Explaining Speculative Expansions

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1 Introduction

The spectacular economic expansion in the 1990s differs from previous episodes of business cycles in an important aspect: this expansion is strongly driven by fluctuations of investment, most notably those associated with information technology. As Figure 1 shows, detrended GDP expanded for more than 30 quarters before reaching a peak in late 2000 (upper right panel).[1] 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 (I-Y) ratio, which fell from the peak of 19.5% to 16% in less than 8 quarters.

This investment-driven feature of the expansion also makes the 2001 recession quite different from its recent predecessors. For example, it is commonly accepted that the two recessions of the early 1980s occurred because of the Federal Reserve Board's decisive action to halt inflation. The 1990 recession was due to a decrease in consumption in response to the uncertainty of war and fluctuations in oil prices (Blanchard, 1993). The 2001 recession, on the other hand, 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 in the real estate and other sectors produced a record-long expansion, but was followed by a recession as the investment "bubbles" burst. The two lower panels of Figure 1 plot the investment-output ratio and detrended GDP of Japan in the 1980s. Interestingly, they exhibit very similar patterns as those of the U.S. economy in the 1990s.

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 the investment boom had a "bubble" feature which contributed to the subsequent recession. There are two distinct perspectives. One perspective is

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[1] The data are detrended by subtracting a best-fit linear trend from the logarithm of the original series. Sources for all the data used in this paper are discussed in the appendix.

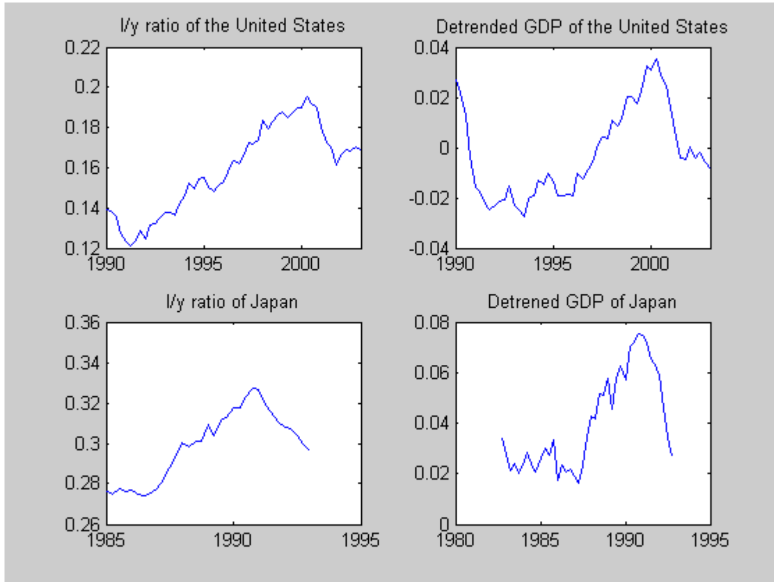

Figure 1: Detrended GDP and I-Y ratios in Japan and the United States

that the expansion was driven by a technological revolution that accelerated productivity growth, which in turn boosted investment and other real economic activities (Greenwood and Jovanovic, 1999; Jorgenson, 2001; Oliner and Sichel, 2000). This argument is consistent with those researchers' findings of productivity gains in the 1990s. In Figure 2, we present two plots of measured productivity growth, both obtained from the Bureau of Labor Statistics. The upper panel is a plot of the annual growth rates of multi-factor productivity for private businesses and manufacturing firms between 1989 and 2000, and the lower panel is a plot of the annualized quarterly growth rates 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: the importance of productivity growth is acknowledged. However, it is argued that the technological revolution is not the only contributing force. Instead, the expansion was very much *speculative* in nature: aware of the technological advances, investors become overly optimistic, or "exuberant," about future investment returns. This speculation boosted investment and therefore GDP growth (Caballero and Hammour, 2002; Shiller, 2000). According to this argument, the subsequent recession is quite similar to the burst of real estate bubbles in Japan: when the expected high returns cannot be realized, investors abstain from further investment, and the economy slows down. This perspective is consistent with evidence of stock market bubbles (Cecchetti et al., 2000; IMF, 2000; Shiller, 2000).

In this paper we study the nature of the expansion of the 1990s. In particular, we investigate the possibility that the expansion was driven by speculations. To do this we examine a version of the neoclassical business cycle model in which the

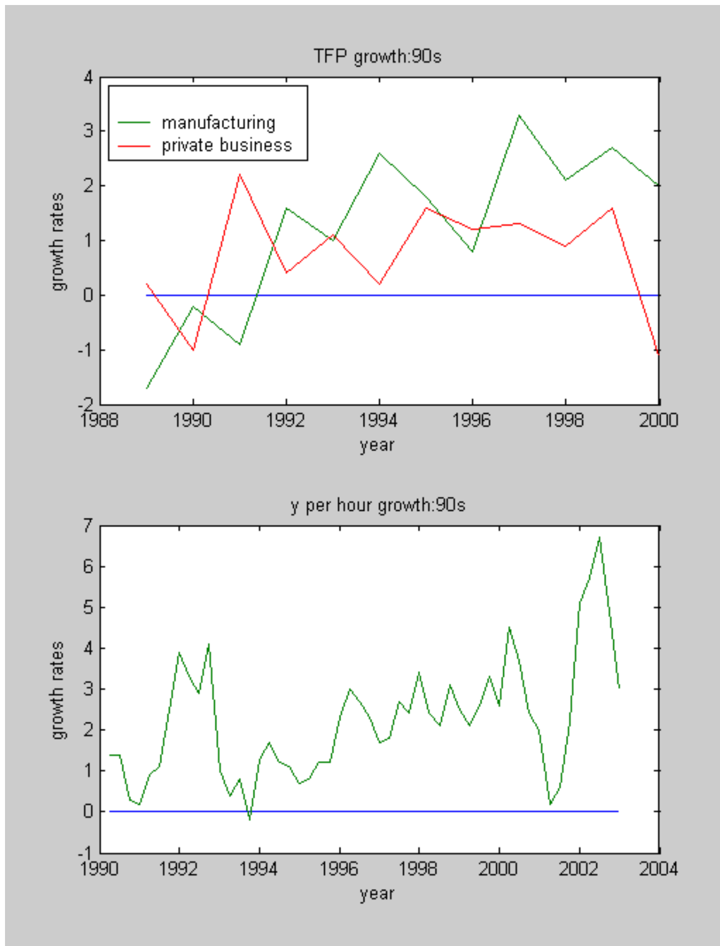

Figure 2: Productivity Growth in the 1990s. Upper panel: annual growth rates of multifactor productivity for priviate businesses and manufacturing firms. Lower panel: annual growth rates of labor productivity measured by output per hour.

possibility of indeterminacy of equilibria arises, which allows for self-fulfilling expectations to serve as an impulse mechanism for fluctuations. We believe this model is a convenient vehicle for studying speculative expansions, because self-fulfilling expectations, or sunspot shocks, are natural quantitative representations of speculative bubbles. Moreover, the model's framework does not deviate from the neoclassical paradigm and the rational expectations assumption, and this makes a comparison with the standard productivity-driven model very easy.

The 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 a 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 of the entire Great Depression era. Benhabib and Wen (2004) combine indeterminate equilibria with exogenous shocks to consumption and investment, and report the removal of several problems 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 Congress, Alan Greenspan explained why aggregate demand drove the economy forward:[2]

> This [aggregate demand exceeding aggregate 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:

> 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-fulfilling expectations do not exist in the standard RBC model. To generate such equilibria, we modify a standard RBC model (King and Rebelo, 1999) by assuming mild externalities which give rise to increasing

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

returns to scale in production. An explanation of why increasing returns are crucial for speculative expansions is provided in Section 3. In the context of the 1990s, the assumption of increasing returns to scale is especially relevant. As researchers point out, the widespread usage of IT technology may have important externality effects that give 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 spillover 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).

To test the explanatory power of the speculation hypothesis, we fit series of estimated speculative shocks into the model, and examine how well the model can replicate the business cycle facts in the United States during the 1990s. We follow the approach of Chauvet and Guo (2003) and Matsusaka and Sbordone (1995) by using the index of consumer sentiment as a proxy for market speculations. 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 the residuals. Our criteria for measuring success are based on empirical observations: we require that the model predict an expansion and a recession of the same size and duration as those of the 1990s. In particular, the model should predict a long expansion of about 30 quarters, and a recession subsequently. We also require that the expansion and recession be accompanied by similar movements in physical investment. The predicted investment-output ratio should at least mimic those in Figure 1. Finally, we require that the model pass a standard F-test for Granger causality.

To contrast the predictions of the speculation-driven model, we also calibrate and simulate a "standard RBC" version of the model, which has determinate equilibrium and constant returns to scale. Since the RBC model is driven only by productivity shocks, we can view it as a theoretical representation of the "technological-revolution" explanation of the expansion in the 1990s. However, given the very mild reduction in productivity growth rates in 2000 and 2001, the probability that this productivity-only model can predict the recession in 2001 is quite low. Therefore, the inclusion of this model serves primarily as a benchmark for comparison with the speculation-driven model. We discuss possible extensions of this model in the conclusion section.

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 more accurate 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 recession that started in the fourth quarter of

2000, and second, it correctly predicts the rise in the investment-output ratio during the expansion and its subsequent sharp decline. Speculative behavior of investors, therefore, may have contributed to the investment boom, the prolonged expansion, and the subsequent recession of the period 1991-2001.

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

2 The Model

This is a decentralized version of King and Rebelo (1999) and Wen (1998)'s models. The model differs from earlier versions in that it allows the capacity utilization rate to vary endogenously. Research has shown that variations in utilization are important in accounting for business cycle facts (Greenwood et al., 1988). To be consistent with the two hypotheses about the expansion in the 1990s, we consider two variations of the model after laying out the general framework. One version is a standard RBC model with a determinate equilibrium and is driven only 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 equilibria, which allow 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.

The consumer has two sources of income: wages and capital income. Wages are denoted by w_t. Property ownership is modeled as follows: the consumer owns A_t shares of the representative firm's output, and trades these shares in the asset market in each period. Total ownership shares are normalized to be 1. Let p_t be the market price, and d_t be the dividend yield 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:

$$
\begin{aligned}
1/c_t &= \lambda_t, && (3)\\
n_t^{\gamma} &= \lambda_t w_t, && (4)\\
p_t &= E_t \rho \frac{\lambda_{t+1}}{\lambda_t}(p_{t+1} + d_{t+1}). && (5)
\end{aligned}
$$

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 gross 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

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

There are a large number of identical firms. In each period, managers maximize the 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 yield of the firm d_t is 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, the 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 level of externalities in the economy.

Investment drives the process of capital accumulation via 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 utilization rate u_t:

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

The speed of capital depreciation is therefore endogenously determined.

The firm's necessary conditions for profit maximization are

$$\begin{aligned} u_t^\theta &= a \frac{y_t}{k_t}, & (11)\\ w_t &= (1-a) \frac{y_t}{n_t}, & (12)\\ \lambda_t &= E_t \rho \lambda_{t+1} \left(a \frac{y_{t+1}}{k_{t+1}} + 1 - \delta_{t+1}\right). & (13) \end{aligned}$$

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 net return to physical capital or real interest rate as

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

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

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

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

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 the capacity utilization rate 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 $\tau_k = \frac{\theta-1}{\theta-\alpha}, \tau_n = \frac{\theta}{\theta-\alpha}$. 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

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

$$c_t + k_{t+1} - (1-\delta_t)k_t = y_t. \tag{20}$$

2.2 Parameter values

Except for the production technology, most parameter values are chosen to conform with the standard RBC literature. γ is set to 0, which implies infinite labor supply elasticity with respect to the real wage (Hansen, 1985). 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 imply 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 is

$$\frac{x}{y} = \frac{\delta k}{y} = 0.21.$$

Empirical research cannot provide accurate estimates for the level of increasing returns in U.S. industries. The lower bounds of the estimates have decreased over time as econometricians refine their estimation techniques. Hall (1990) suggests that the aggregate level of returns to scale in the U.S. economy is larger than 1.5. Norrbin (1993)'s estimates range from 1.14 to 1.54. Most authors now base their model calibrations on the findings of Basu and Fernald (1997), who conclude that the overall returns to scale of the U.S. economy are quite small (1.02 - 1.26). Recent theoretical works in this area, such as those of Benhabib and Wen (2004) and Wen (1998), have adopted values between 1.1 and 1.2. In our simulations, we use benchmark values of $\eta_1 = \eta_2 = 0.15$. We choose these values for the following reasons: according to the 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 tests we experiment with four other different combinations of η_1 and η_2. To be consistent with empirical findings, we put

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

an upper bound of 0.2 on the overall level of externality in each of the combinations. 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 $\eta_1 = \eta_2 = 0.2$. These in turn imply levels of returns to scale of 1.14, 1.17, 1.185 and 1.2.

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, we 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]

$$\begin{bmatrix} x_{t+1} \\ k_{t+1} \\ z_{t+1} \end{bmatrix} = J \begin{bmatrix} x_t \\ k_t \\ z_t \end{bmatrix} + R \begin{bmatrix} e^s_{t+1} \\ 0 \\ e^z_{t+1} \end{bmatrix}, \tag{21}$$

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

$$e^s_{t+1} = x_{t+1} - E_t x_{t+1}. \tag{22}$$

Note that x_t is private investment. The error term therefore captures the difference between true and anticipated investment in the next period.

The solution of this system depends critically on how many roots of the Jacobian matrix J in equation (21) 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 we eliminate the unstable 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 error 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

[4] See Benhabib (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.

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 expectations equilibrium of the model.

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

$$E_t \widehat{r}_{t+1} = E_t \widehat{R}_{t+1}, \tag{23}$$

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 on physical capital in production.

Next, imagine what happens if agents expect r_{t+1} to increase. First, consider the case of a standard RBC model with constant returns. The agents act on this belief and increase their investment in capital. The prospect of higher income will also induce them to increase employment. A rise in capital reduces the marginal product of capital, and a rise in labor increases it. When the Cobb-Douglas production function has constant returns to scale, the former effect dominates the latter, and the returns on capital will be reduced (the border condition is explained below). This 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 consider the case 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, then 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 is consistent with the 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 employment (upper left), GDP (upper right), investment (lower left) and the marginal product of capital (lower right) on impact of a sunspot shock.

It is also interesting to observe the post-impact responses of the economy in Figure 3. Since we assume the shock occurs only in period one, the subsequent responses

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

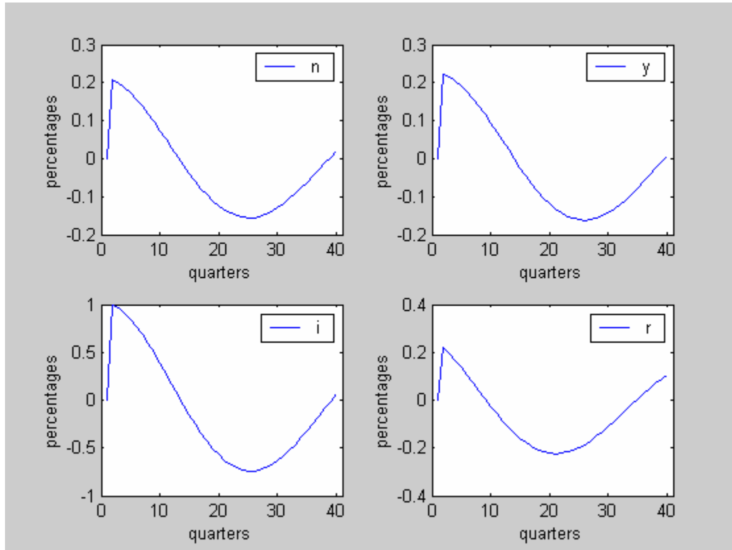

Figure 3: Impulse Response Functions of the Speculation Model on impact of a sunspot shock. The variables plotted are: labor (upper left), GDP (upper right), investment (lower left), and the marginal product of capital (lower right).

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 is 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 be reduced to a point where 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 are initiated by the speculation that asset returns will increase.

4 Identifying Shocks

4.1 Estimating productivity shocks

We use Solow residuals to proxy variations in productivity, which we estimate as

$$\triangle z_t = \triangle y_t - a \triangle k_t - a \triangle u_t - (1-a) \triangle n_t, \tag{24}$$

where $\triangle$ denotes log differences. This procedure is similar to that of Burnside, Eichenbaum, and Rebelo (1996). The data are obtained from various sources, which we describe in detail in the appendix.

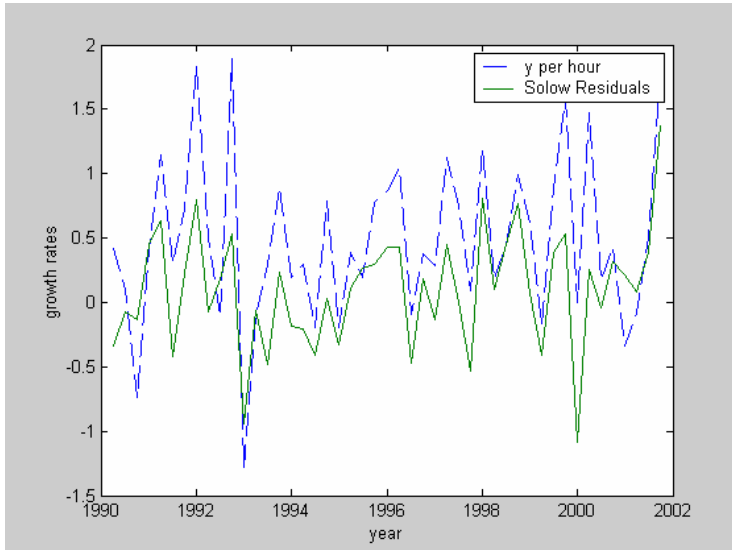

Figure 4: Quarterly Growth Rates of Labor Productivity (dashed) and Calculated Solow Residuals (Solid).

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. This is what we expect to see, since output per hour is directly affected by productivity shocks.

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

$$z_t = \underset{(0.0009)}{0.002} + \underset{(0.005)}{1.002} z_{t-1} + e_t^z, \tag{25}$$

where the standard errors 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 serve as a proxy for speculative shocks.

To measure consumer expectations, we use the index of consumer sentiment (CSI) published by the Survey Research Center of the University of Michigan. The data are 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, M2, the federal funds rate, the unemployment rate, the yield spread between the 10 year Treasury Bond and the 3 month Treasury Bill, the S&P 500 stock index, the consumer price index (CPI), and total government spending. Real GDP, M2, the S&P 500 index, government spending and the CPI are non-stationary variables. They are first differenced before entering the VAR.

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, coefficients of determination and Granger causality tests as criteria to measure a variable's performance. To determine the optimal number of lags, we use likelihood ratio tests to examine time lags from 1 to 8.

The best VAR model turns out to consist of 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 ordering of consumer sentiment relative to other variables that enter the VAR is potentially 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 the S&P 500 index. This ordering implies that a shock in consumer sentiment affects 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 ordering, we put consumer sentiment as the last variable. The logic here is to make sure that shocks in all other 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. Therefore we report results for the first 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 the i.i.d. residuals, we fit them into the model to simulate the economy of the 1990s. But before we proceed, it is helpful to use these residuals to construct an "index of speculations" so that we can visualize any significant changes in market expectations. This is accomplished as follows. First, we observe that each residual represents a change of the CSI that cannot be explained by fundamentals. We pick a base period, say the first quarter of 1960, and set the initial value as $s_0 = 0$. The rest of the series can be constructed as $s_1 = s_0 + e_1, s_2 = s_1 + e_2, ...$, where e_i is the residual collected for period i. We have thus constructed an index of movements

Table 1: Results of VAR Estimation (CSI Equation)

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
Adjusted $R^2 = 0.86, \sigma = 0.002$		

in expectations that are purely speculative, i.e. not based on fundamentals. We plot the index for the 1990s (upper panel) and for 1960-2003 (lower panel) in Figure 5. Interestingly, the index exhibits a pattern that seems to be consistent with the business cycle: there is steady hill-climbing between 1994 and 2000, and considerable downward movement afterwards. We examine its quantitative significance in the next section.

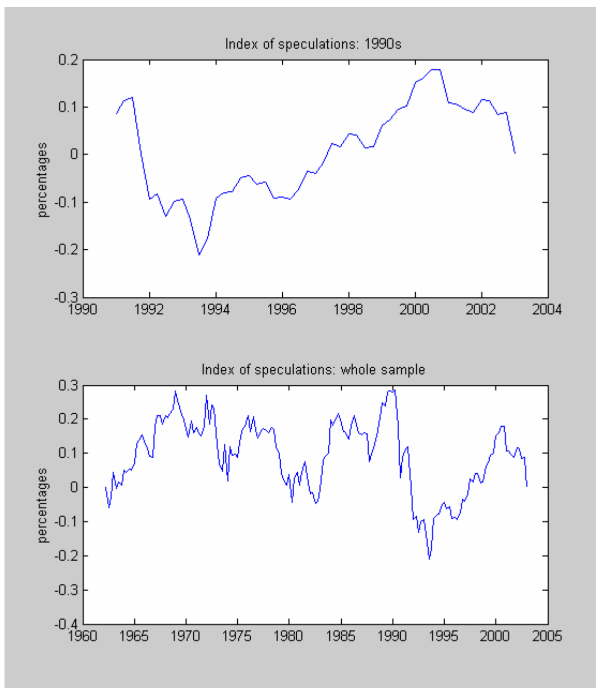

Figure 5: Constructed Index of Speculations

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 solely by productivity shocks. 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 period is 1.57% 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 fails to generate the economic dynamics of the 1990s in two aspects: first, it predicts a recession during 1993-1995, which did not happen in reality; second, the model cannot predict the recession of 2000-2001. GDP declines slightly in the second half of 2000, but quickly recovers. A look back at Figure 4 reveals that the movements in productivity are the primary cause of such predictions. The predicted recession in 1993-1995 is clearly driven by the decrease of productivity growth in 1993 and 1994. The model responds robustly to this, and predicts declines in GDP for almost 8 quarters. Likewise, there is no obvious downturn in productivity in 2001, which is responsible for the model's failure to account for the recession. However, if we look only at the period 1995-2000, the model's predictions seem reasonably good: it does predict a long period of economic expansion, along with an increasing investment-output ratio (lower panel of Figure 6).

The lower panel of Figure 6 plots the investment-output ratios of the artificial and the real economies. In the plot, the actual I-Y ratio (dotted line) swings from 12% to 19.5% between 1991 and 2000, while the predicted I-Y ratio only changes by about 1.2% (solid line). Note that this discrepancy is largely due to the limitations of the neoclassical model itself: the model is simulated around its steady state in response to small shocks, which predicts a standard deviation of around 3.5% for investment and 1.3% for output to match the data. Therefore it is impossible for the I-Y ratio to display fluctuations as large as in the real data.[8] The real disappointment, however, is that the model does not capture the "pattern" of investment movement 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 2001. In 2001, there is a small drop in the ratio, but soon after it increases again, running in the opposite direction as the real data.

In Figure 7 we show some results to demonstrate the robustness of the above findings. The upper left panel shows the predictions of the same experiment, with

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

[8] In the real data the I-Y ratio is also slightly trended, which the RBC model cannot capture.

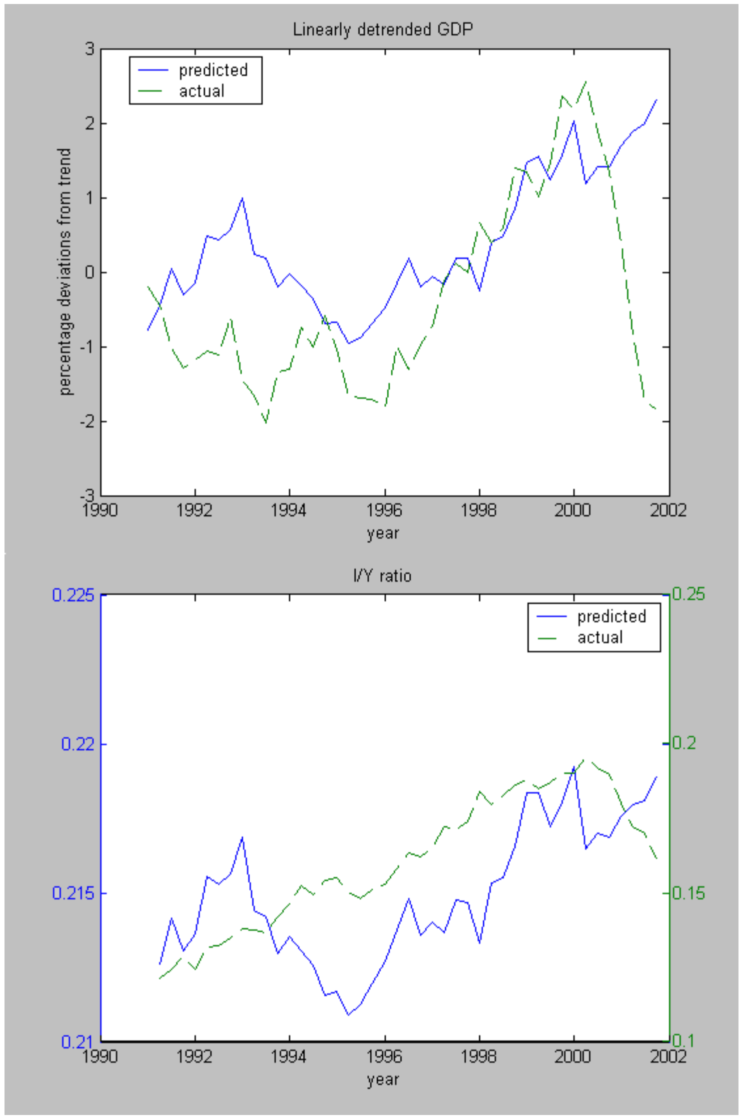

Figure 6: The 1990s in the Productivity-Driven Model. Upper panel: plots of predicted and actual detrended GDPs. Lower panel: plots of predicted and acutal I-Y ratios on different scales.

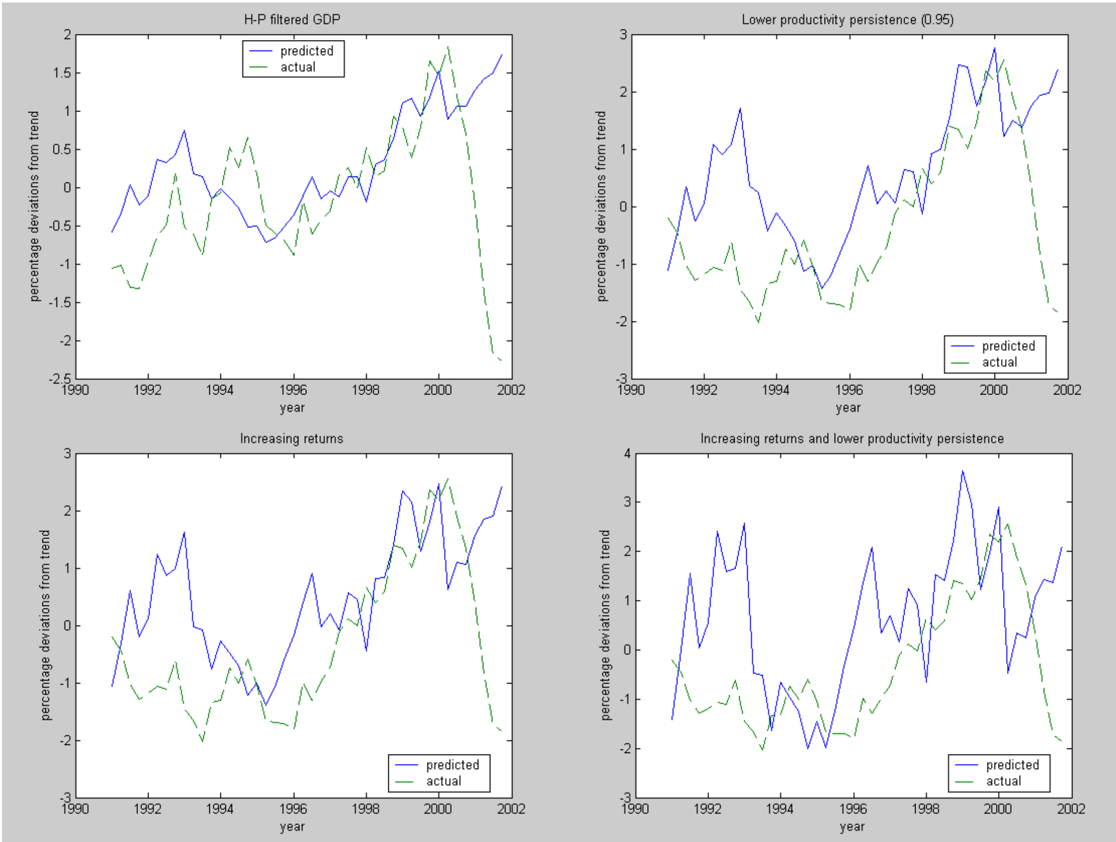

Figure 7: The 1990s in the Productivity Driven Model (Robustness). Upper left: the data are H-P filtered. Upper right: persistence of productivity shocks is 0.95. Lower left: increasing returns = 1.1. Lower right: increasing returns = 1.1, and persistence = 0.95.

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 illustrates 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 most frequently used 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 determinate; 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 overestimate the economic downturn between 1993-1995, and underestimate the recession of 2000-2001.

These results suggest that productivity alone cannot explain the economic dynamics of the 1990s, at least in the neoclassical framework that we are interested in. Therefore, we 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 the experiments, we let the economy be solely driven by speculative shocks. This will allow us to 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, and the economy goes into a recession; both the expansion and the recession are very much investment-driven (lower panel of Figure 8).

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

The lower panel of Figure 8 shows the investment-output ratios for the predicted and actual economies. While the predicted I-Y ratios still do not exactly match the sizes of the actual ratios, they outperform the predictions of model 1 in two respects. First, the predicted I-Y ratios follow the ups and downs of the actual I-Y ratios quite well. There is a steady increase in the ratio during 1995-2000, followed by a sharp decline. Second, there are more investment fluctuations in comparison to model 1. The gap between the highest and the lowest predicted I-Y ratio is around 3.5%, which is more than twice the size of the range predicted by model 1.

It is useful to recall what drives investment movements in a standard RBC model and in the speculation model. When there is a positive shock to productivity in the RBC model, current and expected output increase (z_t is an argument of the production function), along with the returns to capital. Consumers optimally increase their savings, which leads to increased investment. Therefore, the productivity shock drives both investment and output. The mechanism for investment to directly affect output is not very strong. In the speculation model, a speculative shock first raises investment x_t (see equation 21), which in turn increases the capital stock and output. Here the economy is much more directly driven by investment. We believe this is the primary reason for the speculation model's better match with reality.

The dynamics of sunspot-driven economies are sometimes sensitive to the level of increasing returns, since different values imply different eigenvalues for the transitional matrix and hence different frequencies of the simulated data. We test the sensitivity of the above results by simulating the model under four different sets of parameters for the levels of externality: $\eta_1 = 0$, $\eta_2 = 0.2; \eta_1 = 0.1, \eta_2 = 0.2; \eta_1 =$

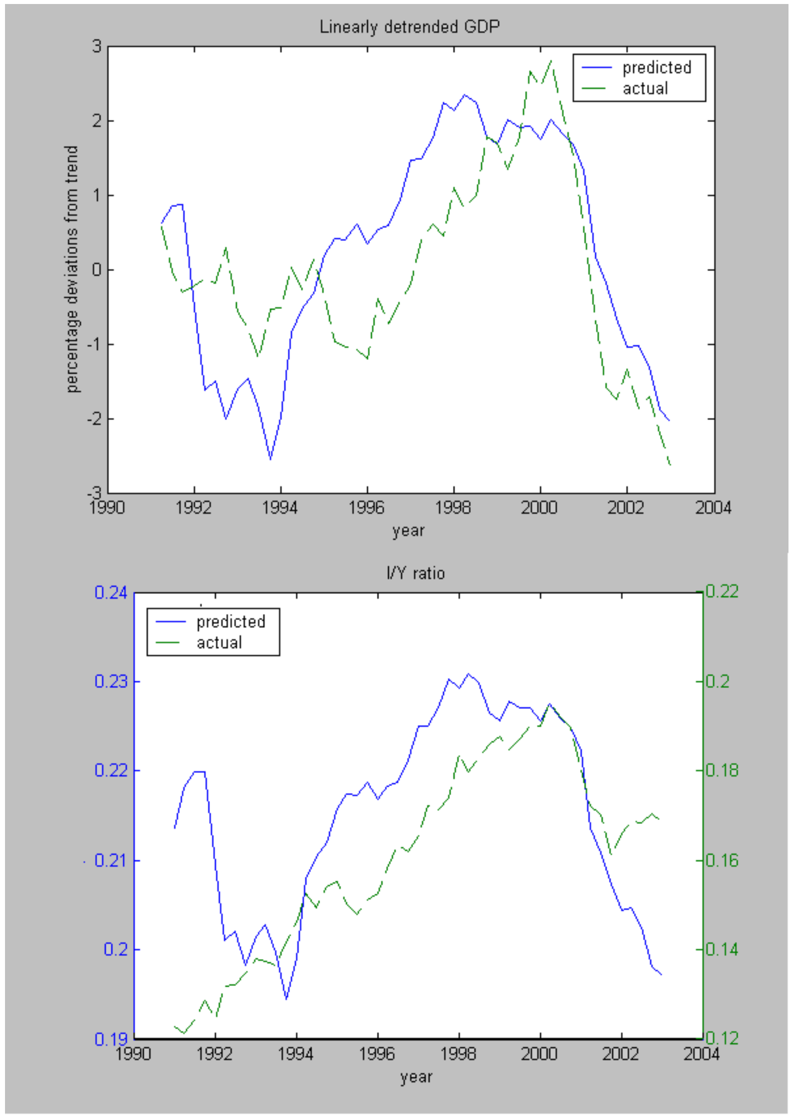

Figure 8: The 1990s in the Speculation-Driven Model. Upper panel: plots of predicted and actual detrended GDPs. Lower panel: plots of predicted and acutal I-Y ratios on different scales.

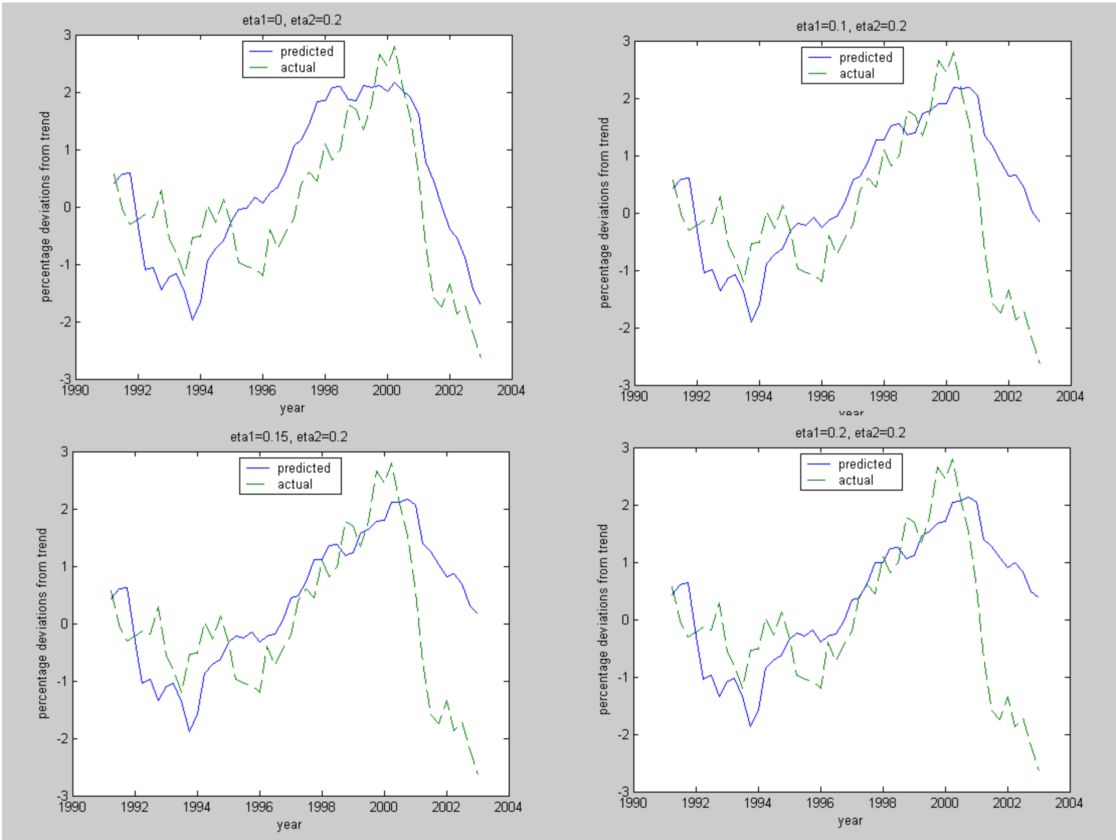

Figure 9: The 1990s in the Speculation-Driven Model (Robustness). Upper left: $\eta_1 = 0, \eta_2 = 0.2$. Upper right: $\eta_1 = 0.1, \eta_2 = 0.2$. Lower left: $\eta_1 = 0.15, \eta_2 = 0.2$. Lower right: $\eta_1 = \eta_2 = 0.2$.

$0.15, \eta_2 = 0.2$; and $\eta_1 = \eta_2 = 0.2$. These in turn imply returns to scale of 1.14, 1.17, 1.185 and 1.2. The results are displayed in Figure 9. In all four settings, the model correctly predicts the three features of the data, with varying degrees of accuracy.

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

Table 2: Results of VAR Estimation (output equation)

A. Granger Causality Test ($\overline{R}^2 = 0.856, \sigma = 0.0001$)			
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. s_t: speculation index.

model with productivity shocks being the only driving force. The results are shown in Figure 10. The predicted GDP does not match the movement of actual real GDP. The predicted I-Y ratio does have the "peaky" shape this time, but the peak is in 1995 rather than in 2000, and the I-Y ratio trends upwards between 2000 and 2002, which is exactly counterfactual. We conclude that sunspot shocks are very important in terms of replicating the economic 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 structural model, the VAR specification is simple: we include detrended real GDP and the two exogenous processes, the speculation index (s_t) and productivity (z_t), in the regression, and use one 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 does not cause changes in GDP is rejected at the 5% level, while the hypothesis that productivity does not cause changes in GDP cannot be rejected with an F probability of 0.3. Panel B shows that speculation residuals can account for 8.1%, 20.6%, and 31.2% 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% of GDP forecast errors for the same time horizon.

6 Conclusion

In this paper we use a modified neoclassical business cycle model to study the nature 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

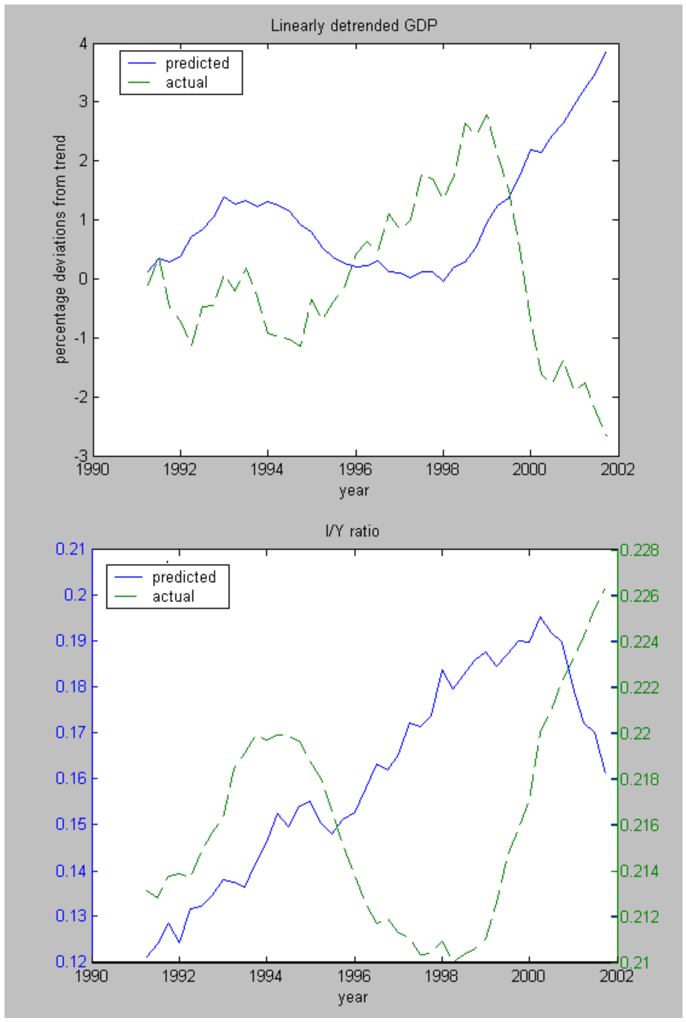

Figure 10: The Indeterminacy Model Driven by Productivity Shocks. Upper panel: plots of predicted and actual detrended GDPs. Lower panel: plots of predicted and acutal I-Y ratios on different scales.

equilibria. We fit series of estimated speculative and productivity shocks into the model and compare its predictions with empirical data. Our results suggest that the speculation-driven model has more explanatory power in terms of explaining the U.S. 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.

It should be stressed that the goal of this paper is not to exhaust all alternative explanations of the 1990s and find the best one. Indeed, the model that we use to contrast the sunspot-driven hypothesis is the RBC model in its simplest form. It is likely that a more sophisticated version of the RBC model, driven by fundamental shocks, can be constructed to yield a better fit with the data. For example, one may consider an RBC model with two shocks: an increase in the early to mid 1990s in both productivity growth and perceptions of such growth, and a downward revision in the late 1990s in estimates of the size of the increase in productivity growth. Alternatively, one could also incorporate exogenous shocks to the marginal efficiency of investment, which are known to affect business cycles (Greenwood et al., 1988). Since such shocks affect investment directly, the economy will definitely become more "investment-driven." These modified models might well demonstrate that fundamental shocks are also important for the 1990s. Since the point of the paper is to highlight the importance of speculative shocks, we do not pursue those alternatives here.

Our results are no doubt also 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 underlying long term growth trend is determined by productivity growth, our results *do not* suggest that technological progress is unimportant for the growth of the 1990s. Instead, they suggest that temporary variations in technological growth are not sufficient to account for the short-run economic fluctuations of that historical period.

7 Appendix: Data Sources

The data used in the tables and figures were taken from several different sources. The following U.S. data were taken from the Federal Reserve Bank of St. Louis' FRED II database (with original index ID in parentheses): real gross domestic product (GDPC1), real fixed private domestic investment (GPDIC1), capacity utilization rate of manufacturing firms (NAICS), average weekly hours of private nonagricultural establishments (AWHNONAG), civilian employment: sixteen years & over (CE16OV), M2 money stock (M2SL), the effective federal funds rate (FEDFUNDS), civilian unemployment rate (UNRATE), U.S. 3-month Treasury Bill rate (MUS3M), the consumer price index for all urban consumers (CPIAUCSL), and real government consumption expenditures and investment (GCEC1). The U.S.

10-year treasury bond rate and the S&P 500 index were taken from the database of www.freelunch.com. The data span the first quarter of 1967 to the first quarter of 2003. All monthly data were converted to quarterly data by taking averages. Total capital stock (the sum of total residential and non-residential fixed assets plus consumer durable goods) was taken from the database of the Bureau of Economic Analysis. The original capital data was annual, and we have used the INTERPOL method in TSP to convert them into quarterly data. This data span the first quarter of 1967 to the last quarter of 2001. The index of consumer sentiment (CSI) was taken from the Survey Research Center of the University of Michigan. The monthly data were converted to quarterly data by taking averages. Stock and Watson's leading economic indicators are published on Watson's website (http://www.wws.princeton.edu/~mwatson/). Japan's gross domestic product, gross fixed capital formation, and GDP deflator were taken from the IMF's *International Financial Statistics*. We used the three series to produce real GDP and real physical investment for Japan.

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