)V_t}{P_t} + G_t + C_t + \left(\frac{1}{\Upsilon^t \mu_{\Upsilon,t}}\right) I_t \leq Y_t. \tag{21}$$

The first object in (21) represents the quantity of final output used up by banks in monitoring entrepreneurs. The second term captures capital utilization costs.[8] The third term corresponds to the consumption of the $1-\gamma_t$ entrepreneurs who exit the economy in period t. We model government consumption, G_t, as in Christiano and Eichenbaum (1992):

$$G_t = z_t^* g_t,$$

where g_t is a stationary stochastic process. By expressing G_t as a stationary fraction of z_t^*, we help to ensure that the model has a balanced growth path. The last term on the left of the equality in the goods clearing condition is the amount of final goods used up in producing I_t investment goods.

2.8 Fundamental Shocks

We place the 15 shocks in our model in the vector S_t :

$$\underset{15\times 1}{S_t} = \begin{pmatrix} \pi_t^* & x_t^b & \mu_{\Upsilon,t} & \chi_t & g_t & \mu_{z^*,t} & \gamma_t & \epsilon_t & \varepsilon_t & \sigma_t & \zeta_{c,t} & \zeta_{i,t} & \tau_t^{oil} & \lambda_{f,t} & \sigma_{\aleph,t} \end{pmatrix}'. \tag{22}$$

[7] See Gerlach and Svensson (2001), Adolfson, Laseen, Linde, and Villani (2004) and Schorfheide (2005).

[8] Here, we use the fact that an entrepreneur's rate of utilization, u_t, is independent of the draw of ω. In addition, we use the fact that the integral of ω across entrepreneurs is unity.

Again, π_t^* is the central bank's inflation objective, x_t^b is a technology shock in the bank production function; $\mu_{\Upsilon,t}$ is an investment-specific technology shock; g_t is a shock to government consumption; $\mu_{z^*,t}$ is the permanent, neutral technology shock; γ_t is the entrepreneurial survival probability shock; ε_t is a monetary policy shock; ϵ_t is the stationary, neutral shock to technology; σ_t is the shock to the risk of entrepreneurs' activities; $\zeta_{c,t}$ is a discount rate shock in households' utility function; $\zeta_{i,t}$ is a shock to the production function for new capital; and τ_t^{oil} is the price of oil (which shocks the cost of capital utilization); $\lambda_{f,t}$ is a shock to the elasticity of demand for intermediate goods (i.e., a price-markup shock). Finally, $\sigma_{\aleph,t}$ is a shock in the term structure equation. Here,

$$\mu_{z^*,t} = \mu_{z,t} + \frac{\alpha}{1-\alpha}.$$

We constructed a 15×1 vector s_t from S_t as follows. With one exception, if S_{it} is the i^{th} element of S_t, and S_i is its mean value, then $s_{it} = (S_{it} - S_i)/S_i$, for $i = 1, ..., 15$. The exceptional case is $s_{9,t}$ and S_{9t} (i.e., this corresponds to ε_t, the monetary policy shock). In this case, $s_{9,t} = S_{9,t}$. We assume that s_t is a first order vector autoregression:

$$s_t = Ps_{t-1} + u_t,\ Eu_tu_t' = D, \tag{23}$$

where P is a diagonal matrix. With one exception, we assume the innovations in the shocks are all uncorrelated. The exception is the innovations corresponding to γ_t and $\zeta_{i,t}$, which we allow to be correlated. Apart from this exception, D is a diagonal matrix.

2.9 Adjustment Cost Functions

The adjustment costs in investment are modeled as follows:

$$S(x) = \exp\left[A_S\left(x - \frac{I}{I_{-1}}\right)\right] + \exp\left[-A_S\left(x - \frac{I}{I_{-1}}\right)\right] - 2,$$

where

$$A_S = \left(\frac{1}{2}S''\right)^2,$$

and I/I_{-1} denotes the steady state growth rate of investment.

We adopt the following utilization cost function:

$$a(u) = 0.5b\sigma_a u^2 + b(1-\sigma_a)u + b((\sigma_a/2) - 1),$$

where b is selected so that $u = 1$ in steady state and $\sigma_a \geq 0$ is a parameter that controls the degree of convexity of costs.

2.10 Solution and Equilibrium

We solved the model by log-linearizing the equilibrium conditions about steady state, using the strategy in Christiano (2002). There are 29 endogenous variables whose values are determined at time t, and these are contained in a 29×1 vector denoted Z_t. Given values for the parameters of the model, we compute steady state values for each variable in Z_t. We then construct the 29×1 vector, z_t as follows. If Z_{it} is the i^{th} element of Z_t and Z_i is the corresponding steady state, then the i^{th} element of z_t is $z_{it} = (Z_{it} - Z_i)/Z_i$. Given the shocks described in the previous section, we can write the equilibrium conditions in the following form:

$$E_t \left[\alpha_0 z_{t+2} + \alpha_1 z_{t+1} + \alpha_2 z_t + \beta_0 s_{t+1} + \beta_1 s_t \right] = 0,$$

where α_i are 29×29 matrices, $i = 0, 1, 2$, and β_i are 29×15 matrices, $i = 0, 1$. The solution to this system, which takes into account the law of motion of the shocks, (23), is:

$$z_t = A z_{t-1} + B s_t, \tag{24}$$

where A is a 29×29 matrix with eigenvalues less than unity and B is a 29×15 matrix.

The variables in z_t are chosen partly for computational convenience, and not at all with the variables in mind that we wish to use in estimation. The 15 variables used in estimation are:

$$X_t = \begin{pmatrix} \Delta \log \left(\frac{N_{t+1}}{P_t} \right) \\ \pi_t \\ \log \left(\text{per capita hours}_t \right) \\ \Delta \log \left(\text{per capita real GDP}_t \right) \\ \Delta \log \left(\frac{W_t}{P_t} \right) \\ \Delta \log \left(\text{per capita real } I_t \right) \\ \Delta \log \left(M1_t \right) \\ \Delta \log \left(M3_t \right) \\ \Delta \log \left(\text{per capita real consumption}_t \right) \\ \text{External Finance Premium}_t \\ R_t^e \\ \Delta \log G_t \\ \Delta \log P_{I,t} \\ \Delta \log \text{real oil price}_t \\ R_t^{10} - R_t^e \end{pmatrix}, \tag{25}$$

where R_t^{10} is the 10-year government bond rate.[9] For both the EA and US models, we measure N_{t+1}/P_t by the value of the Dow Jones Industrial average, scaled the GDP deflator.

[9] In the case of the US the bond is issued by the US Federal government and in the case

For the US, the external finance premium is measured by the difference between BAA and AAA yield on corporate bonds. For the EA it is measured using the spread between, on the one hand, banks' lending rates and on the other hand, corporate bonds yields and government bonds of similar maturity. Here, the weights used to aggregate rates of return correspond to outstanding amounts. The model's implication for R_t^{10} is based on the model's first order condition for a 10-year nominally risk free rate of interest. For more details on these and other variables in X_t, see Christiano, Motto and Rostagno (2007).

To derive our model's implications for X_t, we log-linearize the mapping from X_t to z_t and s_t :

$$X_t = \alpha + \tau z_t + \tau^s s_t + \bar{\tau} z_{t-1}. \tag{26}$$

The real oil price in our model corresponds to τ_t^{oil}, discussed in section 2.3.

Equations (23), (24) and (26) represent a complete description of the joint (linearized) distribution of the variables, X_t. We make use of this for purposes of model estimation.

3 The EA and US in the 2001 Recession

This section reports our analysis of the different experiences in the 2001 recession of the EA and the US. The first subsection discusses our estimates of the parameters governing the monetary policy rules of the ECB and the Fed. We show that, because ECB monetary policy is characterized by greater persistence, monetary policy shocks have a much bigger impact on the EA economy than on the US economy. The second subsection discusses the different shocks that drove the EA and the US in the 2001 recession. This section shows that monetary policy shocks generated by the ECB had a cumulative effect of increasing output by 17 percent in the EA. The analogous number for the US is only 3 percent. The notion that by comparison with the Fed, the ECB stood by passively as the economy languished in the 2001 recession is hard to reconcile with these findings. The third subsection helps document our point that a key difference between the US and the EA had to do with the shocks that they experienced. We show that if the EA had experienced the US shocks, the 2001 recession in the EA would have resembled the US recession in key ways. The fourth subsection displays our evidence that differences in the structure of the EA and US private economies have relatively little to do with the different economic outcomes in the two regions. The final subsection suggests that if the Fed policy rule had been used in the EA, output would have been lower and inflation, higher.

of the EA, the bond corresponds to a weighted average of member country government bonds.

3.1 Monetary Policy Rules

The Christiano, Motto and Rostagno (2007) estimates of the parameters of the Fed and ECB monetary policy rules, (20), are:

$$\begin{array}{ll}\text{US:} & \rho_i = 0.82,\ \alpha_\pi = 1.93,\ \alpha_y = 0.17, \alpha_M = 0 \\ \text{EA:} & \rho_i = 0.91,\ \alpha_\pi = 1.58,\ \alpha_y = 0.19, \alpha_M = 0.031.\end{array}$$

Several things are worth noting. First, the ECB's monetary policy rule exhibits more inertia than the Fed's. We explore the consequences of this further, below. Second, the two central banks' responses to inflation are different. At the same time, the difference is probably overstated by the fact that the ECB is also estimated to respond to M_3 growth, a variable that is presumably positively correlated with inflation. Third, both central banks respond about equally to output.

To understand the consequences of our monetary policy rules for the effects of the iid monetary policy shocks, ε_t, consider Figure 5. It displays the dynamic effects on output, consumption, investment, the interest rate, inflation and hours worked of a shock to monetary policy. In both cases, the shock represents roughly a 22 basis point negative, iid, shock to the interest rate. Note that the response of consumption, output, investment and hours is much stronger in the EA model than in the US model. The policy shock leads to 0.9 and 0.3 percent cumulative increases in real GDP within the first year in the EA and US, respectively. The analogous figures for investment are 1.61 and 0.33 percent, respectively. The figure shows that when the ECB policy persistence (or, inertia) parameter, ρ_i, is set to the Fed's value, then the difference between the US and the Fed's impulse response functions falls substantially.

Later, we report that our estimate of the degree of price stickiness in the EA is greater than what it is for the EA. Figure 5 displays the impulse response functions when the EA's price stickiness parameter is replaced by the US's. Note that this change makes very little difference. Other differences in price and wage setting parameters (see below) also have little impact on the impulse response functions in Figure 5. The key parameter accounting for the pronounced difference in impulse response functions is the persistence parameter, ρ_i.

3.2 Shocks

This section establishes two results. First, the shocks driving the 2001 recession in the EA and the US economies differed in terms of their timing and nature. The shocks that pushed the US into recession hit almost a year before the ones that produced the recession in the EA. Also, in the EA technology shocks followed the usual negative pattern during the recession, while the US experienced favorable supply shocks in almost every quarter of the recession. Second, our estimates indicate that as soon as recession-producing shocks struck, each central bank deviated from its normal policy rule in a way that, while maintaining inflation under control, had the effect of supporting real economic activity. The contribution of monetary policy shocks to output was greater in the EA than in the US.

There are too many shocks in our model to study the individual role of each one on the post-2000 data. To keep the analysis manageable, we organize our fifteen shocks into six broad categories. The 'Goods Technology' category is composed of the technology shocks affecting the production of the final output good, Y_t. The 'Capital producers and Entrepreneurs' category is composed of shocks that affect the demand and supply of capital. On the demand side, we include all the shocks that affect the entrepreneurs: the oil shock, τ_t^{oil}, the riskiness shock, σ_t, and the asset valuation shock, γ_t. On the supply side, we include the shocks that affect the producers of capital: the marginal efficiency of investment shock, ζ_{it}, and the shock to the price of investment goods, $\mu_{\Upsilon,t}$. Two of these shocks, γ_t and ζ_{it}, are particularly important in the dynamics of the stock market, which we identify with entrepreneurial net worth. The 'Demand' category includes the shock to government spending, as well as to the preference for current utility. The 'Banking and Money Demand' category includes the two shocks perturbing households' demand for and banks' provision of inside money. The 'Monetary policy' category contains the high frequency disturbance to monetary policy, ε_t. Finally, the inflation objective is in its own category. The six groups of shocks are summarized as follows:[10]

$$\begin{array}{rl}
\text{Goods supply:} & \lambda_{ft},\ \epsilon_t,\ \mu_{z,t}^* \\
\text{Capital producers and entrepreneurs:} & \mu_{\Upsilon,t},\ \zeta_{i,t}\ ,\ \tau_t^{oil},\ \gamma_t,\ \sigma_t \\
\text{Demand:} & \zeta_{c,t},\ g_t \\
\text{Banking and Money demand}\ : & \chi_t,\ x_t^b \\
\text{Monetary policy}\ : & \varepsilon_t \\
\text{Inflation objective:} & \pi_t^*
\end{array}$$

A by product of our estimation strategy is a time series of fitted shocks. A property of these shocks is that, when they are fed simultaneously to our estimated model, the simulated X_t (see (25)) coincides exactly with the actual data. Thus, because of the linearity of our approximation of the model's solution, the shocks provide us with an additive decomposition of the data. The decomposition of the (demeaned, year-over-year, percent) growth rate of GDP in the 2001 recession for the US and the EA appears in Figures 6a and 6b, respectively.

Consider the US results first. Note how the primary shocks responsible for the recession are a combination of demand shocks and shocks to capital producers and entrepreneurs. Beginning in 2000Q1, the first in a string of negative demand shocks occurs, and these are later

[10] A fifteenth shock, $\sigma_{\aleph,t}$, is not included here, because it has no impact on the allocations.

reinforced by negative shocks from capital producers and entrepreneurs. Interestingly, while technology shocks become smaller during the recession, they remain positive in each quarter, with the exception of 2001Q3 and Q4. Thereafter, technology shocks become stronger and help bring the recession to an end. Regarding monetary policy, we can see that the Fed deviated from its monetary policy rule in a way that supported output as the economy began to weaken in 2000, and then deviated much more strongly as the recession began to unfold in earnest in 2001. We estimate that monetary policy shocks contributed at least one-half percent to GDP growth in each of the 4 quarters from 2001Q2 to 2002Q2. On average, monetary policy shocks contributed 0.75 percentage points over these four quarters, for a cumulative effect of roughly 3 percent of GDP. The sequence of expansionary monetary policy shocks came to an end in the beginning of 2002, when the strong positive technology shocks took over and drove the economy out of recession.

Now consider the EA in Figure 6b. Note how the growth in the EA does not begin to weaken until the end of 2000, almost a year after the start of the US recession. As in the US, the recession is attributed primarily to a combination of demand shocks and shocks to capital producers and entrepreneurs. Unlike the US, unfavorable technology shocks also contributed to the recession. When the recession got underway, the ECB deviated from its normal monetary policy rule. It did so over an extended period, and with considerable effect. Monetary policy shocks added more than one-half percent to growth in each of the 13 quarters from 2001Q4 to 2004Q4. On average, it contributed 1.27 percent to GDP growth over these 13 quarters, for a cumulative effect of 17 percent of GDP.

3.3 Swapping Shocks

Figure 7a indicates that if the EA had been hit by the US shocks, it would have fallen into the recession sooner than it actually did (see Figure 7a, 'GDP Growth (US shocks)'). The calculations in this figure assume that the ECB follows its estimated policy rule, as well as the estimated inflation target and monetary policy shocks. According to Figure 7c, there would have been a policy loosening comparable to the Fed's, in the sense that the ECB interest rate would eventually have been brought down to nearly the level of the Fed's rate (see 'Policy Rate (US shocks)'). This policy easing, together with the favorable technology shocks, would have produced a sharp recovery without much inflation (see Figure 7b). On the whole, this counterfactual resembles what happened in the US. The results support our conclusion that differences in shocks are a key reason for the different economic performance of the EA and the US over the 2001 recession.

In comparing the US and the EA in response to the US shocks, we see that there is one difference worth noting. The EA policy rate does not exhibit the abrupt drop we see in the US rate. The more moderate response of the ECB rate in part reflects the greater persistence in the ECB monetary policy rule. We can see this in Figure 8c, which shows how the EA would have responded to US shocks, if the ECB policy rule had the Fed degree of persistence. Note how this change creates greater volatility in the ECB policy rate (compare 'EA policy rate (US shocks and Fed inertia)' with 'EA policy rate (US shocks)'). Figure 8c shows that the different weights assigned to inflation in the ECB and the Fed policy rules make very little difference to the policy rate (compare 'EA policy rate (US shocks and Fed inflation reaction)' with 'EA policy rate (US shocks)'). Finally, Figure 8c shows that the Fed policy shocks are part of the explanation for the abrupt drop in the interest rate in the wake of US shocks (compare 'EA policy rate (US shocks and Fed policy innovations)' with 'EA policy rate (US shocks)').

3.4 Swapping Structures

Among the parameters governing the dynamics of the model, the biggest differences between the EA and the US concern the parameters that govern the setting of wages and prices. Our estimates for the two regions are as follows:

$$\begin{array}{ll} \text{US:} & \xi_p = 0.63,\ \xi_w = 0.80,\ \iota_1 = 0.16,\ \iota_{w_1} = 0.86 \\ \text{EA:} & \xi_p = 0.81,\ \xi_w = 0.83,\ \iota_1 = 0.70,\ \iota_{w_1} = 0.79. \end{array}$$

Consistent with conventional wisdom, we find that prices are more flexible in the US than in the EA. The rigidity of wages is roughly the same across the EA and the US. The indexation of prices to the central bank's inflation target is very different in the two regions. This may be a consequence of the fact that the ECB is more explicit than the Fed about its inflation objective.[11]

If prices and wages in the EA were set as in the US, then with one exception, the EA's experience over the 2001 recession and recovery would not have been very different than it actually was. According to Figures 7a and c (see 'GDP growth (US structure)' and 'Policy rate (US structure)'), GDP growth and the interest rate in the EA over the 2001 recession would not have been much different if wages and prices were set in the EA as they are in the US. The exception is that inflation would have been more volatile (see Figure 7b, 'Inflation (US structure)'). These considerations are the basis for our conclusion that the differences in the US and EA experience of the 2001 recession are not primarily a consequence of differences in economic structure.

[11] The analysis of Gurkaynak, Sack and Swanson (2005) is related to our indexation finding. They argue that because the Fed does not announce its inflation objective, long-term inflation expectations display excess sensitivity relative to short-term inflation news.

3.5 Swapping Policy Rules

Our experiments suggest that if the ECB had followed the Fed's monetary policy rule and shocks, the EA would have had lower output and higher inflation. According to Figure 7c ('Policy rate (Fed rule)'), under the counterfactual experiment the ECB's policy rate would have been higher than the Fed's throughout most of the 2001 recession and recovery. Output growth in the contraction phase of the recession would not have been strongly affected (Figure 7a, 'GDP growth (Fed rule)'). However, output growth during the recovery phase would have been more anemic than it actually was. According to Figure 7b, the EA would have experienced higher inflation throughout most of the 2001 recession (see 'Inflation (Fed rule)'). In short, the EA would have had higher inflation, higher interest rates, and lower output growth during the expansion if it had followed the Fed's monetary policy rule and shocks.

In results not reported here, we investigated what it is about the Fed's monetary policy that produces these results. The key reason that inflation is higher under the counterfactual simulation is our finding that there is a rise in the Fed's inflation objective after 2002Q1. This has a substantial impact on inflation in the EA in part because of our estimate that EA price setters are quick to incorporate the inflation objective into their wage and price decisions (see the EA value of ι_1 above). The higher realized inflation is part of the reason that the ECB's policy rate in the counterfactual is so high. This in turn helps to account for the relatively anemic EA recovery in the counterfactual. Still, we found that the single most important factor accounting for the relatively weak EA recovery in the counterfactual is our estimate of the Fed's monetary policy shocks. These are smaller than the monetary policy shocks, ε_t, that we estimate for the EA.

4 Conclusion

We noted in the introduction that the ECB moved its policy rate by less than the Fed did during the 2001 recession. Some have argued that this is evidence of passivity at the ECB. We disagree. Both central banks deviated from their policy rules during the 2001 recession. The policy shocks produced by the ECB had a bigger effect supporting output than did the policy shocks produced by the Fed. The reason ECB policy shocks had a bigger effect is that the ECB's policy rule is characterized by greater persistence. As a result, to achieve a given effect on output, the ECB has to move its policy rate by less than the Fed. Another reason that policy outcomes in the EA and the US differed in the 2001 recession is that the two regions were hit by different shocks. For example, recession-producing shocks arrived in the US before the EA, and this is why the Fed moved its policy rate first. Bad shocks lingered longer in the EA, and this is why the ECB kept its policy rate low longer.

Our work suggests one important area for additional research. In our analysis we adopt the standard Taylor-rule formulation of monetary policy. However, we find that deviations from this Taylor rule ('monetary policy shocks') play an important role in policy in the 2001 recession. For example, the abruptness with which the Fed reduced rates in response to the recession is largely attributed to deviations from past behavior. ECB policy is also characterized by a willingness to depart from the estimated simple rule postulated in the model. We suspect that actual policy is in fact more predictable than these findings suggest. As a result, we think there are gains to be had from exploring alternative representations of monetary policy which assign less responsibility to shocks.

References

[1] Adolfson, Malin, Stefan Laseen, Jesper Linde, and Mattias Villani, 2004, "Bayesian Estimation of an Open Economy DSGE Model with Incomplete Pass-Through," manuscript, Sveriges Riskbank, Stockholm.

[2] Bernanke, Ben, Mark Gertler and Simon Gilchrist. (1999). "The Financial Accelerator in a Quantitative Business Cycle Framework." Handbook of Macroeconomics, edited by John B. Taylor and Michael Woodford, pp. 1341-93. Amsterdam, New York and Oxford: Elsevier Science, North-Holland.

[3] Carlstrom, Charles, and Timothy Fuerst, 1997, 'Agency Costs, Net Worth, and Business Fluctuations: A Computable General Equilibrium Analysis,' *The American Economic Review*, vol. 87, no. 5 (December), 893-910.

[4] Chari, V.V., Lawrence J. Christiano, and Martin Eichenbaum, 1995, "Inside Money, Outside Money and Short Term Interest Rates." Journal of Money, Credit and Banking 27, 1354-86.

[5] Christiano, Lawrence J., 2002, 'Solving Dynamic Equilibrium Models by a Method of Undetermined Coefficients', *Computational Economics*, October, Volume 20, Issue 1-2.

[6] Christiano, Lawrence J., and Martin Eichenbaum, 1992, 'Current Real Business Cycle Theories and Aggregate Labor Market Fluctuations,' *American Economic Review*, June; 82(3): 430-50

[7] Christiano, Lawrence J., Martin Eichenbaum and Charles Evans, 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy.*

[8] Christiano, Lawrence J., Roberto Motto, and Massimo Rostagno. 2003. "The Great Depression and the Friedman-Schwartz Hypothesis." *Journal of Money, Credit and Banking.* 35, no. 6, pt. 2 (December): 1119-1198.

[9] Christiano, Lawrence J., Roberto Motto, and Massimo Rostagno, 2007, 'Financial Factors in Business Cycles,' manuscript.

[10] Erceg, Christopher J., Henderson, Dale, W. and Andrew T. Levin, 2000, 'Optimal Monetary Policy with Staggered Wage and Price Contracts,' *Journal of Monetary Economics*, 46(2), October, pages 281-313..

[11] Fisher, Jonas D. M., 1999, 'Credit Market Imperfections and the Heterogeneous Response of Firms to Monetary Shocks," *Journal of Money, Credit and Banking*, May, pp. 187-211.

[12] Gerlach, Stefan and Lars Svensson, 2001, 'Money and Inflation in the Euro Area: A case for Monetary Indicators?', BIS Working Paper No. 98.

[13] Gurkaynak, Refet S., Brian Sack and Eric Swanson, 2005, 'The Sensitivity of Long-Term Interest Rates to Economic News: Evidence and Implications for Macroeconomic Models,' *American Economic Review* 95(1), March 2005, 425-36.

[14] Rotemberg, Julio, and Michael Woodford, 1999, 'Interest Rate Rules in an Estimated Sticky-Price Model,' in J.B. Taylor, ed., *Monetary Policy Rules*, Chicago: Univ. of Chicago Press.

[15] Schorfheide, Frank, 2005, "Learning and Monetary Policy Shifts," *Review of Economic Dynamics*, 8, 392-419.

[16] Smets, Frank and Raf Wouters, 2003, 'An Estimated Stochastic General Equilibrium Model of the Euro Area,' *Journal of the European Economic Association*, 1, 1123-75.

[17] Woodford, Michael, 1999, 'Optimal Monetary Policy Inertia,' NBER Working paper 7261, July.

[18] Woodford, Michael, 2003, 'Optimal Interest-Rate Smoothing,' *Review of Economic Studies* 70: 861-886.

Figure 1a: Interbank Loan Rates

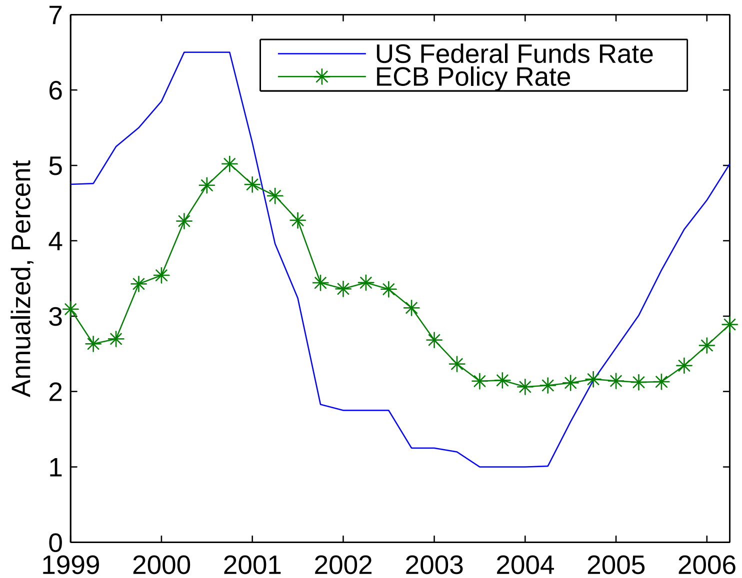


Figure 1b: US versus Euro Area GDP

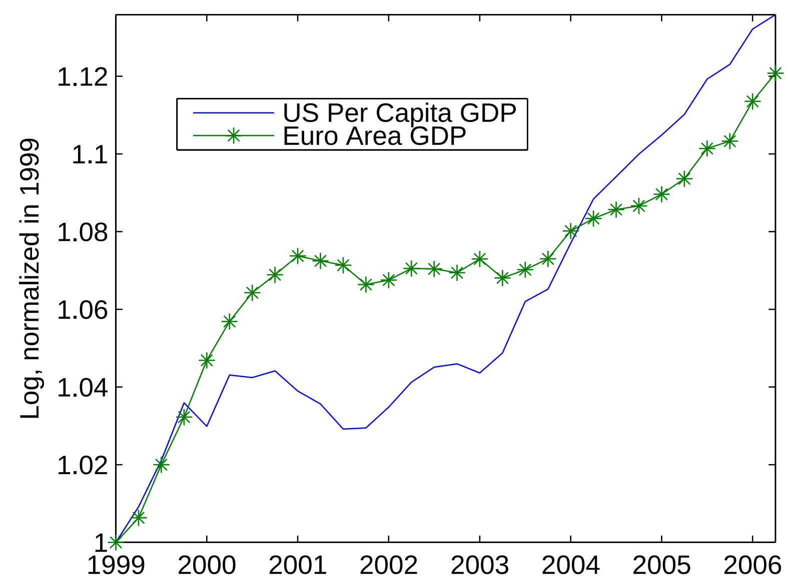


Figure 1c: Inflation in US and Euro Area

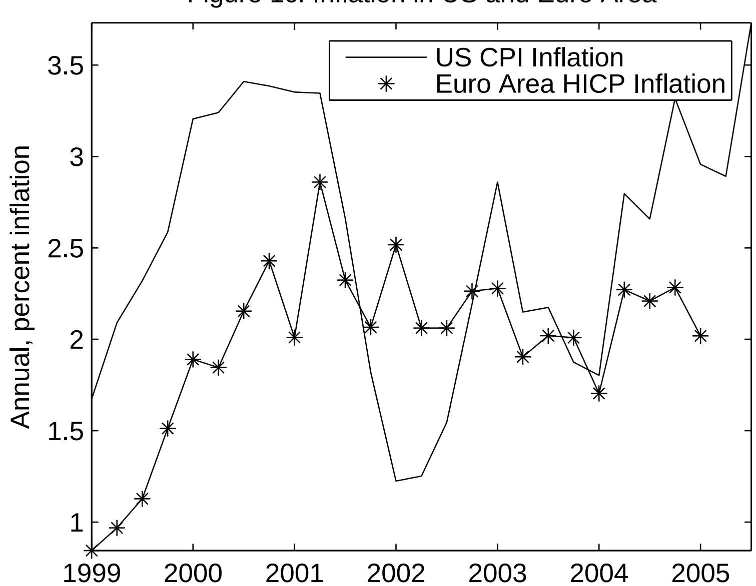


FIGURE 2: One Period in the Life of an Entrepreneur

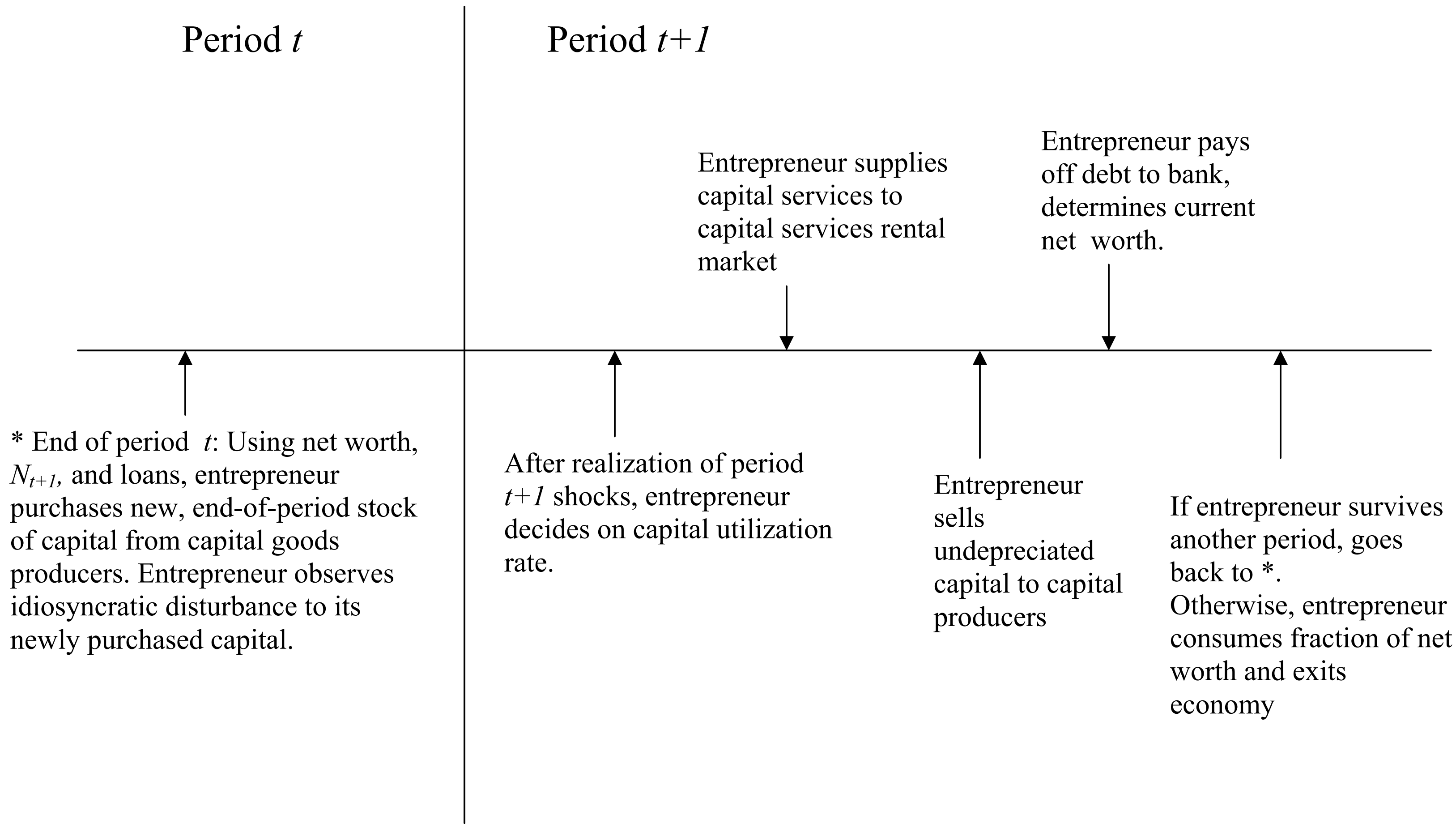
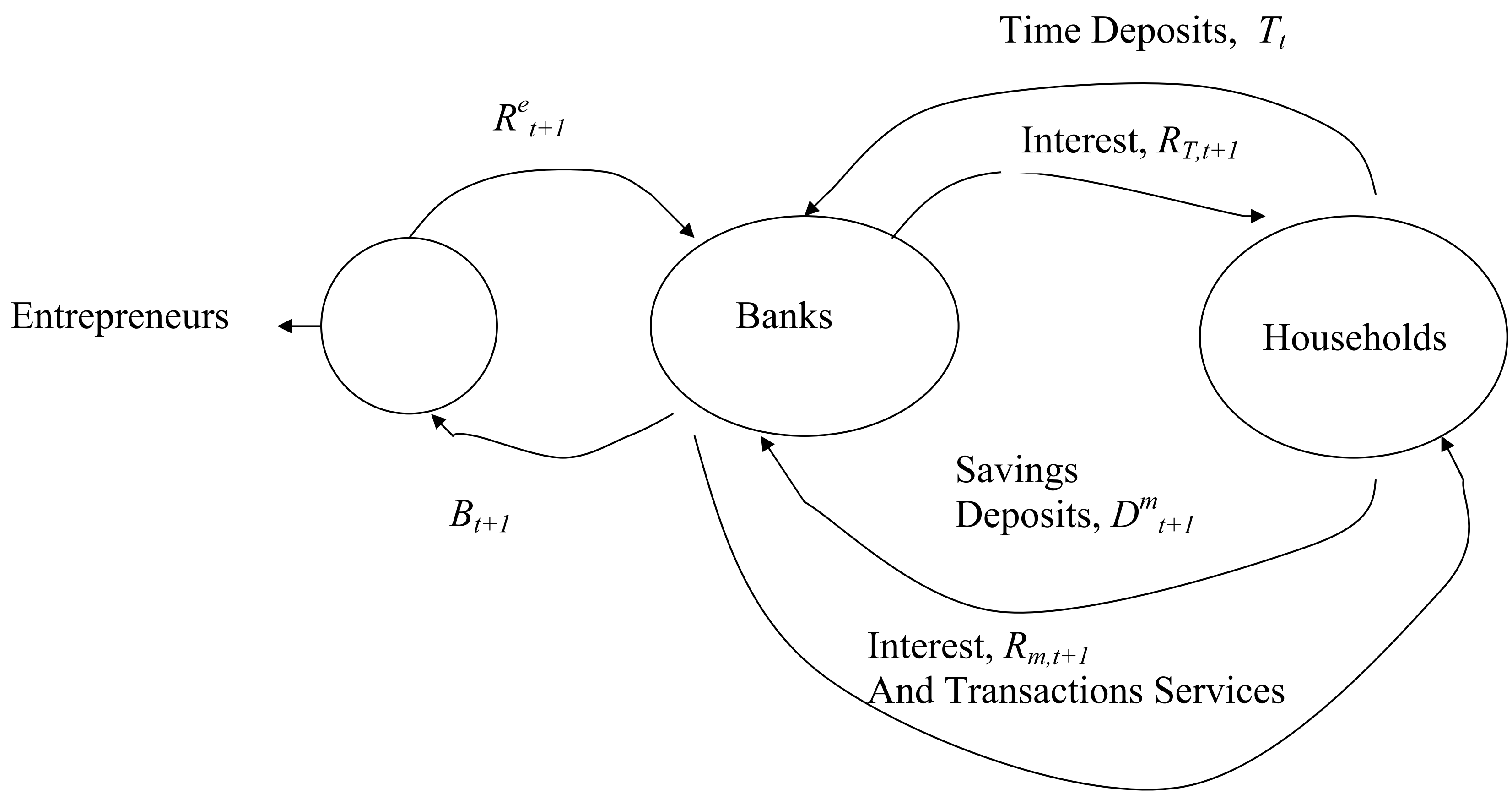


Figure 3: Financing the Entrepreneurs



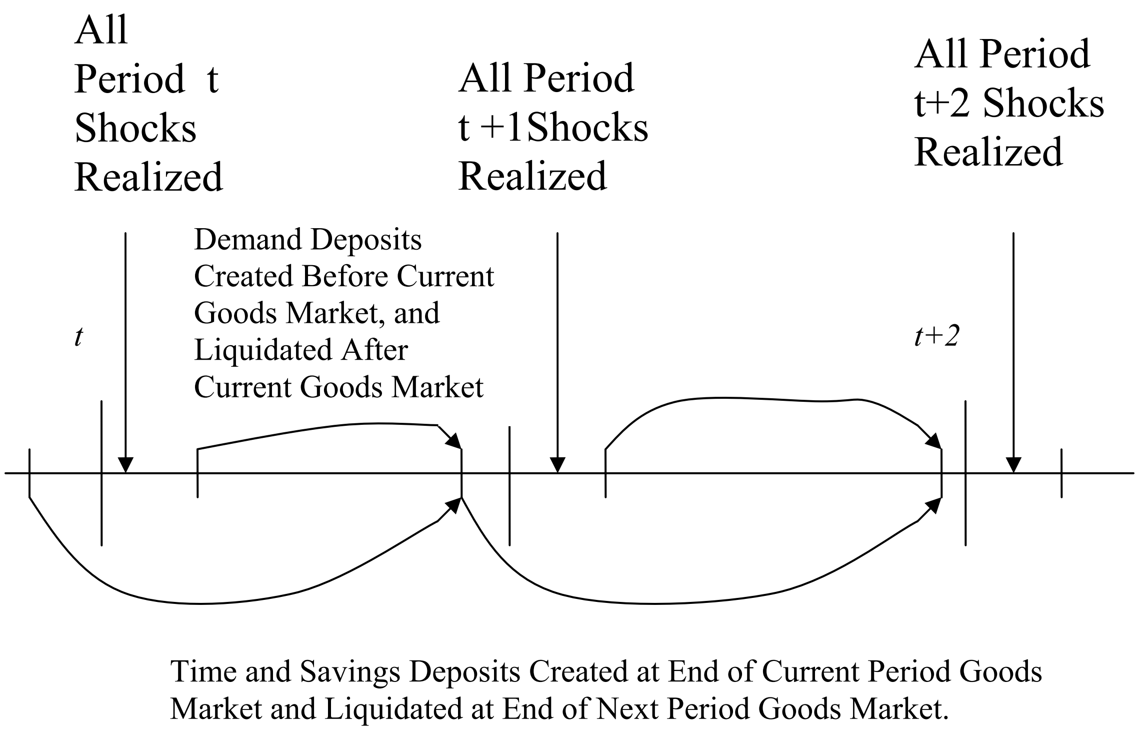


Figure 4: Maturity Structure of Time, Savings, and Demand Deposits

Figure 5: Dynamic Response to Monetary Policy Shock, US Model and Various Versions of EA Model

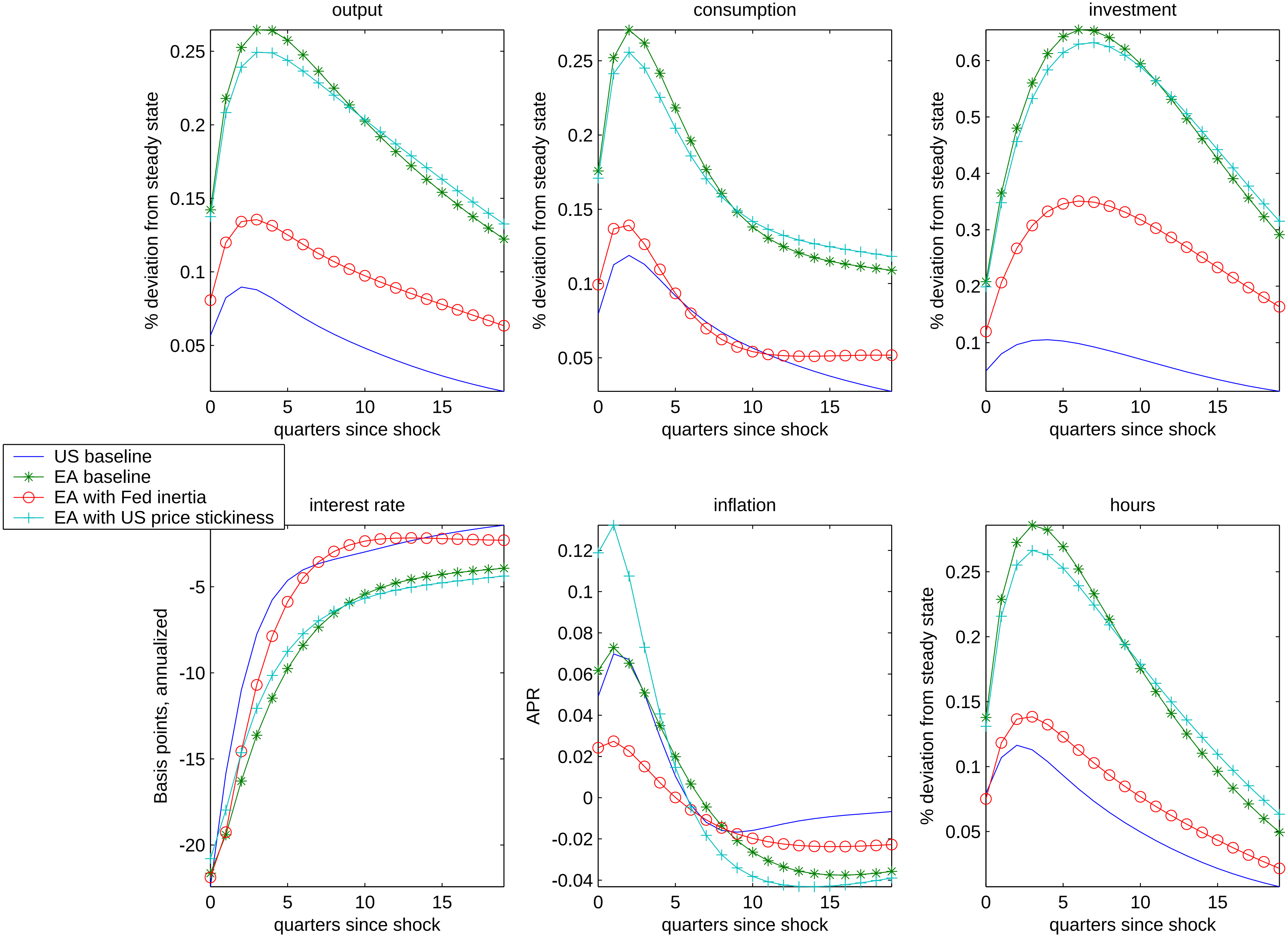


Figure 6a: US, GDP Growth Decomposition (1999Q1-2006Q2)

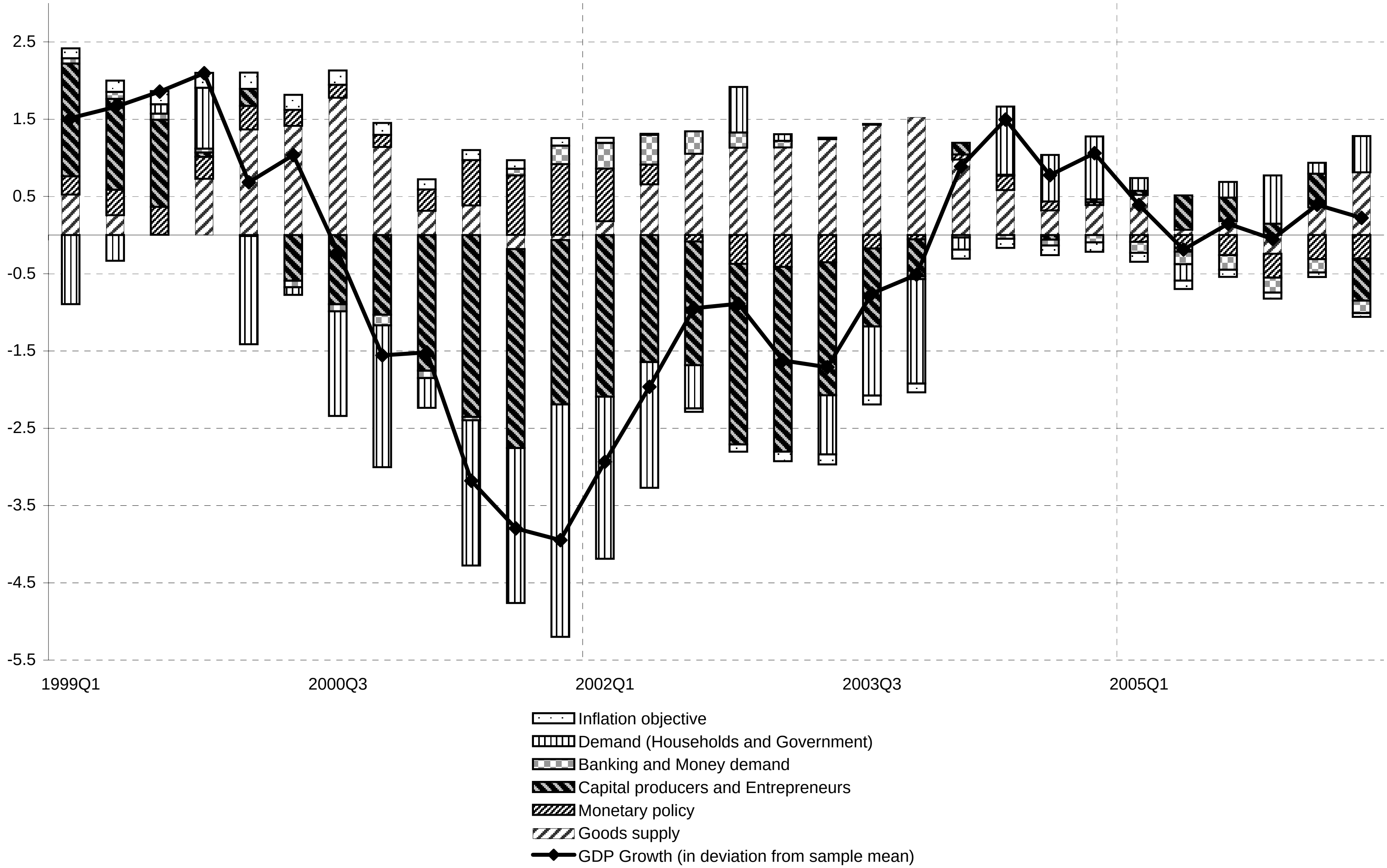


Figure 6b: EA, GDP Growth Decomposition (1999Q1-2006Q2)

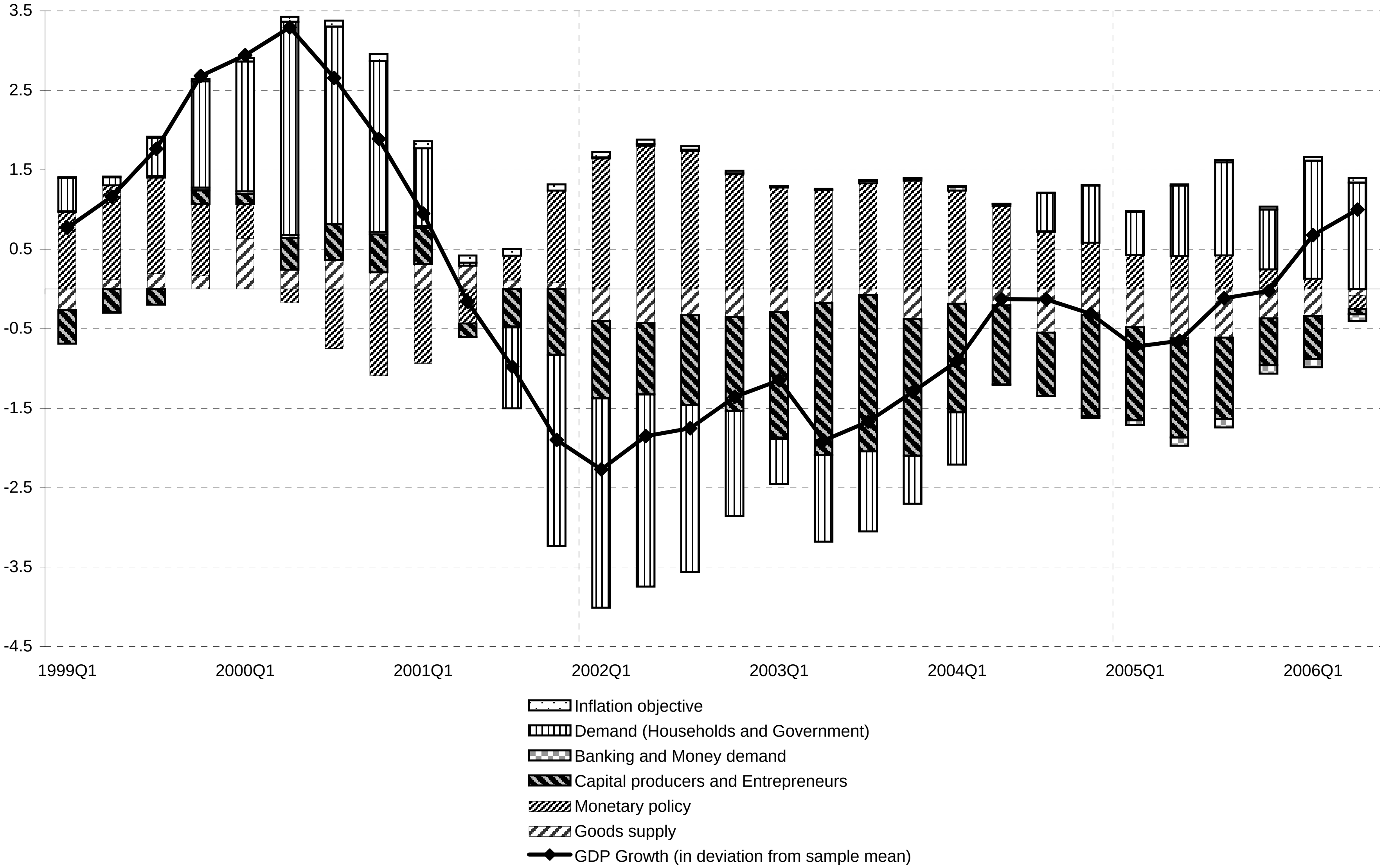


Figure 7a: EA, GDP Counterfactuals

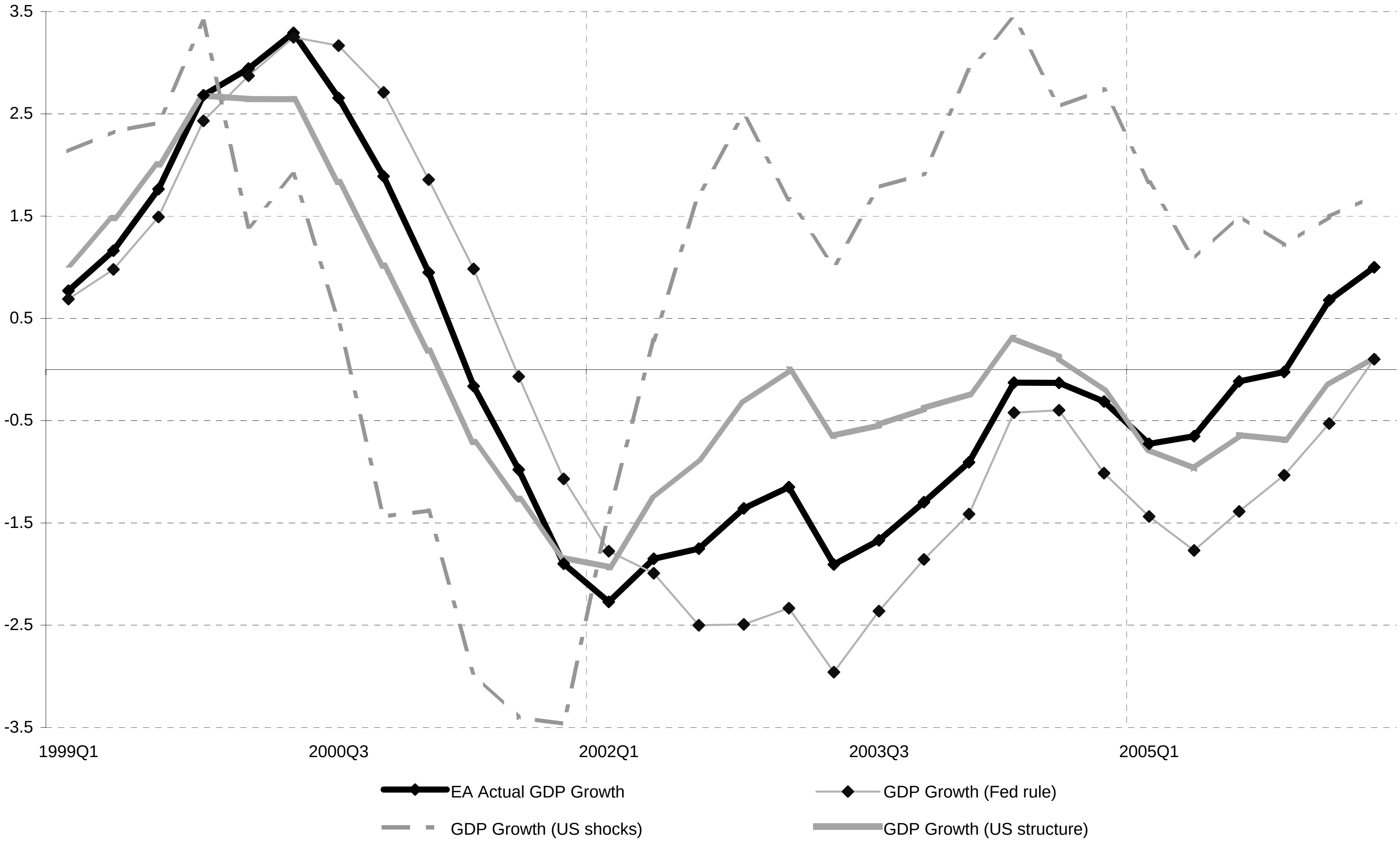


Figure 7b: EA, Inflation Counterfacuals

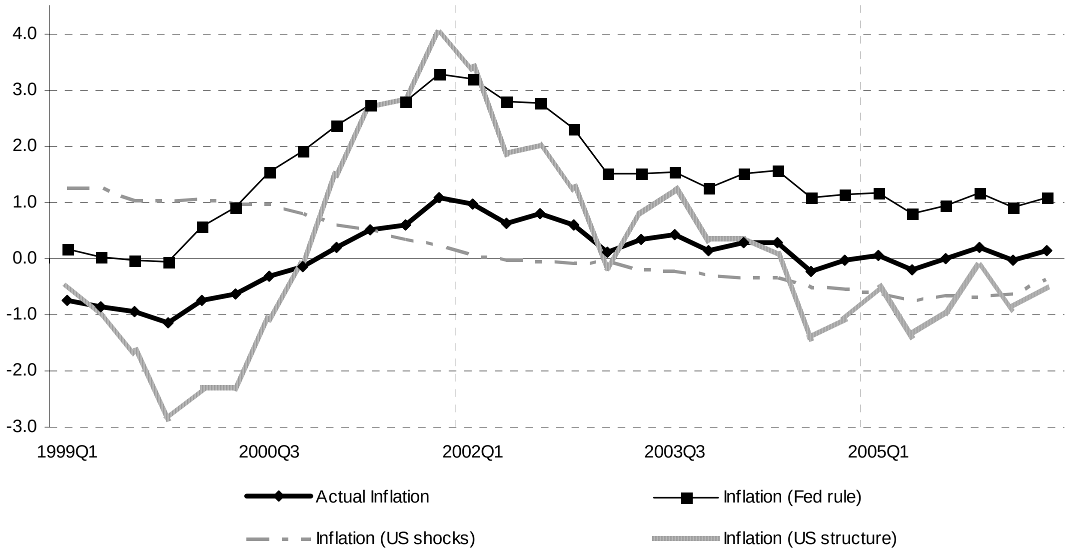


Figure 7c: EA Interest Rate Counterfactuals

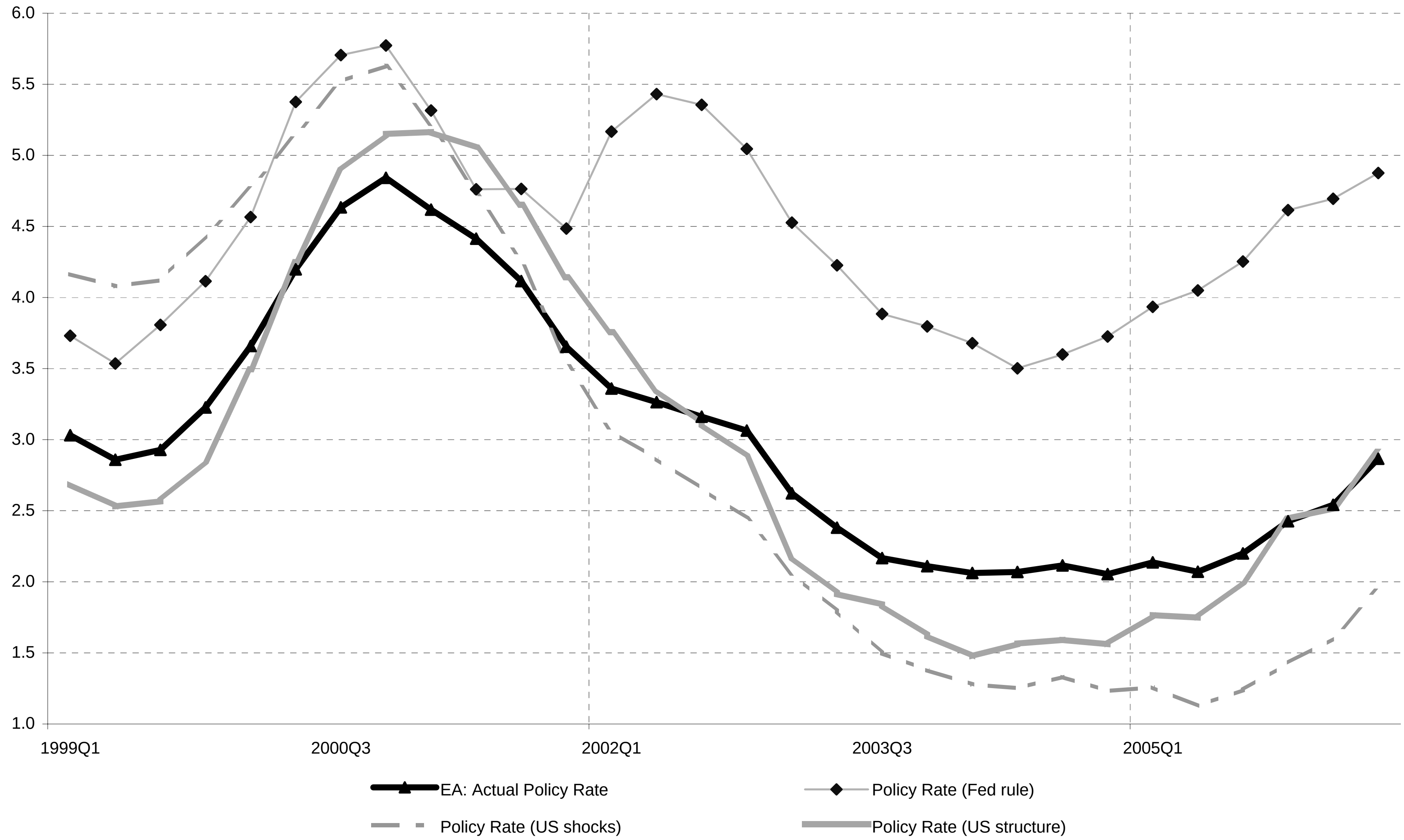


Figure 8a: EA, GDP Counterfactuals with US Shocks

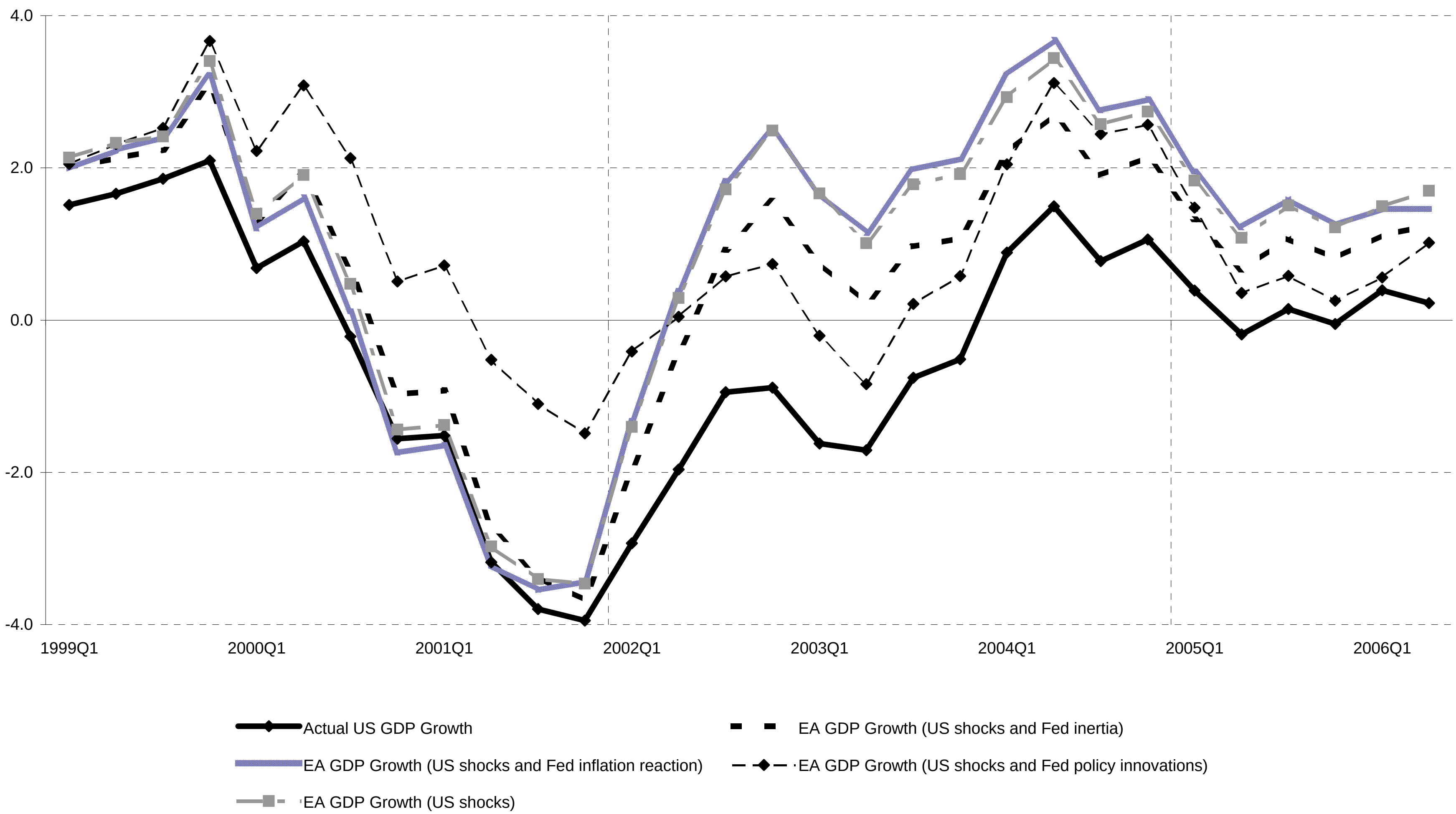


Figure 8b: EA, Inflation Counterfactuals with US Shocks

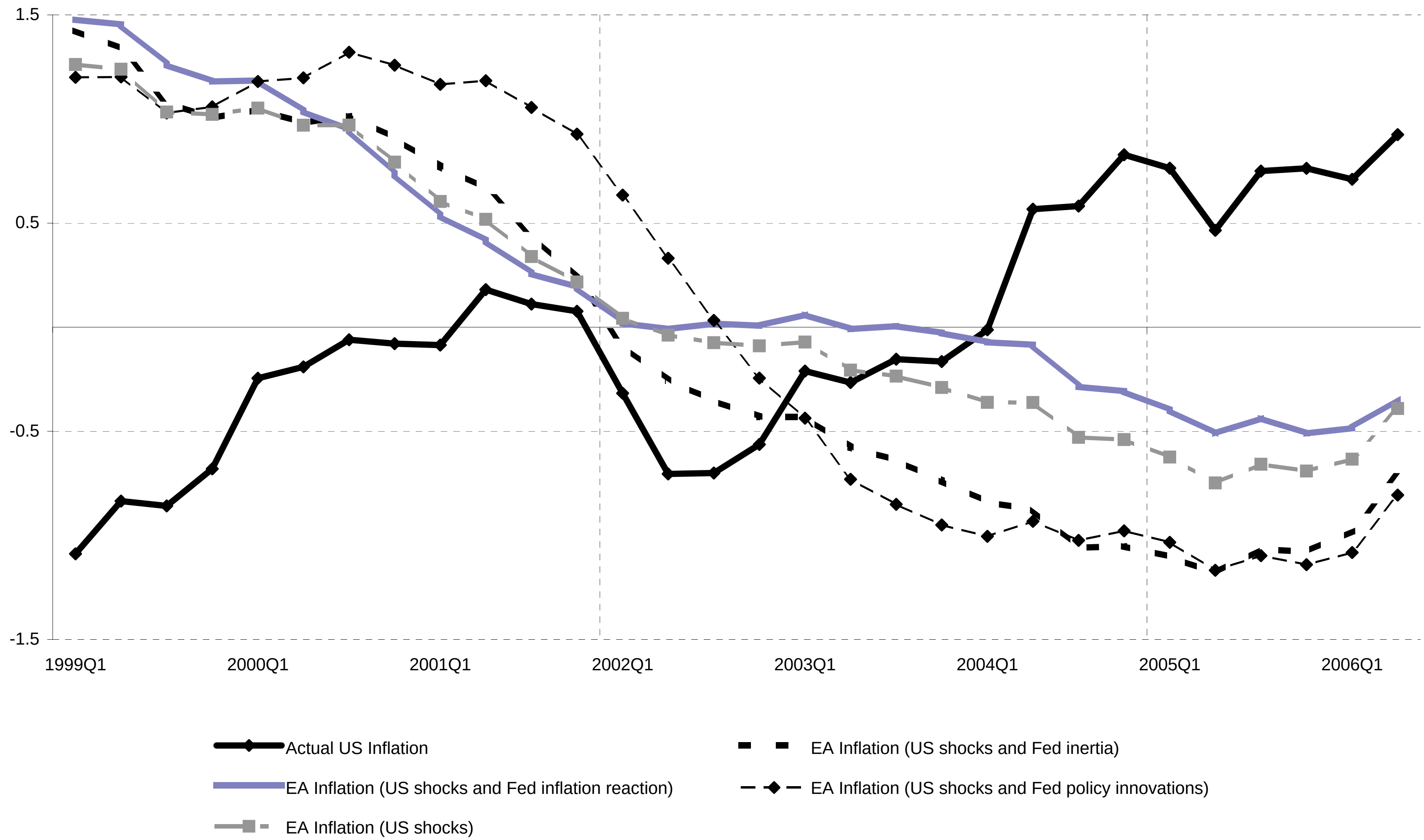


Figure 8c: EA, Interest Rate Counterfactuals with US Shocks