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Explaining Speculative Expansions

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June 16, 2003

Abstract

In this paper we use a modified neoclassical business cycle model to test two competing explanations of the expansion of the 1990s. The model can have indeterminate, multiple equilibria that give rise to expectation-driven business cycles. We fit into the model series of estimated speculative and productivity shocks and compare its predictions with empirical data. Our results suggest that the speculation hypothesis has more explanatory power than the productivity hypothesis in terms of matching the data. Speculative behavior of investors, therefore, may have contributed to the investment boom, the prolonged expansion, and the subsequent recession of the period 1991-2001.

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1 Introduction

The spectacular economic expansion in the 1990s and the recession in 2001 differ from previous episodes of business cycles in an important aspect: this cycle is strongly driven by fluctuations of investments, most importantly those associated with information technology. As figure 1 (upper right panel) shows, (detrended) GDP expanded for more than 30 quarters before reaching a peak in late 2000. In the meantime, the ratio of physical capital investment over GDP steadily increased (upper left panel). The expansion, however, was followed by a period of recession starting from late 2000, when detrended GDP fell sharply below trend. Accompanying it was the investment-output ratio, which fell from the peak of 19.5% to a low of 16% in less than 8 quarters.

The investment-driven feature makes the 2001 recession quite different from its recent predecessors. For example, it is well-known that the two recessions of the early 1980s occurred because the Federal Reserve Board's decisive actions to halt inflation. The 1990 recession was due to a fall in consumption in response to the uncertainty of war and fluctuations in oil prices (Blanchard, 1993). The 2001 recession, on the contrary, was almost solely caused by businesses' sharp cut-backs on investment (Stock and Watson, 2003). This feature is reminiscent of the Japanese economy in the 1980s, when an investment boom, most notably in the real estate industry, produced a record-long expansion. The two lower panels of figure 1 show the plots of investment-output ratio and detrended GDP of Japan in the 1980s. Interestingly, they exhibit very similar patterns as those of the US economy in the 90s.

The nature of this expansion has attracted much attention in *academia*. One central question is what triggered the vast amount of physical investment in the 1990s, and whether or not the investment boom had a "bubble" feature which contributed to the subsequent recession. There are two distinct perspectives. One perspective is that the expansion was driven by a technological

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revolution that accelerated productivity growth, which in turn boosted investment and other real economic activities (Jorgenson, 2001; Oliner and Sichel, 2000; and Greenwood and Jovanovic, 1999). This argument is consistent with those researchers' findings of productivity gains. In figure 2, we plot two time series of measured productivity growth, both obtained from the Bureau of Labor Statistics. One is the annual growth rate of multi-factor productivity between 1989 and 2000, and the other is annualized quarterly growth rate of labor productivity between 1990 and the first quarter of 2003. Both plots show significant productivity growth during this period.

The second perspective of the expansion is not incompatible with the first one: it acknowledges the importance of technology growth. But it is argued that technology revolution is not the only contributing force. Instead, the expansion was very much *speculative* in nature: aware of the technology advances, investors become overly optimistic, or "exuberant," about future investment returns. The speculation boosts investment and therefore GDP growth (Shiller, 2000; Caballero and Hammour, 2002). According to this argument, the subsequent recession is quite similar to the burst of real estate bubbles in Japan: when the high expected returns cannot be realized, investors abstain from further investment, and the economy slows down. This perspective is also consistent with evidence of stock market bubbles (Shiller, 2000; IMF, 2000; Cecchetti, Genberg, Lipsky and Wadhwanim, 2000).

In this paper we study the nature of such expansions by investigating the predictions of a quantitative business cycle model, which we modify to incorporate both of the above perspectives. In particular, we examine a version of the neoclassical model in which the possibility of indeterminacy of equilibria arises, which allows for self-fulling expectations to serve as an impulse mechanism for fluctuations. We believe this model is a convenient vehicle for studying speculative expansions, because self-fulling expectations, or sunspot shocks, are natural quantitative

representations of speculative bubbles. Moreover, the model framework does not deviate from the neoclassical paradigm and the rational expectation assumption, which makes a comparison with the standard productivity-driven model very easy.

To test the explanatory power of the two hypotheses, we fit into the model series of estimated speculative and productivity shocks, and examine which version of the model can best replicate the business cycle facts in the US during the 1990s. Productivity shocks can be easily represented by Solow residuals. For market speculations, we follow the approach of Matsusaka and Sbordone (1995) and Chauvet and Guo (2003) by using the index of consumer sentiment as a proxy. Speculative shocks are obtained by estimating a vector autoregression (VAR) model with the consumer sentiment index and a set of aggregate economic variables, and collecting its residuals.

That fluctuations in technology or productivity growth cause business cycles is consistent with the main theme of the real business cycle (RBC) school. We use a version of the RBC model of King and Rebelo (1999) to begin our analysis. This version of the model differs from earlier versions in that it allows the capacity utilization rate to vary endogenously. Recent research has shown that variations in utilization are important in accounting for business cycle facts (Greenwood, Hercowitz, and Huffman, 1988).

The alternative idea that booms and recessions are driven by expectations or "animal spirits" is the cornerstone of the Keynesian business cycle theory. Recently, this idea has been revitalized within the framework of rational expectations and market clearing. Farmer and Guo (1994) show that a simple RBC model driven by "sunspots" can replicate postwar business cycles better than a standard model driven by productivity shocks. Wen (1998) shows that when coupled with dynamic utilization rate, the model is capable of generating realistic business cycles with very mild increasing returns to scale. Harrison and Weder (2002) find that a sunspot-driven model can explain the data

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of the entire *Great Depression* era. Benhabib and Wen (2001) combine indeterminate equilibria with exogenous shocks to consumption and investment, and report the removal of several puzzles of the standard RBC model.

Policy-makers have long recognized the importance of market confidence in causing expansions and recessions. In his February 2000 testimony to the congress, Alan Greenspan explained why aggregate demand drove the economy forward:[1]

> This (aggregate demand exceeds supply) occurs principally because a rise in structural productivity growth has its counterpart in higher expectations for long-term corporate earnings. This, in turn, not only spurs business investment but also increases stock prices and the market value of assets held by households, creating additional purchasing power for which no additional goods or services have yet been produced.

One year later, as the economy slipped into a recession, he again testified in congress that

> This unpredictable rending of confidence is one reason that recessions are so difficult to forecast. They may not be just changes in degree from a period of economic expansion, but a different process engendered by fear. Our economic models have never been particularly successful in capturing a process driven in large part by nonrational behavior.

Indeterminate equilibria and self-fulling expectations do not exist in the standard RBC model. To generate such equilibria, we further modify the RBC model by assuming mild externalities which gives rise to increasing returns to scale in production. An explanation of why increasing returns are crucial for speculative expansion is provided in section 3. In the context of the 1990s,

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[1]Both this quote and the next are obtained from the Federal Reserve Board's semiannual monetary policy report to the Congress.

the assumption of increasing returns to scale is especially relevant. As researchers point out, the widespread usage of IT technology may have important externality effect that gives rise to aggregate increasing returns in production. For example, the value of new IT products like an internet connection or a software program increases when others invest and obtain compatible equipment. Thus, investment of firm A improves the productivity and value of firm B's investment. This type of production spill-over allows for on-going growth that can quickly outpace traditional explanations. Some researchers argue that increasing returns constitute a characteristic of the "new economy." (Cox and Alm, 1999; Kelly, 1998; OECD, 2000; Summers, 2000). With this feature, the model closely resembles that of Wen (1998). Furthermore, our approach is similar to that of Harrison and Weder (2002).

Within this theoretical framework we put both ideas to a test. Our criteria are based on empirical observations: we require that the model predict the expansion and recession of the same size and duration as in the 1990s. In particular, the model should predict a long expansion of about 30 quarters, and a recession subsequently. Furthermore, the expansion and recession must share the investment-driven feature of the 90s; the investment-output ratio should at least mimic those in figure 1. Finally, we require that the (successful) version pass the standard Granger Causality test.

Our main findings are as follows: while both the productivity-driven and sunspot-driven models predict a long expansion for the 1990s, the latter model produces a much better match with the data. Moreover, the sunspot-driven model predicts two features of the data that the productivity-driven model cannot predict: first, it correctly predicts the rise in the investment-output ratio during the expansion and its subsequent sharp decline; second, it correctly predicts the recession that started in the fourth quarter of 2000. These findings suggest that speculative expectations

played an important role in the business fluctuations of the 1990s.

The rest of the paper is organized as follows. Part 2 presents the model environment. Part 3 explains the mechanism that generates speculative expansions and recessions. Part 4 describes the estimation of shocks. Part 5 presents and discusses the final results, and part 6 concludes.

2 The Model

This is a decentralized version of King and Rebelo (1999) and Wen (1998)'s RBC model. After laying out the general framework, we consider two variations of the model to be consistent with the two hypotheses about the expansion in the 90s. One version is a standard RBC model with a determinate equilibrium and is driven by productivity shocks. The determinate equilibrium prohibits non-fundamental uncertainty such as sunspot shocks. The second version is a modified RBC model with increasing returns and indeterminate equilibrium, which allows sunspots to drive the business cycles.

2.1 The economy

The preferences of the representative consumer are characterized by an expected utility function

$$\max E_0 \sum_{t=0}^{\infty} \rho^t \left(\log c_t - \frac{n_t^{1+\gamma}}{1+\gamma} \right), \tag{1}$$

where $0 < \rho < 1$ is the discount factor, $\gamma \geq 0$ is a parameter of labor supply elasticity, and c_t and n_t are consumption and hours worked.

Consumers have two sources of income: wages and capital income. Wages are denoted by w_t. Property ownership is modeled as follows: the domestic representative agent owns A_t shares of the representative firm's output, and trades these shares in the asset market in each period. Total

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ownership shares are normalized to be 1. Let p_t be the market values, and d_t be the dividend yields of these shares. The budget constraint is

$$c_t + A_{t+1}p_t \leq w_t n_t + A_t(p_t + d_t) \tag{2}$$

The agent chooses consumption, labor hours, and asset shares to maximize her objective. This yields the following necessary conditions:

$$1/c_t = \lambda_t \tag{3}$$

$$n_t^\gamma = \lambda_t w_t \tag{4}$$

$$p_t = E_t \rho \frac{\lambda_{t+1}}{\lambda_t}(p_{t+1} + d_{t+1}) \tag{5}$$

Equation (3) equates the marginal utility of consumption with its opportunity cost. Equation (4) equates the marginal "disutility" of a unit of labor with its utility-measured benefit. Equation (5) is the consumption-based asset pricing equation. If we define the asset return as

$$R_{t+1} = \frac{p_{t+1} + d_{t+1}}{p_t},$$

then (5) can be written down as the familiar asset pricing equation

$$E_t \frac{\lambda_{t+1}}{\lambda_t} R_{t+1} = 1 \tag{6}$$

The production sector is similar to Jermann (1998)'s asset pricing economy with production. The home country has a large number of identical firms. In each period, managers maximize the

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value of the firm to its owners, which is equal to the present discounted value of all current and future dividends (d_t).

$$E_t \sum_{i=0}^{\infty} \rho^t \frac{\lambda_{t+i}}{\lambda_t} d_{t+i},$$

where ρ is the discount factor, and $\frac{\lambda_{t+i}}{\lambda_t}$ is the marginal rate of intertemporal substitution of the owners. The dividend yields of the firm d_t are defined as output (y_t) less labor cost $(w_t n_t)$ and investment (x_t):

$$d_t = y_t - w_t n_t - x_t$$

The firm's production technology is

$$y_t = Z_t (u_t k_t)^a n_t^{1-a} Q_t, \tag{7}$$

where $0 < a < 1$, Z_t is a stochastic shock to productivity, k_t is capital stock, $u_t \in (0,1)$ is the rate of capital utilization, and Q_t is a measure of production externalities defined as

$$Q_t = (\overline{u}_t \overline{k}_t)^{a\eta_1} \overline{n}_t^{(1-a)\eta_2} \tag{8}$$

$\overline{k}_t$, $\overline{u}_t$ and $\overline{n}_t$ are the average economy-wide levels of capital, utilization rate and labor, which are exogenous from the point of view of each firm. $\eta_1 \geq 0$ and $\eta_2 \geq 0$ measure the levels of externalities in the economy.

Investment drives the process of capital accumulation through the dynamic constraint

$$x_t = k_{t+1} - (1 - \delta_t)k_t \tag{9}$$

where δ_t is the rate of depreciation of capital stock defined as an increasing function of capital

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utilization rate u_t:

$$\delta_t = \frac{1}{\theta} u_t^\theta, \ \theta > 1 \tag{10}$$

The speed of capital depreciation is therefore endogenously determined.

The firm's necessary conditions for profit maximization are

$$u_t^\theta = a\frac{y_t}{k_t} \tag{11}$$

$$w_t = (1-a)\frac{y_t}{n_t} \tag{12}$$

$$\lambda_t = E_t \rho \lambda_{t+1}(a\frac{y_{t+1}}{k_{t+1}} + 1 - \delta_{t+1}) \tag{13}$$

Equation (11) determines the efficient level of capacity utilization. Equation (12) defines the real wage rate. Equation (13) equalizes the current and future (shadow) values of capital investment.

Defining the real interest rate of the economy as

$$r_t = \frac{y_t}{k_t} - \delta_t,$$

then (13) can be written as

$$E_t \rho \frac{\lambda_{t+1}}{\lambda_t}(1 + r_{t+1}) = 1 \tag{14}$$

Since all firms are identical, in equilibrium we have $n_t = \overline{n}_t$, $k_t = \overline{k}_t$, and $u_t = \overline{u}_t$. By making the parameter substitutions

$$\alpha = a(1 + \eta_1) \geq 0 \tag{15}$$

$$\beta = (1-a)(1 + \eta_2) \geq 0 \tag{16}$$

we obtain the aggregate production function

$$y_t = z_t(u_t k_t)^\alpha n_t^\beta \tag{17}$$

The conditions that $\eta_1 \geq 0$ and $\eta_2 \geq 0$ allow for both constant and increasing returns to scale in production. When $\eta_1 = \eta_2 = 0$, the model collapses to the standard RBC model with dynamic utilization rate. This is the version we use to study productivity-driven expansions. We call this version "model 1." When $\eta_1 > 0$ and/or $\eta_2 > 0$, the production function has increasing returns to scale. We can further substitute out capacity utilization with (11), and the production function becomes

$$y_t = z_t k_t^{a^*} n_t^{b^*}, \tag{18}$$

where $a^* = \alpha \tau_k$, $b^* = \beta \tau_k$, and $\tau_k = \frac{\theta - 1}{\theta - \alpha}, \tau_n = \frac{\theta}{\theta - \alpha}$. $a^* + b^*$ is the *effective* returns to scale.[2] We call this version "model 2."

A dynamic equilibrium consists of a set of prices and quantities such that the agents maximize their objectives as described above, and all markets clear. The market clearing conditions for the asset and goods markets are

$$A_t = 1 \tag{19}$$

$$c_t + k_{t+1} - (1 - \delta_t)k_t = y_t$$

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[2]See Wen (1998) for a more elaborate derivation.

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2.2 Parameter values

Except for the production technology, most parameter values are chosen to conform with standard RBC models. The steady state real interest rate is set equal to 1 percent per quarter, which is close to the average rate of return on capital over the past century. This implies a discount factor of 0.99. The depreciation rate is consistent with properties of quarterly data (2.5% per quarter or 10% per annum). The values for capital and labor shares are set at 0.3 and 0.7, respectively, to be consistent with Wen (1998). These values and the steady state equilibrium implies a value for θ:

$$\theta = \frac{1 - \beta(1 - \delta)}{\beta\delta}$$

which is equal to 1.4. The steady state equilibrium also implies that the investment-output ratio be

$$\frac{x}{y} = \frac{\delta k}{y} = \frac{\alpha}{\eta} = 0.21$$

Empirical research cannot provide accurate estimates for the level of increasing returns in US industries. Recent findings (Basu and Fernald, 1997) seem to suggest that the overall returns to scale of the US economy are quite small. In our simulations, we use benchmark values of $\eta_1 = \eta_2 = 0.15$. We chose this value for the following reasons: according to NBER, the latest business cycle started in 1991:Q2 and ended in 2001:Q4, which implies a periodicity of 43 quarters or a frequency of 0.02 per quarter. With $\eta_1 = \eta_2 = 0.15$, the two complex eigenvalues of our economic system will also imply a frequency of about 0.02^3. For sensitivity test we experiment with four other different combinations of η_1 and η_2. To be consistent with empirical findings as much as possible,

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[3]The frequency of the roots $x \pm yi$ is $\cos^{-1}(\frac{x}{\sqrt{x^2+y^2}})\frac{1}{2\pi}$. I search for the level of η_1 and η_2 such that the frequency defined above is equal to 0.02.

in each of the combinations we put an upper bound of 0.2 on the overall level of externality. The four combinations are: $\eta_1 = 0, \eta_2 = 0.2; \eta_1 = 0.1, \eta_2 = 0.2; \eta_1 = 0.15, \eta_2 = 0.2;$ and $\eta_1 = \eta_2 = 0.2$.

3   Understanding the mechanism

Before we proceed to study the model quantitatively, it helps to understand its mechanisms. The key question is why we need increasing returns to scale to generate speculative shocks, and how speculations can drive business cycles.[4]

To analyze the short-run dynamics of the model, I linearize the first order conditions around the steady state as in King and Rebelo (1988). Dynamics of the model are determined by the set of linear difference equations[5]

$$
\begin{bmatrix} x_{t+1} \\ k_{t+1} \\ z_{t+1} \end{bmatrix} = J \begin{bmatrix} x_t \\ k_t \\ z_t \end{bmatrix} + R \begin{bmatrix} e^s_{t+1} \\ 0 \\ e^z_{t+1} \end{bmatrix},
\tag{20}
$$

where e^z is a productivity shock, and e^s represents one step-ahead forecast errors:

$$
e^s_{t+1} = x_{t+1} - E_t x_{t+1}
\tag{21}
$$

The solution of this system depends critically on how many roots of the Jacobian matrix J in equation (20) lie inside the unit circle. If the number of stable roots is equal to the number of predetermined variables, the system has a unique "saddle-path" solution. In this case the predetermined variables are k and z, so we have two stable roots. When eliminating the unstable

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[4]See Benhabib and Wen (1999) for a more elaborate and general explanation of how to generate sunspot dynamics. The description in this section is specific to the model.

[5]All other variables can be expressed as functions of the state and costate vectors.

roots, x_t will be solved as functions of the state vector, and the expectation error term e^s_{t+1} does not have any effect on the economic dynamics. This is why in a standard RBC economy, speculations do not generate business cycles (model 1).

If the number of stable roots of J is three, however, x_t will no longer be uniquely pinned down by the state vector. The system becomes a "sink." Each realization of the expectation errors will put the economy on a different path. Fluctuations in the expectation errors will cause the entire economy to fluctuate. In this paper, the economic system will turn from a saddle-path to a sink (model 2) only when the level of increasing returns to scale is sufficiently large. This is why increasing returns are important for indeterminacy.

The above explains the mechanism mathematically. Let's now consider the economic intuition behind the distinct system dynamics. In particular, how exactly does a speculative shock generate an investment boom, and economic fluctuations? Suppose agents speculate that asset returns R_t will increase in the next period, and increase their investment. We need to find out if such behavior is consistent with the rational equilibrium of the model.

First, note that (6) and (14) imply that asset returns R_t and real interest rate r_t are closely related. In fact from the linearized versions of the two equations, one can derive

$$E_t \widehat{r}_{t+1} = E_t \widehat{R}_{t+1} \tag{22}$$

Since the real interest rate is equal to the marginal product of capital less the depreciation rate, expecting a high asset return is equivalent to expecting a high return to physical capital in production.

Next, let's imagine what happens if agents expect r_{t+1} to increase. First, consider the case of a standard RBC model with constant returns. They act on this belief and increase their investment

in capital. To do so they need to reduce consumption, which can be compensated by less leisure and more work. Therefore employment goes up too. But if both capital and labor increases, the marginal product of capital must fall because of constant returns to scale. So the returns to capital falls, which does not justify the previous speculation that asset returns will rise. The speculation is not "self-fulfilling," since it does not create an investment-driven expansion.

Now we consider the case when speculations do create business fluctuations. The key element is the assumption of increasing returns to scale. It can be shown that the necessary condition for this economy to exhibit indeterminacy is $b^* > 1$,[6] where b^* is the level of returns to scale associated with labor input in the production function (18). Therefore, the marginal product of capital is a decreasing function of capital, but is a strongly increasing function of labor. Suppose both capital and labor increase, it is likely that the effect of labor dominates that of capital, and gives rise to an increase in the marginal product of capital.

Consider now a speculative shock that makes agents believe that stock returns will rise in the future. They act on the belief by increasing investment and employment. This time, the strong increasing returns in labor dominates the effect of increasing capital on the marginal product of capital, and the latter rises instead of falling. As a result, the total returns to investment also rise, which exactly justifies the earlier speculation. Therefore, in such an economy speculations are "self-fulfilling" and the speculative behavior of investors can be justified in an equilibrium. In figure 3 we illustrate this process graphically. We plot the impulse response functions of this economy on impact of a sunspot shock. The graph shows increases in stock returns, employment and investment on impact of a sunspot shock.

It is also interesting to observe the post-impact responses of the economy in figure 3. Since we

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[6]More accurately, the necessary condition is $\rho b^* > 1 + \gamma$. In this model γ is calibrated to be 0. See Wen (1998) for an analytical derivation.

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assume the shock occurs only in period one, the subsequent responses of the economy are completely endogenous. Interestingly, it displays hump-shaped dynamics that we typically observe in the data. Consider the periods after impact: as more and more capital are accumulated, the effect of increasing capital on the marginal product of capital eventually dominates the effect of labor, and the marginal product of capital starts to fall. Accordingly, employment and output also shrink, which gradually pushes the economy below trend to produce a recession. However, the marginal product of capital will eventually be reduced to a point when it is optimal to increase investment again. This triggers another round of expansion. We have an endogenous cycle mechanism: an economic expansion is followed by a recession, which in turn is followed by another expansion until the economy reaches its steady state. All were initiated by a speculation that asset returns will increase.

4   Identifying Shocks

4.1   Estimating Productivity Shocks

Productivity shocks are straightforward to measure. We use Solow Residuals to proxy variations in productivity, which we estimate as

$$\triangle z_t = \triangle y_t - \alpha \triangle k_t - \alpha \triangle u_t - (1 - \alpha) \triangle n_t, \tag{23}$$

where $\triangle$ denotes log differences. This procedure is similar to that of Burnside, Eichenbaum, and Rebelo (1996).

The data sources are as follows: real gross domestic product (y_t), capacity utilization rate of manufacturing firms (u_t), and total hours worked (n_t) are obtained from the Federal Reserve Bank

of St. Louis' FRED II database. The data spans the first quarter of 1967 and the first quarter of 2003; capital (k_t) is measured as the sum of total residential and non-residential fixed assets plus consumer durable goods, and is available at the Bureau of Economic Analysis. The original capital data is annual, which we use the INTERPOL method in TSP to convert to quarterly data. This data spans the first quarter of 1967 and the last quarter of 2001.

In figure 4, we plot the estimated $\triangle z_t$, along with the growth rates of labor productivity (output per hour, released by the Bureau of Labor Statistics). As the figure shows, the movements of the two series closely match each other, which is what we expect, since output per hour is directly affected by productivity shocks.

After calculating the values of z_t, we run an AR(1) to obtain

$$z_t = \underset{(2.3)}{0.002} + \underset{(199)}{1.002} z_{t-1} + e_t^z, \tag{24}$$

where the t-statistics are included in parentheses. Note that the unit root hypothesis cannot be rejected. Since RBC models require stable eigenvalues for a solution, we use 0.999 for a good approximation in our simulations. When simulating the theoretical model, we use the estimated residuals e_t^z to proxy exogenous shocks, and the above equation to define the law of motion of productivity.

4.2   Estimating Sunspot Shocks

Sunspot shocks, which describe the behavior of agents' extrinsic uncertainty, must be non-fundamental in nature, and must be serially uncorrelated with mean zero. Following Matsusaka and Sbordone (1995) and Chauvet and Guo (2003), we identify sunspot shocks as follows: we first find a measure of consumer expectations and several variables as measures of fundamentals, then we construct

a vector autoregression model with these variables. The residuals from the equation of consumer expectations should serve as a proxy for speculative shocks.

To measure consumer expectations, we use the *index of consumer sentiment* (CSI), which is published by the Survey Research Center of the University of Michigan. The data is monthly, which we convert to quarterly data by taking averages. To measure fundamentals, we select a number of variables that are commonly recognized as important representations of economic fundamentals. These include real GDP, Stock and Watson's leading economic indicator (published on Watson's website), money aggregate M2, the federal funds rate, the unemployment rate, the yield spread between 10 year Treasury Bond and 3 month Treasury Bill, the S&P 500 stock index, the consumer price index (CPI), and total government spending. All data except the S-W indicator are from the FRED II database and spans 1960, Q1 and 2003, Q1.

The objective of the VAR estimation is to select all possible fundamental variables that affect consumer sentiment, such that the residuals reflect *innovations* in consumer sentiment as closely as possible. Our procedure of selecting variables is as follows: we start with a simple 2 variable VAR of real GDP and consumer sentiment, and then add one variable at a time to examine its marginal predictive power. We use t and F statistics, coefficient of determinations and Granger Causality Test as criteria to measure a variable's performance. To determine the optimal number of lags, we use likelihood ratio tests to examine time lag lengths from 1 to 8.

The best VAR model turns out to consist 4 variables: consumer sentiment, the federal funds rate, the interest rate spread, and the S&P 500 stock index. The optimal time lag is 5 quarters. The order of variables that enter the VAR is sometimes important, since it determines the contemporaneous relations among shocks when they are orthogonalized through Choleski Decomposition. We experiment with two different ordering. The first is CSI, federal funds rate, interest spread and

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S&P500 index. This ordering implies that a shock in consumer sentiment affect all other variables, but other shocks do not affect consumer sentiment contemporaneously. This is consistent with the hypothesis that innovations in consumer sentiment cause economic fluctuations. In the second ranking, we put consumer sentiment as the last variable. The logic here is to make sure that shocks in other all variables have an impact on consumer sentiment, so that the innovations in consumer sentiment are indeed exogenous to fundamentals.

We found *ex post* that the ordering of variables in fact does not make any significant difference. So we report results for the first variable ordering only. The results are in table 1. As the table shows, every variable is significant at the 5% level and the adjusted R^2 indicates a good fit.

After obtaining sunspot shocks as percentages, we augment them to obtain an "index of speculations." That is, an index of movements in expectations that are purely speculative, i.e. not based on fundamentals. We plot this index in figure 5. Interesting, the index exhibits a pattern that seems to trace the movement of GDP: there is steady hill-climbing between 1994 and 2000, and considerable downward movement afterwards. We examine its quantitative significance in the next section.

5   The 1990s in the Model

5.1   Productivity-driven expansion

In this section we examine the predictions of model 1, which has a saddle-path solution and is driven by productivity shocks alone. The simulation starts from the first quarter of 1991, which is the official economic trough of the last NBER cycle. Since our calculation shows that GDP in this

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period is 1.57 percent below trend, we use it as the initial value of the simulation.[7] We scale the volatility of the shocks of Solow Residuals such that the volatility of the artificial data matches that of the real GDP of the 1990s.

In figure 6 we plot the simulated series of this experiment. In the upper panel, the solid line shows the percentage deviations of predicted GDP from its steady state, and the dashed line shows the actual detrended GDP in the 1990s. The model clearly fails to generate the economic dynamics of the 90s, at least in two aspects: firstly, it predicts a recession during 1993-1995, which did not happen in reality. A closer look at figure 2 reveals that the recession is caused by the decrease of productivity growth in 1993 and 94. The model responds robustly to this productivity regress, and produces declines in GDP for almost 8 quarters; secondly, the model cannot predict the recession of 2000 - 2001. GDP slightly declines in the second half of 2000, but quickly recovers. This again reflects the movements of productivity during this period: there were small ups and downs in productivity, but its growth rates were mostly above 0 during this period.

If we only look at the period 1995-2000, the model's predictions seem reasonably good: it does predict a long period of economic expansion, along with increasing investment-output ratio (lower panel of figure 6). The predicted output is far below actual output simply because the wrongly predicted recession in 1993-95 put the economy on a very low level. But the model fails again during the period 2000 - 01, when the real economy turned into a recession without the company of major productivity declines.

The lower panel of figure 6 plots the investment-output ratio of the artificial economy. Clearly the model also cannot correctly predict the investment movements in the 1990s. It predicts a drop in the I/Y ratio between 1993 and 1995, and a steady rise in the I/Y ratio between 1995 and 2002.

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[7]We use this and the equilibrium relationship between y and k to compute an inital value for capital stock, which we use to start the simulation.

In figure 7 we show some results to demonstrate the robustness of the above finding. The upper left panel shows the predictions of the same experiment, with the exception that the data are detrended with the Hodrick-Prescott filter rather than a linear trend. It shows that the results are not sensitive to what filters we use; the upper right panel shows the predictions of the model where the persistent parameter of productivity was 0.95 instead of 0.99. We do this because 0.95 is used most frequently in the RBC literature; the lower left panel shows the predictions of the model when the production technology has increasing returns ($\eta_1 = \eta_2 = 1.1$). This will help us examine the effect of increasing returns when the equilibrium remains determine; the lower right panel shows the predictions of the increasing-returns model, but with a persistence parameter of 0.95 instead of 0.99. All these experiments share the same features: they all overestimate the economic downturn between 1993-1995, and under-estimate the recession of 2000-01.

The result suggests that productivity alone cannot explain the economic dynamics of the 1990s, at least in the neoclassical framework that we are interested in. Since the same model is well-known for being able to capture US business cycle facts of other historical periods, it is not likely that the failure of the experiment is entirely due to model misspecification. We hence move on to the next version of the model.

5.2   Speculative expansion

Next, we examine the simulation results of model 2, which has indeterminate equilibria. In our first set of experiments, we let the economy be driven by speculative shocks alone. This will help us isolate the contributions of indeterminacy and speculative shocks. As before we calibrate the volatility of shocks to match output volatility, and start the simulation from the first quarter of 1991.

The upper panel of figure 8 shows the predictions of the model (solid line) and the actual

detrended GDP (dashed line). Strikingly, the predicted GDP traces the movements of actual GDP very well. The predicted economy exhibits all three features of the real economy in the 1990s: there is a prolonged expansion starting from 1993-94 and expanding the remaining period of the 1990s; in 2001 the expansion ends, the economy goes into a recession; both the expansion and the recession are very much investment-driven: the investment-output ratio steadily increased during 1994 - 2000, and fell sharply afterwards (lower panel of figure 8).

The match between the predicted values and the data is of course not perfect. Notably, the match is not as good in the first five to ten quarters than in the later part of 1990s. This could well be an indication that speculations played a stronger role in the second half of the 90s, when market optimism gradually gained momentum. Another weakness is that the simulated data are smoother than the actual data. But overall, the predicted booms and recessions match the shape and durations of the true ones.

The dynamics of sunspot-driven economies are sometimes sensitive to the level of increasing returns, since different values of which implies different eigenvalues for the transitional matrix and hence different frequencies of the simulated data. We test the sensitivity of the above result by simulating the model under four different set of parameters for the level of externality: $\eta_1 = 0$, $\eta_2 = 0.2; \eta_1 = 0.1, \eta_2 = 0.2; \eta_1 = 0.15, \eta_2 = 0.2;$and $\eta_1 = \eta_2 = 0.2$. The results are displayed in figure 9. With all four settings, the model correctly predicts the three features of the data, with different degrees of accuracy[8].

We note that the results might be sensitive to what variables enter the VAR that we use to estimate the speculative shocks. So we estimated several VAR models with different combinations of variables, and fit the estimated speculative shocks into model 2. For example, in one experiment

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[8]We omitt the plots for I/Y ratios since they closely match the shape of detrended GDP.

we use all the available variables described in section 4 to run the VAR. In another, we use all variables that are significant at the 10% level. It turns out that the model's predictions are very robust to these variations. Since the plots are quite similar to figure 8 and 9, we do not present them here.

What if we fit the *productivity shocks* to the indeterminacy model? If the model behaves as well as the above, then we may conclude that it is increasing returns and indeterminacy that are responsible for the good match with the data, and not speculations per se. To isolate this effect, we next simulate the indeterminacy model with productivity shocks being the only driving force. The results are shown in figure 10. The plot closely resembles those in figure 6 and 7, when the equilibrium of the model is determinate. The predicted GDP does not match the movement of the real GDP. The only notable difference is the predicted I-Y ratio, which does have the "peaky" shape this time. But the peak is in year 1995 rather than in 2000, and the I-Y ratio turns upwards between 2000 and 2002, which is exactly counterfactual. We conclude that sunspot shocks are very important in terms of generating realistic fluctuations of the 1990s.

Finally, we use the VAR method to quantitatively account for the significance of the model's predictions. Since we already have a structure model, the VAR specification is simple: we include *actual* real (detrended) GDP and the two exogenous processes, speculation index (s_t) and productivity (z_t), into the regression, and use one time lag. The speculation index is the one we constructed and defined in section 4. The Granger Causality test and forecast error variance decomposition results are reported in table 2.

As panel A of table 2 shows, the hypothesis that speculation causes GDP cannot be rejected at the 5% level, while the alternative hypothesis that productivity causes GDP is rejected with a F-probability of 0.3. Panel B shows that speculation residuals can account for 8.1, 20.6, and 31.2

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percent of GDP forecast errors at the 4, 8 and 16 time period horizon; productivity residuals can only account for 1.2, 3.2 and 5.1 percent of GDP forecast errors for the same time horizon.

6 Conclusion

In this paper we use a modified neoclassical business cycle model to test two competing explanations of the expansion of the 1990s. The major modification of the model is to assume externalities that give rise to increasing returns to scale and multiple, indeterminate equilibria. We fit into the model series of estimated speculative and productivity shocks and compare its predictions with empirical data. Our results suggest that the speculation-driven model has much more explanatory power in terms of explaining the US economy of the 1990s. Speculative behavior of investors, therefore, may have contributed to the investment boom, the prolonged expansion, and the subsequent recession of the period 1991-2003.

Our results, however, are no doubt limited by the neoclassical framework within which we conduct all our analysis. A possible extension of this work is to try to answer the same question within a different model environment, such as the now popular New Keynesian framework. We leave this for future research.

Since in a neoclassical model the underlined long term growth trend is determined by technology growth, our results *do not* suggest that technology progress is unimportant for the growth of the 1990s. Instead, they suggest that temporary variations in technology growth are not sufficient to account for the short-run economic fluctuations of that historical period.

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Table 1. Results of VAR Estimation (CSI Equation)

Adjusted R-Square = 0.86, $\sigma = 0.002$

Variables	F – Values	F - Probabilities
Federal Funds Rate	3.11	0.01
Interest Spread	2.78	0.02
S & P 500	2.52	0.03
CSI	67	0.00

Table 2. Results of VAR Estimation (output equation)

A. Granger Causality Test

Adjusted R-Square $= 0.856$, $\sigma = 0.0001$

Variables	F – Values	F - Probabilities
y_t	366	0.00
z_t	1.12	0.3
s_t	5.53	0.02

B. Forecast Error Variance Decomposition (for output)

Steps ahead (quarters)	y_t	z_t	s_t
4-step	90.6	1.2	8.2
8-step	76.2	3.2	20.6
16-step	63.7	5.1	31.2
20-step	62.8	5.3	31.9

Definition of variables: y_t - Detrended real output; z_t - productivity shock; and s_t - speculation index.

Figure 1

Detrended GDP and I/Y ratios in Japan and the United States
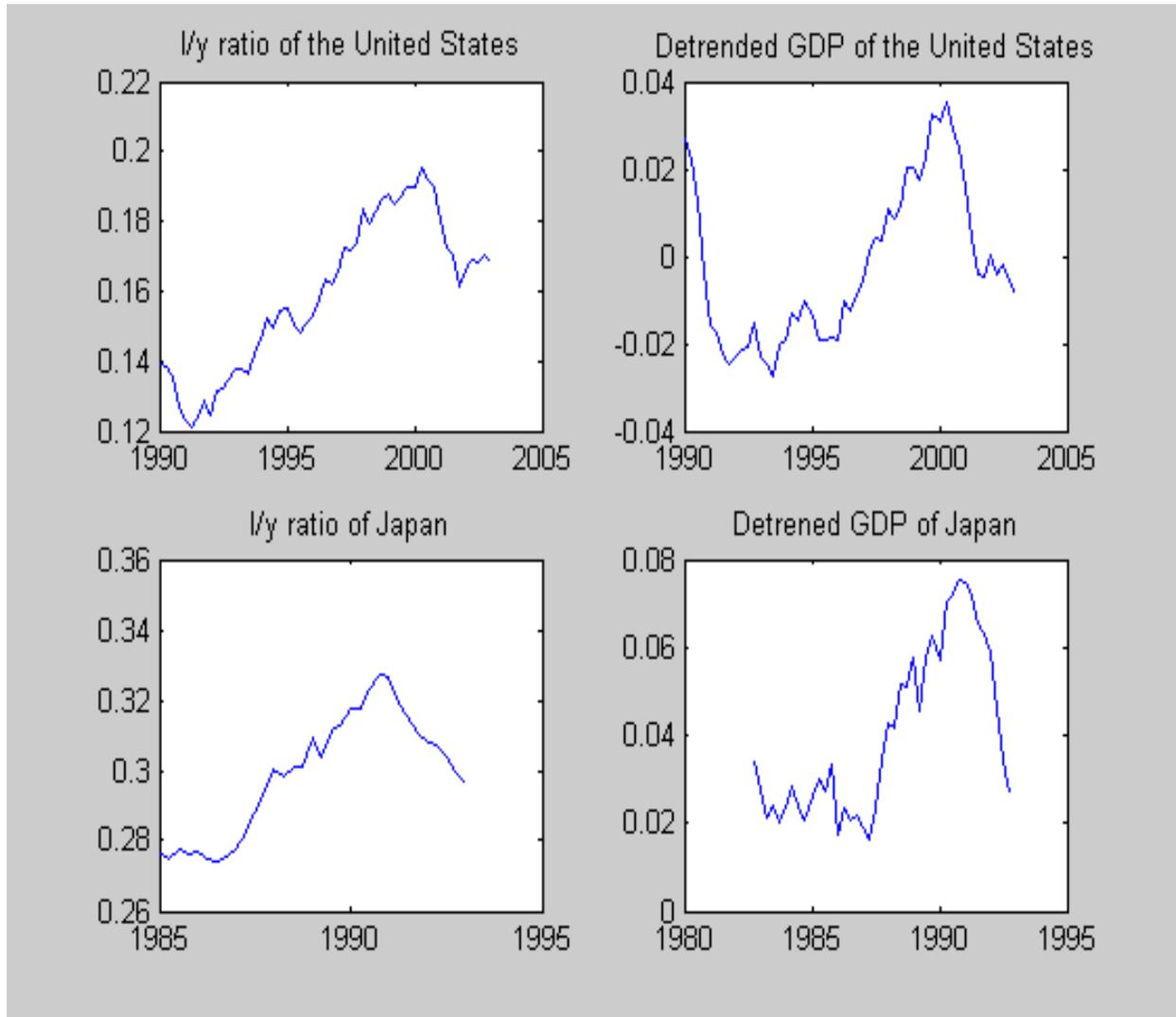
Figure 2. Productivity Growth (Annualized) in the 1990s
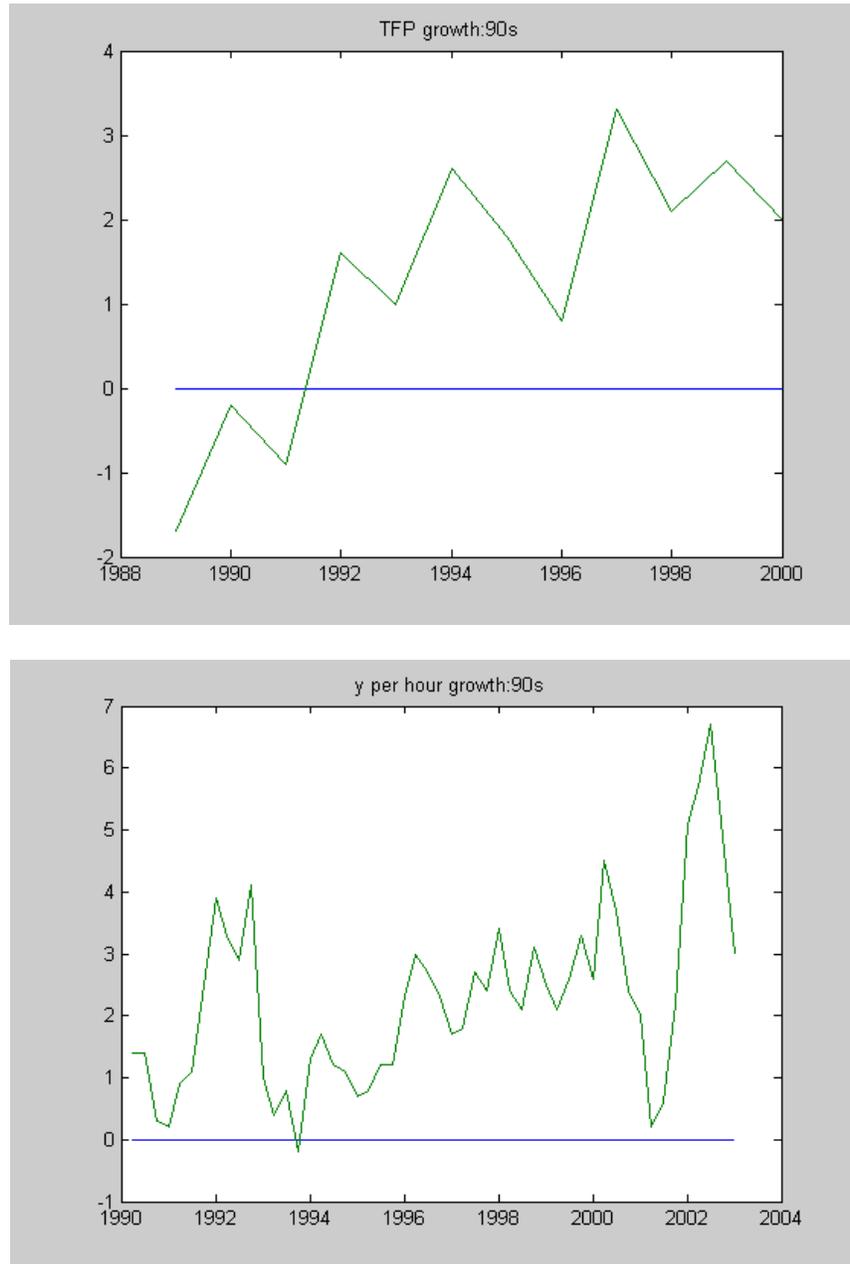
Note: the upper panel shows annual growth rates of total productivity, and the lower panel shows annual growth rates of labor productivity. Both series were obtained from the Bureau of Labor Statistics.

Figure 3. Impulse Response Functions of the Speculation Model
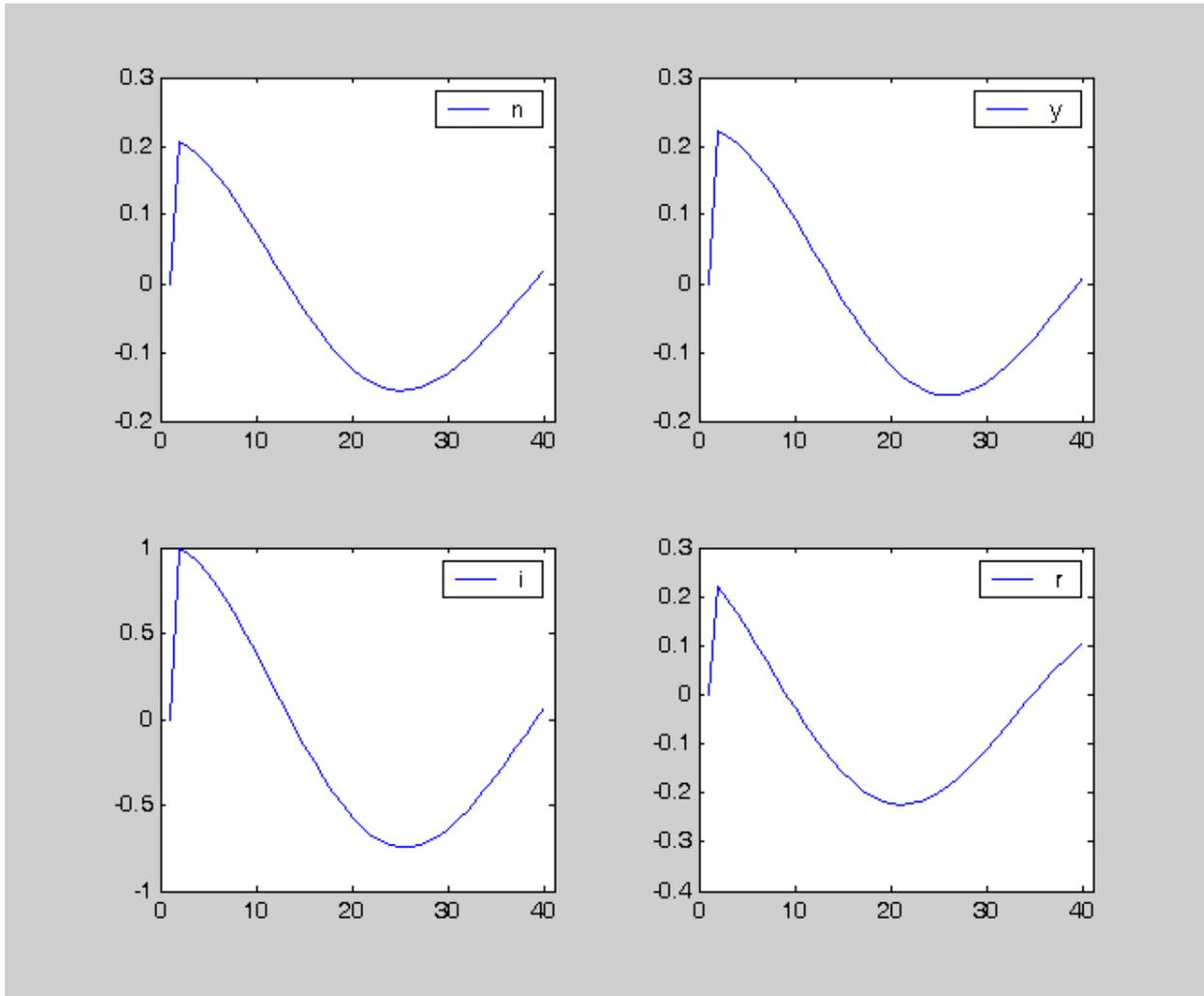
Note: this figure plots the impulse response functions of the speculation model on impact of sunspot shock. The variables plotted are: labor (upper left), GDP (upper right), investment (lower right), and marginal product of capital (lower right).

Figure 4. Quarterly Growth Rates of Labor Productivity (dotted) and Calculated Solow

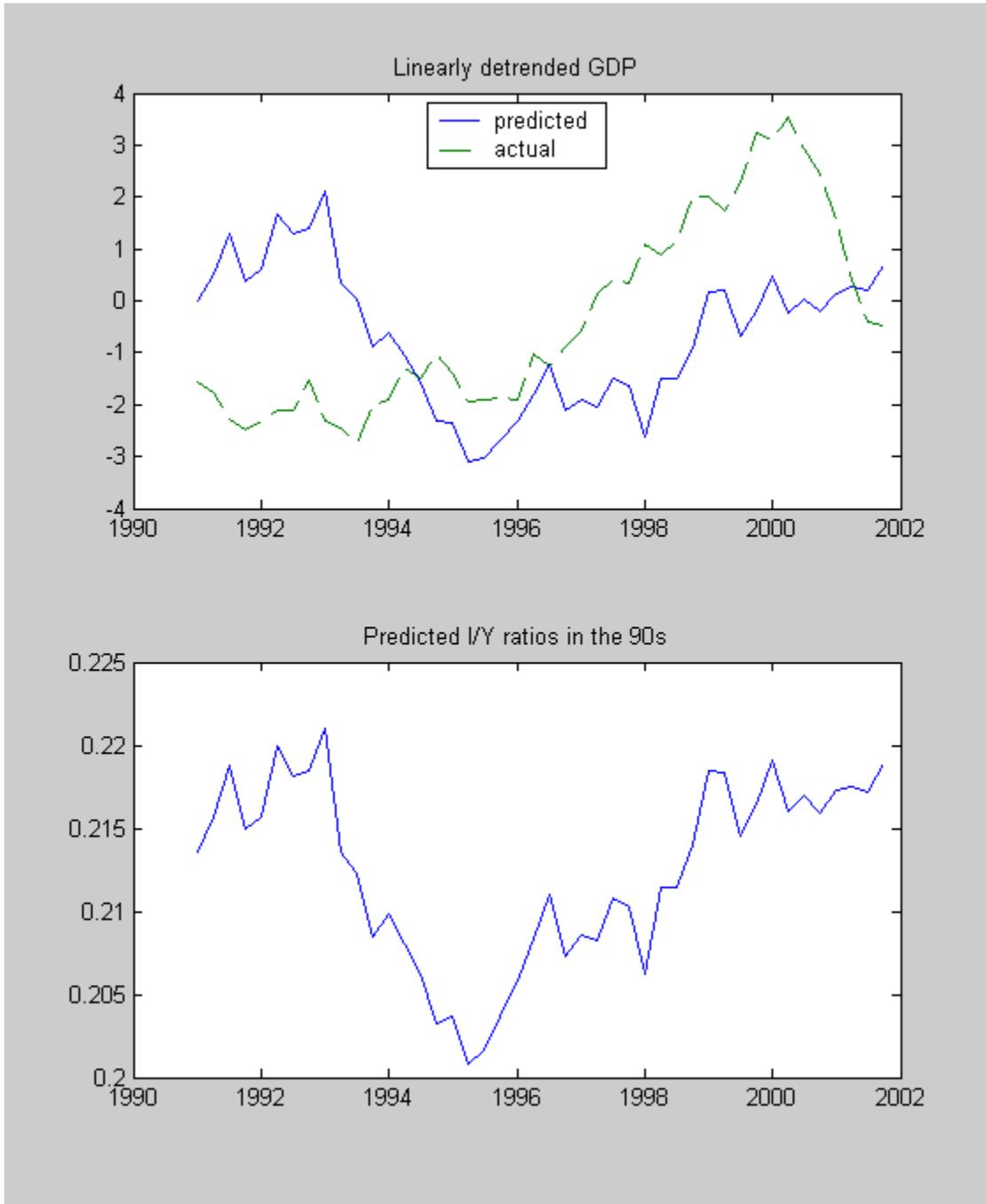**Residuals (Solid)**
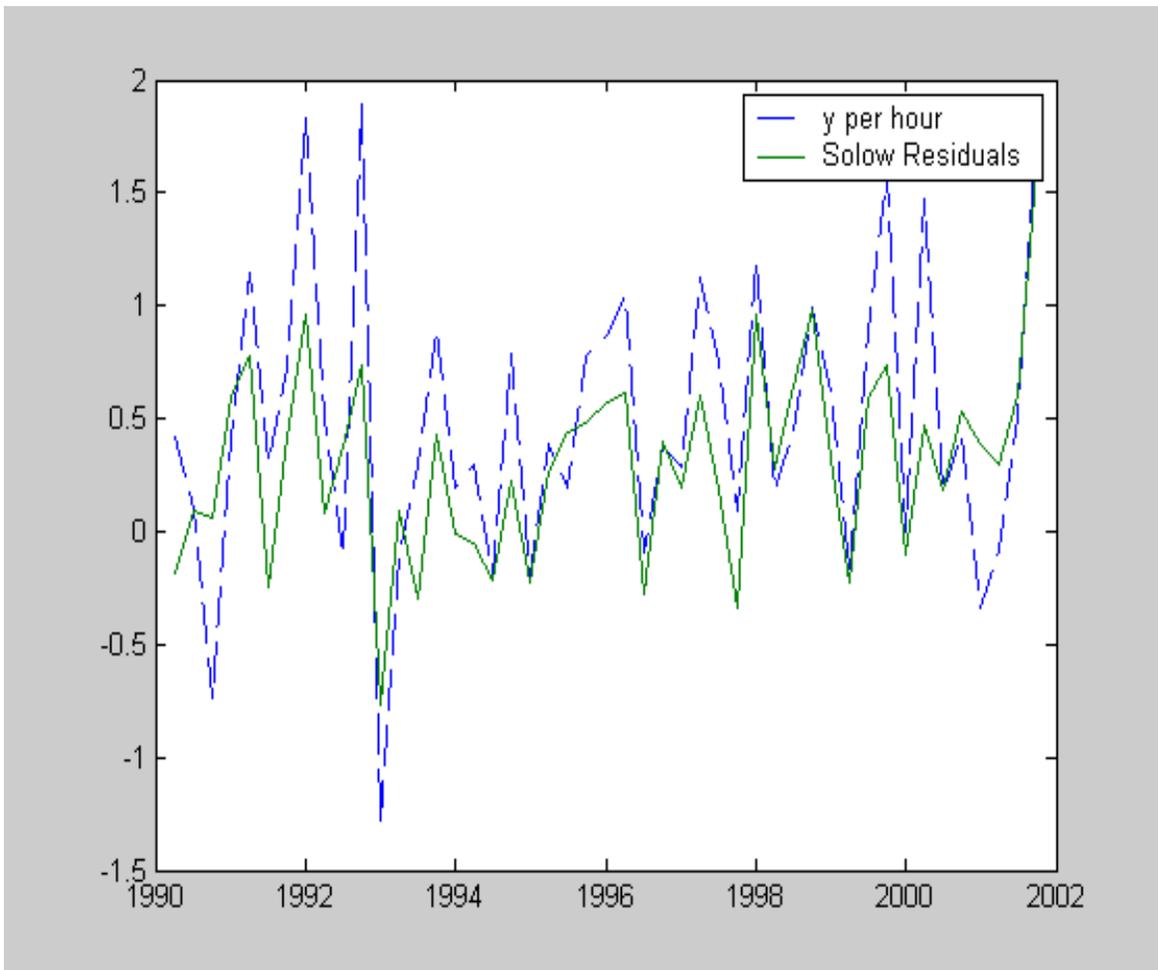
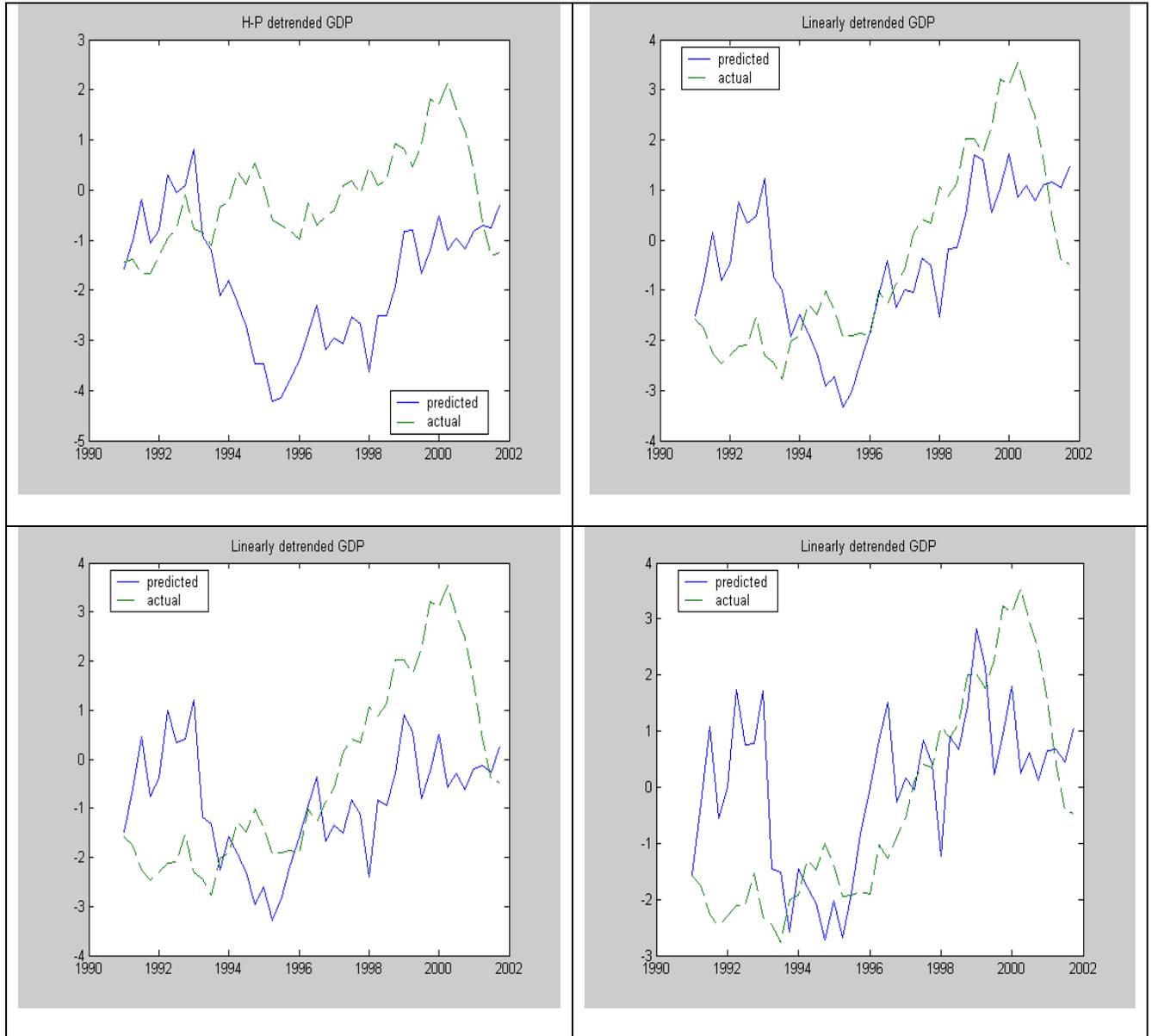**Figure 5. Constructed Consumer Sentiment in the 90s**
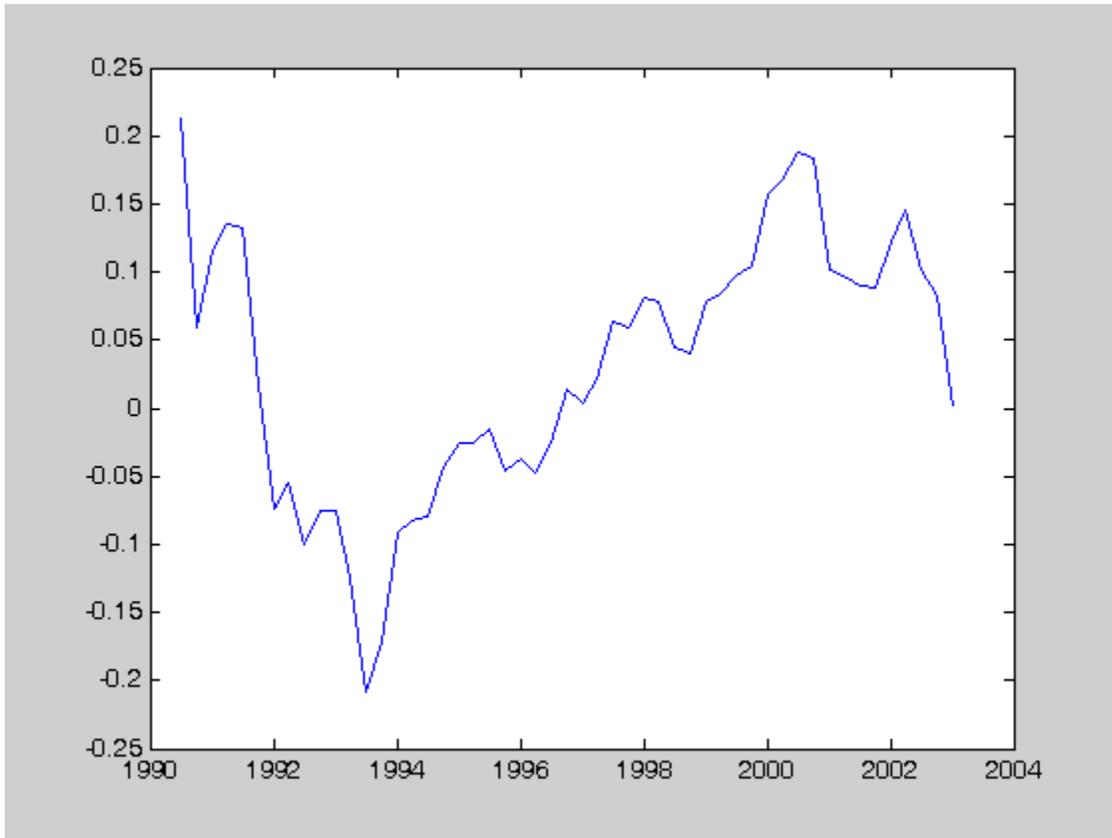
Figure 6. The 1990s in the Productivity-Driven Model

Figure 7. The 1990s in the Productivity-Driven Model (Robustness)

Upper left: H-P filtered data; upper right: productivity persistence parameter = 0.95;

Lower left: increasing returns = 1.1; lower right: increasing returns = 1.1, persistence = 0.95.

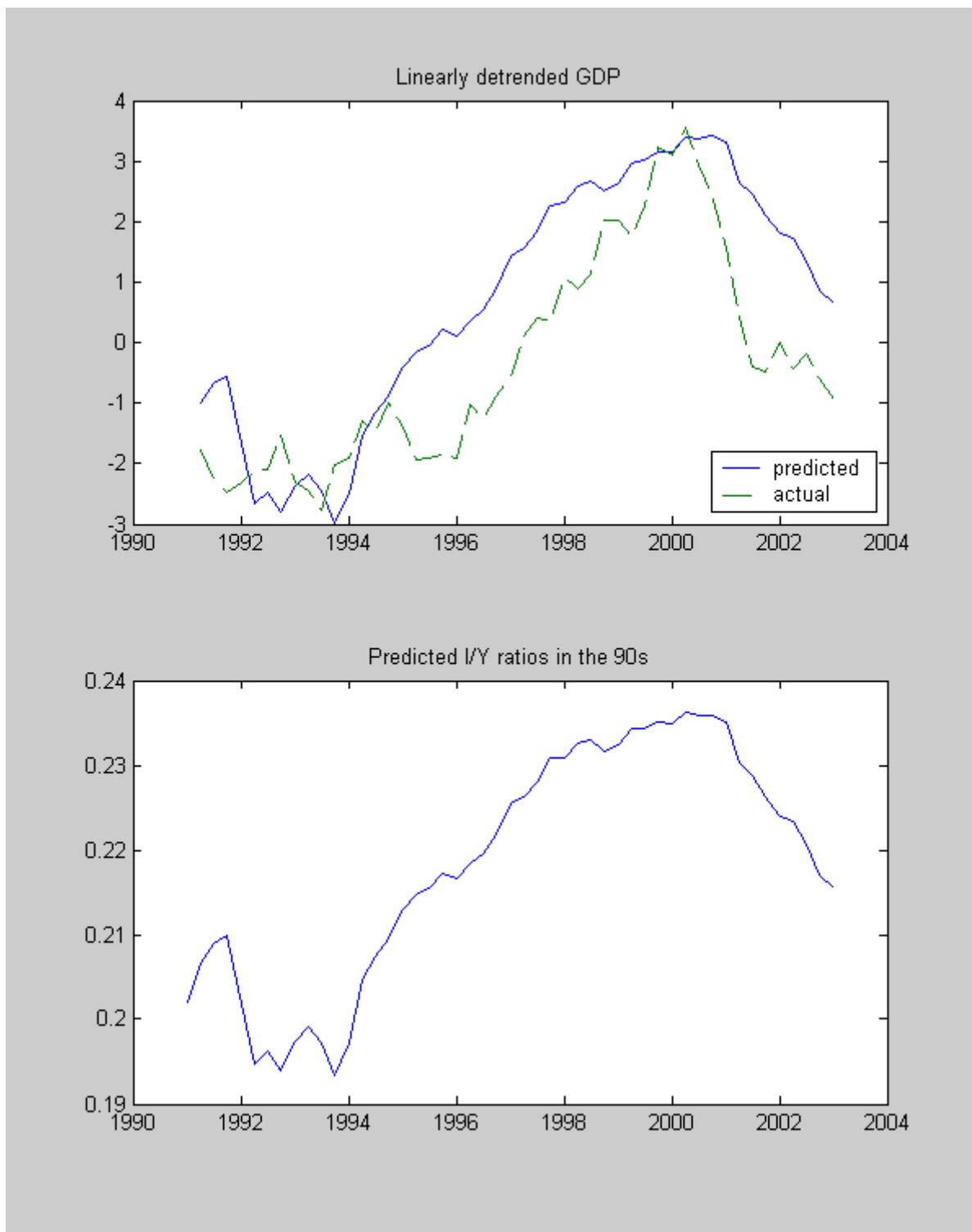**Figure 8. The 1990s in the Speculation-Driven Model**
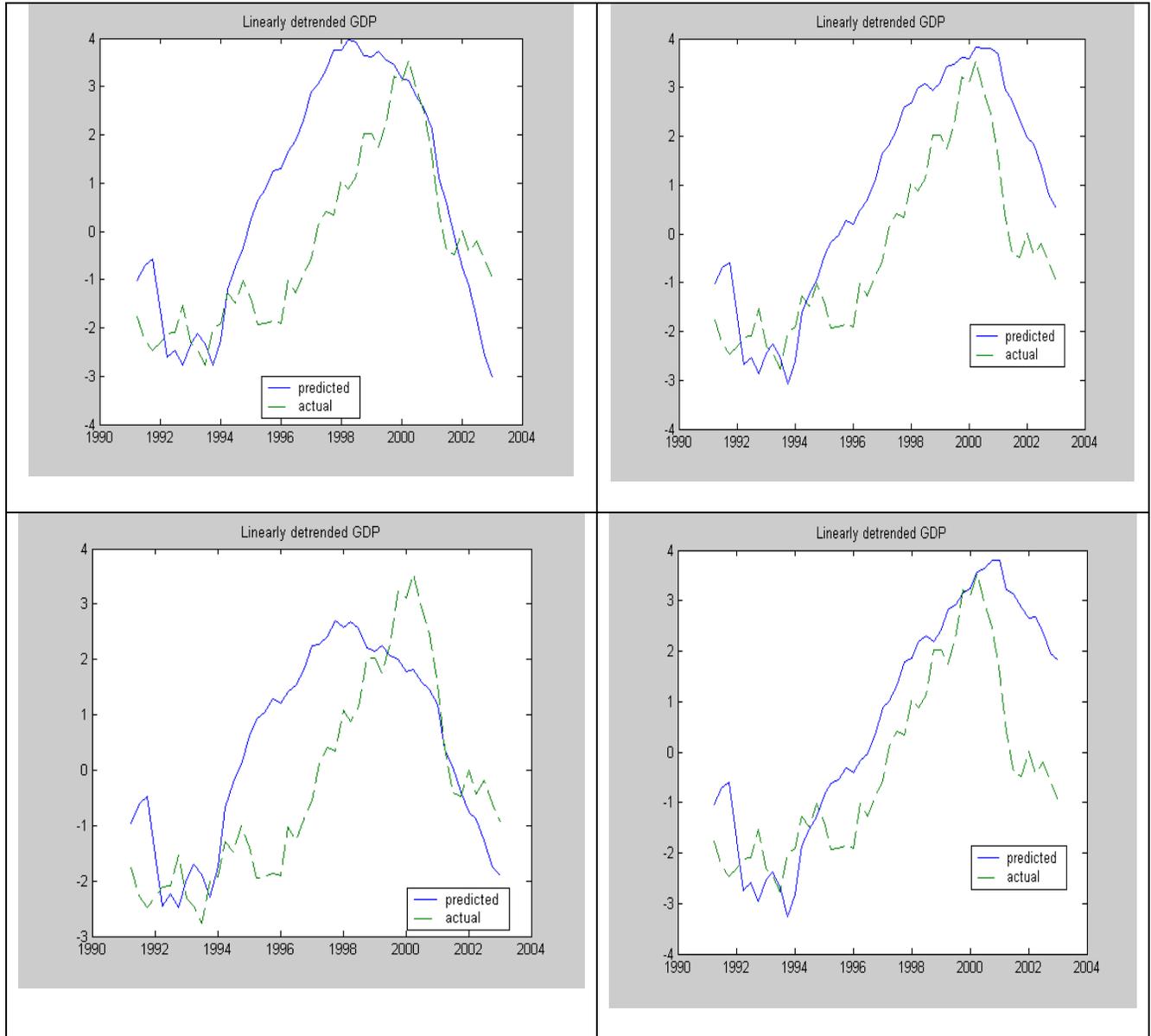
Figure 9. The 1990s in the Speculation Model (Robustness)

Upper left: $\eta_1 = 0, \eta_2 = 0.2$; upper right: $\eta_1 = 0.1, \eta_2 = 0.2$; lower left: $\eta_1 = 0.15, \eta_2 = 0.2$; lower right: $\eta_1 = 0.2, \eta_2 = 0.2$.

Figure 10. The Indeterminacy Model Driven by Productivity Shocks