Monetary Policy and Stock Market Boom-Bust Cycles*

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

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Abstract

We explore the dynamic effects of news about a future technology improvement which turns out ex post to be overoptimistic. We find that it is difficult to generate a boom-bust cycle (a period in which stock prices, consumption, investment and employment all rise and then crash) in response to such a news shock, using a standard real business cycle model. However, a monetized version of the model with sticky prices and a standard Taylor-rule specification of monetary policy very naturally generates a boom-bust cycle in response to an overoptimistic news shock. This raises the possibility that monetary policy may have been a factor in past stockmarket boom-bust cycles.

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†Northwestern University and National Bureau of Economic Research
‡European Central Bank
§European Central Bank

1. Introduction

Inflation has receded from center stage as a major problem, and attention has shifted to other concerns. One concern that has received increased attention is volatility in asset markets. A look at the data reveals the reason. Figure 1 displays monthly observations on the S&P500 (converted into real terms using the CPI) for the period 1870 to early 2006. Note the recent dramatic boom and bust. Two other pronounced "boom-bust" episodes are evident: the one that begins in the early 1920s and busts near the start of the Great Depression, and another one that begins in the mid 1950s and busts in the 1970s. These observations raise several questions. What are the basic forces driving the boom-bust episodes? Are they driven by economic fundamentals, or are they bubbles? The boom phase is associated with strong output, employment, consumption and investment, while there is substantial economic weakness (in one case, the biggest recorded recession in US history) in the bust phase. Does this association reflect causality going from volatility in the stock market to the real economy, or does causality go the other way? Or, is it that both are the outcome of some other factor, say the nature of monetary policy? The analysis of this paper lends support to the latter hypothesis.

We study models that have been useful in the analysis of US and Euro Area business cycles. We adopt the fundamentals perspective on boom-busts suggested by the work of Beaudry and Portier (2000,2003,2004) and recently extended in the analysis of Jaimovich and Rebelo (2006). The idea is that the boom phase is triggered by a signal which leads agents to rationally expect an improvement in technology in the future. Although the signal agents see is informative, it is not perfect. Occasionally, the signal turns out to be false and the bust phase of the cycle begins when people find this out. As an example, we have in mind the signals that led firms to invest heavily in fiber-optic cable, only to be disappointed later by low profits. Another example is the signals that led Motorola to launch satellites into orbit in the expectation (later disappointed) that the satellites would be profitable as cell phone usage expanded. Although our analysis is based on rational expectations, we suspect that the same basic results would go through under other theories of how agents can become optimistic in ways that turn out ex post to be exaggerated.

Our notion of what triggers a boom-bust cycle is very stylized: the signal occurs on a particular date and people learn that it is exactly false on another particular date. In more realistic scenarios, people form expectations based on an accumulation of various signals. If people's expectations are in fact overoptimistic, they come to this realization only slowly and over time. Although the trigger of the boom-bust cycle in our analysis is in some ways simplistic, it has the advantage of allowing us to highlight a result that we think is likely to survive in more realistic settings. We find that - within the confines of the set of models we consider - it is hard to account for a boom-bust episode (an episode in which consumption, investment, output, employment and the stock market all rise sharply and then crash) without introducing nominal variables and an inflation-targeting central bank. In our environment, inflation targeting suboptimally converts what would otherwise be a small fluctuation into a major boom-bust episode.

The notion that inflation targeting increases the likelihood of stock market boom-bust episodes contradicts conventional wisdom. We take it that the conventional wisdom is defined by the work of Bernanke and Gertler (2000), who argue that an inflation-targeting monetary authority automatically stabilizes the stock market. The reason for this is that in the Bernanke-Gertler environment, inflation tends to rise in a stock market boom, so that an inflation targeter would raise interest rates, moderating the rise in stock prices.

In our model environment, inflation falls during a boom. To be sure, the rise in consumption and investment in the wake of the signal exert upward pressure on inflation by way of the usual demand effects.[1] However, the signal of strong future technology also generates a countervailing downward pressure on prices. This is because (i) in our model firms are subject to price-setting frictions (as in Calvo), and this gives them an incentive to set prices in part as a function of future marginal costs; and (ii) the signal of strong future technology creates the expectation that marginal costs will be lower in the future. It turns out that for standard model parameter values, the countervailing downward pressure on prices dominates. This is why inflation is low during the boom phase of a boom-bust cycle in our model. An inflation targeting central bank, seeing the low inflation, implements an expansionary monetary policy. This expansionary monetary action then amplifies the boom-bust in our model.

So, the behavior of inflation in the boom phase of a boom-bust cycle is the crucial factor that distinguishes our story from the conventional wisdom. To assess the two perspectives, consider Figure 2, which displays annual average inflation in the period since 1870. Before the 1920s inflation was extremely volatile. But

[1] That is, the strong current demand, in the absence of any current improvement in technology, requires more intensive utilization of labor. At given wage rates, falling labor productivity implies higher marginal costs of production and is the source of the upward pressure on prices. This effect is amplified by a rise in the equilibrium wage.

afterward, as long as we smooth inflation a little, a pattern emerges.[2] For this, see Figure 3, which shows stock prices and smoothed inflation in the post 1919 period (both variables have been scaled for ease of comparison). Although inflation was still somewhat volatile in the decade before the Great Depression, inflation is clearly falling after 1925, during the boom years. In terms of the next episode, at the very start of the bull market in the mid 1950s, inflation was low and falling. This is also the case for the bull market in the 1990s, which actually began in the early 1980s. In addition to this evidence, it is also well known that inflation was low in another boom-bust cycle, the one that occurred in Japan in the 1980s and early 1990s. In sum, the proposition that inflation is weak during the boom phase of boom-bust cycles receives support from US and Japanese data.

So far, we have stressed that integrating nominal variables and inflation targeting into the analysis is merely helpful for understanding boom-bust episodes. In fact, we find that it is essential.

To clarify this point, it is useful to think of the standard real business cycle model that emerges when we strip away all monetary factors from our model. If we take a completely standard version of such a model, a signal shock is completely incapable of generating a boom-bust that resembles anything like what we see. Households in effect react to the signal by going on vacation: consumption jumps, work goes down and investment falls. When households realize the expected shock will not occur they in effect find themselves in a situation with a low initial capital stock. The dynamic response to this is familiar: they increase employment and investment and reduce consumption. We identify the price of equity in the data with the price of capital in the model. In the simplest version of the real business cycle model this is fixed by technology at unity, so we have no movements in the stock prices. It is hard to imagine a less successful model of a boom-bust cycle!

We then add habit persistence and costs of adjusting the flow of investment (these are two features that have been found useful for understanding postwar business cycles) and find that we make substantial progress towards a successful model. However, this model also has a major failing that initially came to us as a surprise: in the boom phase of the cycle, stock prices in the model fall and in the bust phase they rise. The reason for this counterfactual implication is simple. Investment expands in response to the signal about future productivity because agents expect investment to be high in the future, when technology is high. Under these circumstances, the strategy of cutting investment now and raising it in the

[2] The smoothed monthly data after 1919 is the inflation trend implied by application of the Hodrick-Prescott filter to inflation, with a smoothing parameter of 5,000.

future when technology is high is inefficient because it entails heavy adjustment costs in the future. In effect, high expected future investment adds an extra payoff to current investment in the form of reduced future adjustment costs. This corresponds to a reduction in the current marginal cost of producing capital goods. In a competitive market, this reduction in marginal cost is passed on to consumers in the form of a lower price.

So, our real business cycle model cannot simultaneously generate a rise in the price of capital and a rise in investment, in response to a signal about future productivity. The real business cycle model has two additional shortcomings. It generates an extremely large jump in the real interest rate and it generates very little persistence. It really only generates a boom-bust pattern in consumption, investment, employment and output when the signal is about a shock that will occur four quarters in the future. If the signal is about a shock, say, 12 quarters in the future, agents go on an 8 quarter vacation and then begin working roughly in the 9th quarter. But, as we see in Figure 1, stock market booms last considerably longer than one year. So, while a real model gets us part way in understanding a boom-bust cycle, there are significant shortcomings.

When we introduce monetary factors and an inflation targeting central bank, these shortcomings disappear. The monetary expansion produced in the wake of a signal about higher future productivity generates a boom in the stock price. The monetary response is associated with very little volatility in the real interest rate, and the boom bust cycle is highly persistent. In addition, the monetary response greatly amplifies the magnitude of fluctuations in real quantities. Actually the boom-bust produced in the monetary model is so much larger than it is in the real business cycle model that it is not an exaggeration to say that our boom-bust episode is primarily a monetary phenomenon.

After analyzing the simple monetary model, we move on to the full monetary model of Christiano, Motto and Rostagno(2006). That model incorporates a banking sector and the financial frictions in Bernanke, Gertler and Gilchrist (1999). This model is interesting for two reasons. First, we use the model to investigate the robustness of our findings for boom-busts. We feed the model the same signal about future technology that turns out to be false that we fed to our real business cycle and simple monetary models. We find that the full and simple monetary models behave quite similarly. The second reason it is interesting to study boom-bust episodes in the Christiano, Motto and Rostagno(2006) model is that the model has implications for different monetary aggregates as well as credit. Discussions of boom-bust cycles often focus on the behavior of money and credit during a boom. These discussions often emphasize the importance of distinguishing between money and credit (see, for example, Eichengreen and Mitchener (2003)). They show, for example, that credit grew very rapidly during the 1920s, but M2 showed weak and declining growth. Interestingly, when we feed the signal shock to the model of Christiano, Motto and Rostagno(2006) we find that credit rises strongly during the boom, though the predictions are ambiguous for the monetary aggregates, with some showing strength and others weakness. This is broadly consistent with some existing empirical studies.

Our analysis has more general implications. It is already well known that monetary policy plays an important role in the transmission of fundamental shocks. We can add that monetary policy is also very important in the transmission of expectational shocks.

Following is a brief outline of the paper. The second section below describes the real business cycle version of our model in which all monetary factors have been stripped away. Numerical simulations are used to develop the model's implications for boom-bust cycles. Section 3 introduces the smallest number of monetary factors that will allow the model to successfully generate a boom-bust cycle. In this simple monetary model, monetary policy is assumed to follow a Taylor rule, which has been estimated using post war US data. This Taylor rule places positive weight on the output gap and incorporates 'interest smoothing' in that the interest rate is also a function of the lagged interest rate. The monetary policy rule is an inflation targeting rule in the sense that the coefficient on expected inflation satisfies the 'Taylor Principle' in being larger than unity. In our estimate, it is 1.95. At this writing, this section is incomplete because we have not yet computed the Ramsey equilibrium for this model. Because the amplitude of fluctuation of variables in the boom-bust cycle of the simple monetary model is so much greater than it is in the real business cycle model, we conjecture that the boom-bust in the monetary model is inefficient in a welfare sense. To formally establish this requires examining the Ramsey equilibrium of the simple monetary model. Section 4 presents the implications for a boom-bust model of the full model monetary model whose pieces have been studied up to now. The paper closes with a brief conclusion.

2. Real Business Cycle Model

This section explores the limits of a simple Real Business Cycle explanation of a boom-bust episode. We show that preferences and investment adjustment costs that have become standard in successful empirical models of business cycles move us part way to a full qualitative explanation of a boom-bust episode. However, we are not successful producing a rise in the price of capital in the boom phase of the cycle. In addition, we will see that it is hard to generate a boom that is much longer than one year. Finally, we will see that the model generates extreme fluctuations in the real rate of interest.

2.1. The Model

The preferences of the representative household are given by:

$$E_t \sum_{l=0}^{\infty} \beta^{l-t} \{\log(C_{t+l} - bC_{t+l-1}) - \psi_L \frac{h_t^{1+\sigma_L}}{1+\sigma_L}\}$$

Here, h_t is hours worked, C_t is consumption and the amount of time that is available is unity. When $b > 0$ then there is habit persistence in preferences. The resource constraint is

$$I_t + C_t \leq Y_t, \tag{2.1}$$

where I_t is investment, C_t is consumption and Y_t is output of goods.

Output Y_t is produced using the technology

$$Y_t = \epsilon_t K_t^{\alpha} \left(z_t h_t \right)^{1-\alpha}, \tag{2.2}$$

where ϵ_t represents a stochastic shock to technology and z_t follows a deterministic growth path,

$$z_t = z_{t-1} \exp\left(\mu_z\right). \tag{2.3}$$

The law of motion of ϵ_t will be described shortly.

We consider two specifications of adjustment costs in investment. According to one, adjustment costs are in terms of the change in the flow of investment:

$$K_{t+1} = (1-\delta)K_t + (1 - S\left(\frac{I_t}{I_{t-1}}\right))I_t, \tag{2.4}$$

where

$$S\left(x\right) = \frac{a}{2}\left(x - \exp\left(\mu_z\right)\right)^2,$$

with $a > 0$. We refer to this specification of adjustment costs as the ‘flow specification’. In our second model of investment the adjustment costs are in terms of the level of investment:

$$K_{t+1} = (1-\delta) K_t + I_t - \Phi\left(\frac{I_t}{K_t}\right) K_t, \tag{2.5}$$

where

$$\Phi\left(\frac{I_t}{K_t}\right) = \frac{1}{2\delta\sigma_\Phi}\left(\frac{I_t}{K_t} - \eta\right)^2, \tag{2.6}$$

where η is the steady state investment to capital ratio. Here, the parameter, $\sigma_\Phi > 0$, is the elasticity of the investment-capital ratio with respect to Tobin's q. We refer to this specification of adjustment costs as the 'level specification'.

Throughout the analysis, we consider the following impulse. Up until period 1, the economy is in a steady state. In period $t = 1$, a signal occurs which suggests ϵ_t will be high in period $t = 1+p$. But, when period $1+p$ occurs, the expected rise in technology in fact does not happen. A time series representation for ϵ_t which captures this possibility is:

$$\log \epsilon_t = \rho \log \epsilon_{t-1} + \varepsilon_{t-p} + \xi_t, \tag{2.7}$$

where ε_t and ξ_t are uncorrelated over time and with each other. For example, suppose $p = 1$. Then, if the realized value of ε_1 is high value, this shifts up the expected value of $\log \epsilon_2$. But, if $\xi_2 = -\varepsilon_1$, then the high expected value of $\log \epsilon_2$ does not materialize.

We consider the following parameterization,

$$\begin{aligned} \beta &= 1.01358^{-0.25},\ \mu_z = 1.0136^{0.25},\ b = 0.63,\ a = 15.1, \\ \alpha &= 0.40,\ \delta = 0.025,\ \psi_L = 109.82,\ \sigma_L = 1,\ \rho = 0.83,\ p = 4. \end{aligned}$$

The steady state of the model associated with these parameters is:

$$\frac{C}{Y} = 0.64,\ \frac{K}{Y} = 12.59,\ l = 0.092$$

We interpret the time unit of the model as being one quarter. This model is a special case of the model estimated in Christiano, Motto and Rostagno (2006) using US data. In the above list, the parameters a and ρ were estimated; μ_z was estimated based on the average growth rate of output; β was selected so that given μ_z the model matches the average real return on three-month Treasury bills; σ_L was simply set to produce a Frish labor supply of unity; b was taken from Christiano, Eichenbaum and Evans (2004); α and δ were chosen to allow the model to match several ratios (see Christiano, Motto and Rostagno (2006)).

2.2. Results

Consider the line with circles in Figure 4. This line displays the response of the 'Baseline RBC' model to a signal in period 1 that technology will jump in period 5 by 1 percent. Then, $\xi_5 = -0.01$, so that the impact of the signal on ϵ_t is cancelled and no change ever happens to actual technology. Note how in the figure output, investment and hours worked all rise until period 4 and then slowly decline. The price of capital falls despite the anticipated rise in the payoff associated with capital. This fall is discussed in further detail below, although perhaps it is not surprising in view of the spike in the interest rate on one period consumption loans taken in period 4. This jump in the interest rate is extraordinarily large. In the period before the anticipated jump in technology, the real rate jumps by more than 10 percentage points, at an annual rate.

The solid line in Figure 4 and the results in Figures 5-8 allow us to diagnose the economics underlying the line with circles in Figure 4. In Figures 5-8, the circled line in Figure 4 is reproduced for comparison. The solid line in Figure 4 displays the response of the variables in the case when the technology shock is realized. This shows the scenario which agents expect when they see the signal in period 1. Their response has several interesting features. First, the rise in investment in period 4, the first period in which investment can benefit from the higher expected rate of return, is not especially larger than the rise in other periods, such as period 5. We suspect that the failure of investment to rise more in period 4 reflects the consumption smoothing motive. Period 4 is a period of relatively low productivity, and while high investment then would benefit from the high period 5 rate of return, raising investment in period 4 is costly in terms of consumption. The very high period 4 real interest rate is an indicator of just how costly consumption then is. Second, hours worked drops sharply in the period when the technology shock is realized. The drop in employment in our simulation reflects the importance of the wealth effect on labor. This wealth effect is not felt in periods before 5 because of high interest rate before then. Commenting on an earlier draft of our work, Jaimovich and Rebelo (2006) conjecture that this drop is counterfactual, and they propose an alternative specification of utility in which it does not occur. An alternative possibility is that the sharp movement in employment reflects the absence of labor market frictions in our model. For example, we suspect that if we incorporate a simple model of labor search frictions the drop in employment will be greatly attenuated while the basic message of the paper will be unaffected (see Blanchard and Gali (2006)).

Figure 5 allows us to assess the role of habit persistence in the responses in

Figure 4. Three things are worth emphasizing based on this figure. First, Figure 5 shows that $b > 0$ is a key reason why consumption rises in periods before period 5 in Figure 4. Households, understanding that in period 5 they will want to consume at a high level, experience a jump in the marginal utility of consumption in earlier periods because of habit persistence. This can be seen in the expression for the marginal utility of period t consumption, λ_t, which is increasing in future consumption:

$$\lambda_t = \frac{1}{C_t - bC_{t-1}} - b\beta E_t \frac{1}{C_{t+1} - bC_t}. \tag{2.8}$$

Second, the early jump in the marginal utility of consumption induced by the presence of habit persistence also explains why the employment response to the technology signal is relatively strong in the presence of habit persistence (the bottom left graph in Figure 5). To see this, consider the intratemporal Euler equation:

$$\lambda_t \times MPL_t = MUL_t, \tag{2.9}$$

where MPL_t denotes the marginal product of labor and MUL_t denotes the marginal utility of leisure. From this expression it is clear that with a normal specification of preferences, it is not possible for both consumption and labor to rise in response to a future technology shock. The rise in labor would reduce MPL_t and increase MUL_t, while the rise in consumption would ordinarily reduce λ_t.[3] With habit persistence, this logic is broken because the anticipated rise in $t + 1$ consumption raises λ_t. Third, note that the employment response without habit persistence, though weak, is positive. The reason for this is that in the absence of habit persistence, households find it optimal to reduce consumption in order to make room for an increase in investment. The fall in consumption raises λ_t and is the reason why employment rises in Figure 5, even when $b = 0$.

Figure 6 shows what happens when there are no adjustment costs in investment. In this case, there is no cost to the strategy of simply waiting until later to raise investment. This strategy has the advantage of permitting consumption smoothing. One way to see this is to note how the real rate of interest hardly moves when there are no investment adjustment costs.

Figure 7 shows what happens when we adopt the level specification of adjustment costs. With this specification, investment falls in response to the signal. This makes room for additional consumption which reduces λ_t and accounts for

[3]This logic was stressed by Barro and King (1984), who argued that it would be difficult to square the procylical movement of consumption and labor with the acyclical behavior of wages under standard preferences.

the weak response of employment after the signal (bottom left graph in Figure 7). So, Figure 7 indicates that the flow specification of adjustment costs in our baseline real business cycle model plays an important role in producing the responses in Figure 4.

A final experiment was motivated by the fact that in practice the boom phase of a boom-bust cycle often lasts considerably more than 4 quarters. To investigate whether the real business cycle model can generate a longer boom phase, we considered an example in which there is a period of 3 years from the date of the signal to the bust. Figure 8 displays simulation results for the case when $p = 12$. Notice that we have in fact not lengthened the boom phase very much because output, employment and investment actually only begin to rise about 4 quarters before the bust. In addition, the model no longer generates a rise in consumption in response to the signal. According to the figure, consumption falls (after a very brief rise) in the first 9 quarters. Evidently, households follow a strategy similar to the one in Figure 5, when there is no habit. There, consumption falls in order to increase the resources available for investment. Households with habit persistence do not mind following a similar strategy as long as they can do so over a long enough period of time. With time, habit stocks fall, thus mitigating the pain of reducing consumption.

2.3. The Price of Capital

To understand the response of the price of capital to a signal about future productivity, we study two model equations that characterize the dynamics of $P_{k',t}$. One equation is the present discounted value of future payoffs from capital. This is derived by focusing on the demand for capital. The other implication flows from the fact that capital is produced in the model, and corresponds to what is sometimes referred to as the model's Tobin's q relation.

Let μ_t denote the multiplier on (2.4) and λ_t the multiplier on the resource constraint in the Lagrangian representation of the planning problem. The first order conditions for consumption and labor are (2.8) and (2.9), respectively. The first order condition with respect to K_{t+1} is:

$$\mu_t = \beta \left[\lambda_{t+1} \alpha \left(K_{t+1} \right)^{\alpha - 1} \left(z_{t+1} h_{t+1} \right)^{1-\alpha} + \mu_{t+1} \left(1 - \delta \right) \right].$$

Note that the object on the right side of the equality is the marginal utility of an extra unit of K_{t+1}. It is tomorrow's marginal physical product of capital, converted to marginal utility terms by multiplying by λ_{t+1} plus the value of the undepreciated part of K_{t+1} that is left over for use in subsequent periods, which is converted into marginal utility terms by μ_{t+1}. Divide both sides of the first order condition for K_{t+1} with respect to λ_t and rearrange:

$$\frac{\mu_t}{\lambda_t} = \beta\frac{\lambda_{t+1}}{\lambda_t}\left[\alpha\left(K_{t+1}\right)^{\alpha-1}\left(z_{t+1}h_{t+1}\right)^{1-\alpha} + \frac{\mu_{t+1}}{\lambda_{t+1}}\left(1-\delta\right)\right].$$

Now, recall that μ_t is the marginal utility of K_{t+1}, loosely, dU/dK_{t+1}. Similarly, λ_t is the marginal utility of C_t, loosely dU/dC_t. Thus, the ratio is the consumption cost of a unit of K_{t+1}, or the price of capital, $P_{k',t}$:

$$P_{k',t} = \frac{\mu_t}{\lambda_t} = \frac{\frac{dU_t}{dK_{t+1}}}{\frac{dU_t}{dC_t}} = \frac{dC_t}{dK_{t+1}}.$$

Substituting this into the first order condition for K_{t+1}, we obtain:

$$P_{k',t} = E_t\frac{\beta\lambda_{t+1}}{\lambda_t}\left[r^k_{t+1}\alpha + P_{k',t+1}\left(1-\delta\right)\right],$$

where

$$r^k_{t+1} = \alpha\left(K_{t+1}\right)^{\alpha-1}\left(z_{t+1}h_{t+1}\right)^{1-\alpha}.$$

Iterating this expression forward, we obtain:

$$P_{k',t} = E_t\sum_{i=1}^{\infty}\left(\prod_{j=1}^{i}\frac{\beta\lambda_{t+j}}{\lambda_{t+j-1}}\right)\left(1-\delta\right)^{i-1}r^k_{t+i} \tag{2.10}$$

Focusing on the effect of the signal on future r^k_t's creates the expectation that $P_{k',t}$ should jump in response to a signal about future productivity. However, we saw in Figure 4 that the real interest rate jumps in response to such a signal, and this drives $P_{k',t}$ in the other direction. Since this expression highlights two conflicting forces on $P_{k',t}$, it is not particularly useful for understanding why it is that the force driving $P_{k',t}$ down dominates in our simulations.

We obtain the model's Tobin's q relation by working the first order condition for investment:

$$\begin{aligned} -\lambda_t + \mu_t(1 - S\left(\frac{I_t}{I_{t-1}}\right)) - \mu_t S'\left(\frac{I_t}{I_{t-1}}\right)\frac{I_t}{I_{t-1}} & \\ +\beta\mu_{t+1}S'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 &= 0. \end{aligned}$$

Rewriting this, taking into account the definition of the price of capital,

$$P_{K',t} = \frac{1 - \beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t} P_{K',t+1} \right] \left[S' \left(\frac{I_{t+1}}{I_t} \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right]}{1 - S \left(\frac{I_t}{I_{t-1}} \right) - S' \left(\frac{I_t}{I_{t-1}} \right) \frac{I_t}{I_{t-1}}}$$

The right side of the above expression is the marginal cost of an extra unit of capital. This marginal cost is the sum of two pieces. We see the first by ignoring the expression after the minus sign in the numerator. The resulting expression for $P_{K',t}$ is the usual marginal cost term that occurs with level adjustment costs. It is the ratio of the consumption cost of a unit of investment goods, dC_t/dI_t (which is unity), divided by the marginal productivity (in producing new capital) of an extra investment good, dK_{t+1}/dI_t. To see that this is indeed the marginal cost of producing new capital, note that this corresponds to

$$\frac{\frac{dC_t}{dI_t}}{\frac{dK_{t+1}}{dI_t}} = \frac{dC_t}{dK_{t+1}},$$

i.e., the consumption cost of capital. If we just focus on this part of (**??**), the puzzle about why $P_{K',t}$ drops during a boom only deepens. This is because, with the growth rate of investment high (see Figure 4, which shows that I_t/I_{t-1} is high for several periods), the first term after the equality should unambiguously be high during the boom. Both S and S' rise, and this by itself makes $P_{K',t}$ rise.

Now consider the other term in the numerator of (**??**). The term in square brackets unambiguously rises after a positive signal about future technology because future growth in investment increases both S and S'. The square bracketed term contributes to a fall in $P_{K',t}$. The intuition for this is straightforward. In the wake of a positive signal about productivity, producers of new capital understand that investment will be high in the future. When there are adjustment costs, this means that there is an extra benefit to investing today: the reduction of adjustment costs when investment is made high in the future. In a competitive market, suppliers of capital will respond to this by bidding down the price of capital. That is what happens in the equilibrium of our real business cycle model.

It is similar for the central planner, who understands that a signal about positive future technology implies that building more capital today generates a future 'kickback', in the form of reduced adjustment costs in the future. This kickback is properly thought of as a reduction to the marginal cost of producing current capital, and is fundamentally the reason the planner is motivated to increase current investment. This reasoning suggests to us that there will not be a simple perturbation of the real business cycle model which will generate a rise in investment and a rise in the price of capital after a signal about future technology. This motivates us to consider the monetary version of the model in the next subsection.

3. Introducing Nominal Features and an Inflation-Targeting Central Bank

We now modify our model to introduce monetary policy and wage/price frictions. In the first subsection below, we present the model. In the second subsection we present our numerical results.

3.1. Simple Monetary Model

To accommodate price-setting, we adopt the usual assumption that a representative final good producer manufactures final output using the following linear homogenous technology:

$$Y_t = \left[\int_0^1 Y_{jt}^{\frac{1}{\lambda_t}} dj \right]^{\lambda_f}, \ 1 \leq \lambda_f < \infty, \tag{3.1}$$

Intermediate good j is produced by a price-setting monopolist according to the following technology:

$$Y_{jt} = \begin{cases} \epsilon_t K_{jt}^{\alpha} \left(z_t l_{jt}\right)^{1-\alpha} - \Phi z_t & \text{if } \epsilon_t K_{jt}^{\alpha} \left(z_t l_{jt}\right)^{1-\alpha} > \Phi z_t \\ 0, & \text{otherwise} \end{cases}, \ 0 < \alpha < 1, \tag{3.2}$$

where Φz_t is a fixed cost and K_{jt} and l_{jt} denote the services of capital and homogeneous labor. Capital and labor services are hired in competitive markets at nominal prices, $P_t r_t^k$, and W_t, respectively.

In (3.2), the shock to technology, ϵ_t, has the time series representation in (2.7). We adopt a variant of Calvo sticky prices. In each period, t, a fraction of intermediate-goods firms, $1 - \xi_p$, can reoptimize their price. If the i^{th} firm in period t cannot reoptimize, then it sets price according to:

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

where

$$\tilde{\pi}_t = \pi_{t-1}^{\iota} \bar{\pi}^{1-\iota}. \tag{3.3}$$

Here, π_t denotes the gross rate of inflation, $\pi_t = P_t/P_{t-1}$, and $\bar{\pi}$ denotes steady state inflation. If the i^{th} firm is permitted to optimize its price at time t, it chooses $P_{i,t} = \tilde{P}_t$ to optimize discounted profits:

$$E_t \sum_{j=0}^{\infty} (\beta\xi_p)^j \lambda_{t+j} \left[P_{i,t+j} Y_{i,t+j} - P_{t+j} s_{t+j} \left(Y_{i,t+j} + \Phi z_{t+j}\right)\right]. \tag{3.4}$$

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

In this environment, firms set prices as an increasing function of marginal cost. A firm that has an opportunity to set price will take into account future marginal costs because of the possibility that they may not be able to reoptimize again soon.

We model the labor market in the way suggested by Erceg, Henderson and Levin (2000). The homogeneous labor employed by firms in (3.2) is produced from specialized labor inputs according to the following linear homogeneous technology:

$$l_t = \left[\int_0^1 (h_{t,i})^{\frac{1}{\lambda_w}} di\right]^{\lambda_w}, \ 1 \leq \lambda_w. \tag{3.5}$$

We suppose that this technology is operated by perfectly competitive labor contractors, who hire specialized labor from households at wage, W_{jt}, and sell homogenous labor services to the intermediate good firms at wage, W_t. Optimization by labor contractors leads to the following demand for $h_{t,i}$:

$$h_{t,i} = \left(\frac{W_{t,i}}{W_t}\right)^{\frac{\lambda_w}{1-\lambda_w}} l_t, \ 1 \leq \lambda_w. \tag{3.6}$$

The j^{th} household maximizes utility

$$E_t^j \sum_{l=0}^{\infty} \beta^{l-t} \left\{ u(C_{t+l} - bC_{t+l-1}) - \psi_L \frac{h_{t,j}^{1+\sigma_L}}{1+\sigma_L} - \upsilon \frac{\left(\frac{P_{t+l} C_{t+l}}{M_{t+l}^d}\right)^{1-\sigma_q}}{1-\sigma_q} \right\} \tag{3.7}$$

subject to the constraint

$$P_t \left(C_t + I_t\right) + M_{t+1}^d - M_t^d + T_{t+1} \leq W_{t,j} l_{t,j} + P_t r_t^k K_t + \left(1 + R_t^e\right) T_t + A_{j,t}, \tag{3.8}$$

where M_t^d denotes the household's beginning-of-period stock of money and T_t denotes nominal bonds issued in period $t-1$, which earn interest, R_t^e, in period t. This nominal interest rate is known at $t-1$. In the interest of simplifying, we suppose that υ in (3.7) is positive, but so small that the distortions to consumption, labor and capital first order conditions introduced by money can be ignored. Later, we will consider a model in which υ is chosen to match money velocity data. The j^{th} household is the monopoly supplier of differentiated labor, $h_{j,t}$, and it sets its wage rate subject to the same Calvo frictions faced by intermediate good producers in setting their prices. In particular, in any given period the j^{th} household can reoptimize its wage rate with probability, $1-\xi_w$. With probability ξ_w it cannot reoptimize, in which case it sets its wage rate as follows:

$$W_{j,t} = \tilde{\pi}_{w,t}\mu_z W_{j,t-1},$$

where

$$\tilde{\pi}_{w,t} \equiv (\pi_{t-1})^{\iota_w} \bar{\pi}^{1-\iota_w}. \tag{3.9}$$

In (3.8), the variable, $A_{j,t}$ denotes the net payoff from insurance contracts on the risk that a household cannot reoptimize its wage rate, W_t^j. The existence of these insurance contracts have the consequence that in equilibrium all households have the same level of consumption, capital and money holdings. We have imposed this equilibrium outcome on the notation by dropping the j subscript.

The household's problem is to maximize (3.7) subject to the demand for labor, (3.6), the Calvo wage-setting frictions, and (2.4). Households set their wage as an increasing function of the marginal cost of working. The presence of wage frictions leads households who have the opportunity to reoptimize their wage, to take into account future expected marginal costs.

The monetary authority controls the supply of money, M_t^s. It does so to implement a following Taylor rule. The target interest rate is:

$$R_{t+1}^* = \alpha_\pi \left[E_t\left(\pi_{t+1}\right) - \bar{\pi}\right] + \alpha_y \log\left(\frac{Y_t}{Y_t^+}\right),$$

where Y_t^+ is aggregate output on a nonstochastic steady state growth path. The monetary authority manipulates the money supply to ensure that the equilibrium nominal rate of interest, R_t, satisfies:

$$R_{t+1}^e = \rho_i R_t^e + (1-\rho_i) R_{t+1}^*. \tag{3.10}$$

The parameter values for the model are the ones in the real business cycle model, plus the following:

$$\begin{aligned}\lambda_f &= 1.20,\ \lambda_w = 1.05,\ \xi_p = 0.63,\ \xi_w = 0.81,\ \iota = 0.84,\\ \iota_w &= 0.13,\ \rho_i = 0.81,\ \alpha_\pi = 1.95,\ \alpha_y = 0.18.\end{aligned}$$

Our monetary model is a special case of a more general model which was estimated in US data in Christiano, Motto and Rostagno (2006). All but the first two parameters above were estimated there.

3.2. Results

Figure 9 displays the results of the response to a signal in period 1 about a shock in period 13 (indicated by the '*'), which ultimately does not occur. The results for the real business cycle model in Figure 8 are reproduced here to facilitate comparison. Both models have costs in adjusting the flow of investment, as well as habit persistence in consumption. The two models display strikingly different responses to the signal shock in period 1. First, the magnitude of the responses in output, hours, consumption and investment in the monetary model are more than three times what they are in the real business cycle model. Second, consumption booms in the immediate period after the signal. Third, the risk free rate moves by only a small amount, and it falls rather than rising as in the real business cycle model. Fourth, although inflation initially rises, eventually it falls rather sharply. Fifth, and perhaps most significantly, the stock price rises.

We now diagnose the reasons for the results in Figure 9. Figure 10 shows what happens when the rise in productivity being signalled is realized (for ease of comparison, Figures 10-15 repeat the simulation in Figure 9 of the simple monetary model). This shows the expectations that agents have as they respond to the signal. Note that they are expecting a much bigger and more persistent decline in the nominal interest rate than actually occurs in the equilibrium in Figure 9. Note too, that there is a sharp drop in employment when the technology shock is realized, as in the real business cycle model. This is similar to what we saw in the real business cycle analysis in Figure 4.

Figures 11 and 12 explores the role of sticky prices and wage in our analysis, by repeating our experiment twice. In one case, $\xi_p = 0.01$ and all other parameters are held fixed at their baseline levels. In the Figure 12, $\xi_w = 0.01$ and all other parameters are held constant. The experiments convey a strong message: sticky wages are crucial to our result, not sticky prices. When wages are flexible, the boom-bust in the simple monetary model closely resembles what it is in the real business cycle model. We verified that this result is not an artifact of the fact that ξ_p is smaller than ξ_w in our baseline parameterization. For example, when we set $\xi_p = 0.95$ and $\xi_w = 0.01$, the results for quantities are similar to what we see in Figure 12. We have not yet fully understood this result, which may be a challenge for the interpretation we provide in the introduction, which focusses on price setting by firms.

In Figures 13 and 14 we attempt to investigate the specific role played by policy in generating the boom-bust cycle. Figure 13 reports what happens when the monetary policy rule focuses less on inflation, by setting $\alpha_\pi = 1.05$. The real quantities now fluctuate much as they do in the real business cycle model. This is consistent with the message emphasized in the introduction, which emphasizes that monetary targeting is at the heart of our how the volatility in real variables in the model. At the same time, the perturbed model still displays a rise in stock prices, though only after a delay. And, significantly, the interest rate in the perturbed model looks much more expansionary than it does in the baseline simulation. This is further evidence that the intuition in the introduction is incomplete.

Figure 14 displays a different way of assessing the role of monetary policy in our equilibrium. This experiment focuses specifically on the impact of the sharp drop in the interest rate that agents expect according to the solid line in Figure 10. For this experiment, we add an iid monetary policy shock to the policy rule, (3.10). We suppose that the shock has the same time series representation as (2.7), except $\rho = 0$. We set $p = 10$, and considered a signal which creates the expectation that there will be a 100 basis point negative shock to the quarterly rate of interest in period 11. We imposed that that shock is in fact not realized. The idea is to create a policy-induced move in the actual interest rate, together with a prior expectation that the rate would fall even more. Figure 14 indicates that this anticipated monetary loosening creates a substantial boom right away in the model. The boom accounts for almost all of the boom-bust in the simple monetary model. The difference is roughly the size of the boom in the real business cycle model. The results in Figure 14 suggests the following loose characterization of our boom-bust result in the simple monetary model: the boom-bust cycle is the sum of what is predicted by the real business cycle model, plus the impact of a substantial future anticipated loosening in monetary policy.

In sum, analysis with the simple monetary model suggests that successfully generating a substantial boom-bust episode requires a monetary policy rule which assigns substantial weight to inflation and which incorporates sticky wages.

4. Full Monetary Model

We consider the full monetary model of Christiano, Motto and Rostagno(2006). That model incorporates a banking sector following Chari, Christiano, and Eichenbaum (1995) and the financial frictions in Bernanke, Gertler and Gilchrist (1999). In the model, there are two financing requirements: (i) intermediate good firms require funding in order to pay wages and capital rental costs and (ii) the capital is owned and rented out by entrepreneurs, who do not have enough wealth ('net worth') on their own to acquire the capital stock and so they must borrow. The working capital lending in (i) is financed by demand deposits issued by banks to households. The lending in (ii) is financed by savings deposits and time deposits issued to households. Demand deposits and savings deposits pay interest, but relatively little, because they generate utility services to households. Following Chari, Christiano, and Eichenbaum (1995), the provision of demand and savings deposits by banks requires that they use capital and labor resources, as well as reserves. Time deposits do not generate utility services. In addition to holding demand, savings and time deposits, households also hold currency because they generate utility services. Our measure of M1 in the model is the sum of currency plus demand deposits. Our broader measure of money (we could call it M2 or M3) is the sum of M1 and savings deposits. Total credit is the sum of the lending done in (i) and (ii). Credit differs from money in that it includes time deposits and does not include currency. Finally, the monetary base in the model is the sum of currency plus bank reserves. A key feature of the model that allow it to have contact with the literature on boom-busts is that it includes various monetary aggregates as well as credit, and that their are nontrivial differences between these aggregates.

Figure 15 displays the response of the full model to the signal shock, and includes the response of the simple model for ease of comparison. Note that the full model displays a weaker response, though qualitatively the results are similar. The bottom right figure displays the behavior net worth in response to the signal shock. Figure 16 displays the response of our monetary aggregates to the signal shock. The top left figure shows that the monetary base grows throughout the boom, but then falls in the period it is realized that the shock will not happen. M1 growth is strong throughout the expansion, while M3 growth falls consistently throughout the boom. Thus, the behavior of the monetary aggregates is inconsistent. However, credit growth is strong throughout the boom and remains high during the bust.

In sum, we have simulated the response to a signal shock of a model with considerably more frictions than those in our simple monetary model. The basic qualitative findings of our simple model are robust to this added complexity. Also, the full model generates interesting implications for different monetary aggregates as well as credit growth. We plan to investigate more carefully the economics underlying these implications, as well as compare more carefully our model implications with the corresponding evidence.

5. Implications for Further Research

The introduction laid out our basic argument, so there is no need to repeat it here. The argument laid out here is incomplete in at least three ways. First, the introduction stresses sticky prices as a fundamental mechanism through which an inflation targeting policy helps produce boom-bust episodes. However, the analysis suggests that wage frictions play a relatively more important role. This and other findings in our simulations suggest that the intuition in the introduction is incomplete. Second, throughout the analysis we presume that a large part of a boom-bust episode is sub-optimal in a welfare sense. This presumption is based on our finding that in a real business cycle version of the model, the volatility of variables in response to our signal shock is much smaller than it is in the monetary models. To formally evaluate our presumption requires computing the Ramsey equilibrium in our model and determining if it indeed does resemble the equilibrium of the real business cycle model more closely than that of the monetary models. Third, we plan to investigate the policy implications of the analysis. The analysis suggests that simple inflation targeting of the sort captured by our Taylor rule exposes the economy to the risk of a boom-bust episode. What sort of policy would yield superior results? Of course, the answer in the model studied here, with just one shock, is trivial: simply let monetary policy tighten in response to a variable (like credit) that comoves positively with the cycle. But, this answer is not interesting, because this response may be inappropriate when other shocks are taken into account. So, determining in an interesting way what the implications of our analysis are for policy requires incorporating additional shocks. In Christiano, Motto and Rostagno(2006) we have developed a model with a full complement of shocks and we plan to use the model for this purpose.

References

[1] Barro, Robert, and Robert King, 1984, 'Time Separable Preferences and Intertemporal Substitution Models of Business Cycles,' *Quarterly Journal of Economics*, 99 (4), pp. 817-39.

[2] Beaudry, Paul and Franck Portier, 2000, 'An Exploration into Pigou's Theory of Cycles,' Journal of Monetary Economics, University of British Columbia.

[3] Beaudry, Paul and Franck Portier, 2003, 'Expectationally Driven Booms and Busts in Equilibrium Cycle Models,' mimeo, University of British Columbia.

[4] Beaudry, Paul and Franck Portier, 2004, 'Stock Prices, News and Economic Fluctuations,' manuscript.

[5] Bernanke, Ben, and Mark Gertler, 2000, 'Monetary Policy and Asset Price Volatility,' NBER working paper number 7559.

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

[7] Blanchard, Olivier, and Jordi Galí, 2006, 'A New Keynesian Model with Unemployment,' manuscript.

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

[9] Christiano, Eichenbaum and Evans, 2004, 'Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy', *Journal of Political Economy.*

[10] Eichengreen, Barry, and Kris Mitchener, 2003, 'The Great Depression as a Credit Boom Gone Wrong,' Bank for International Settlements working paper no. 137.

[11] Erceg, Christopher, Dale Henderson, and Andrew Levin, 2000, 'Optimal Monetary Policy with Staggered Wage and Price Contracts,' *Journal of Monetary Economics*, 46, 281-313.

[12] Jaimovich, Nir, and Sergio Rebelo, 2006, ‘Do News Shocks Drive the Business Cycle?,’ Northwestern University.

Figure 1: S&P500 Divided by CPI (Shiller)

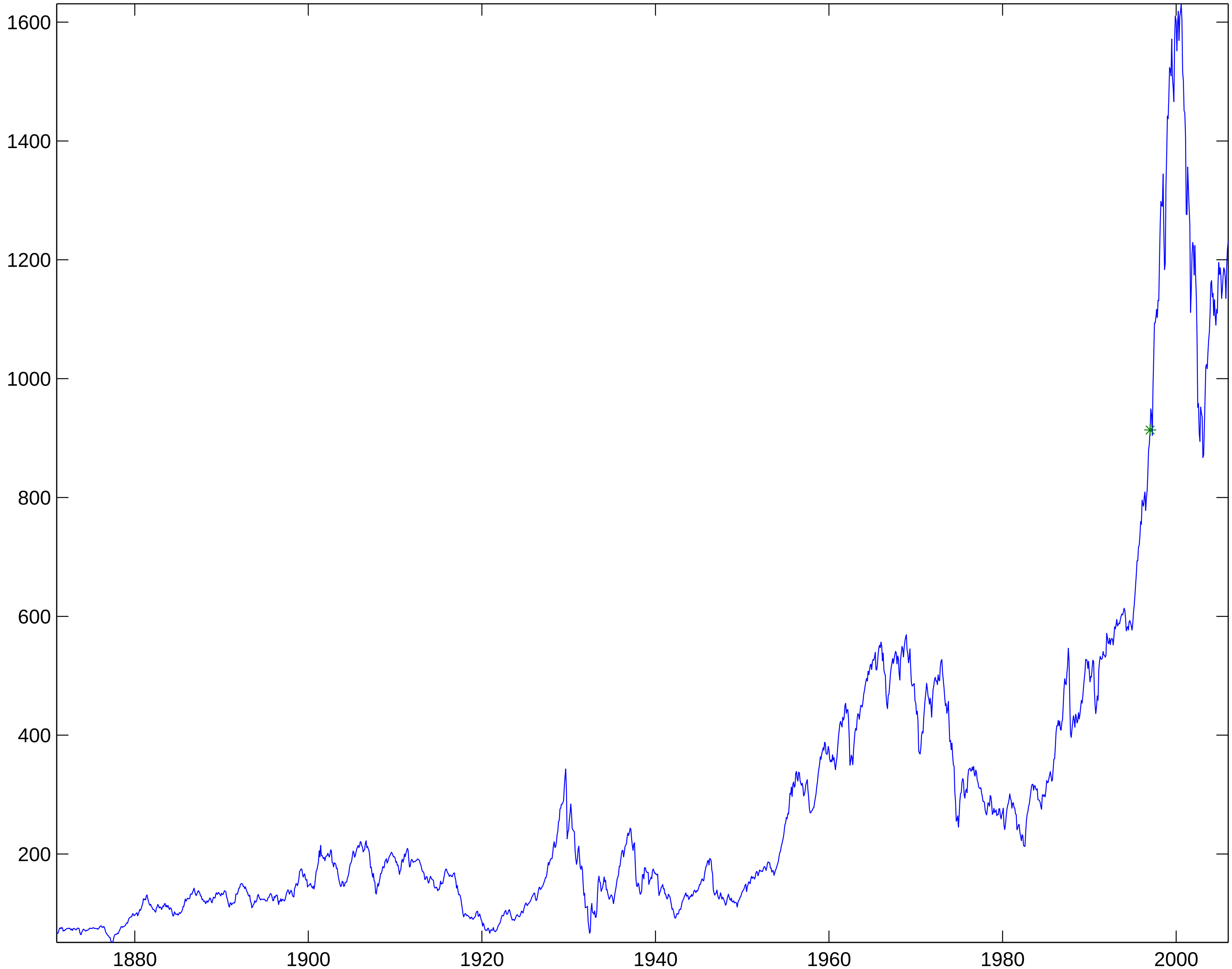


Figure 2: inflation and post-1919 trend

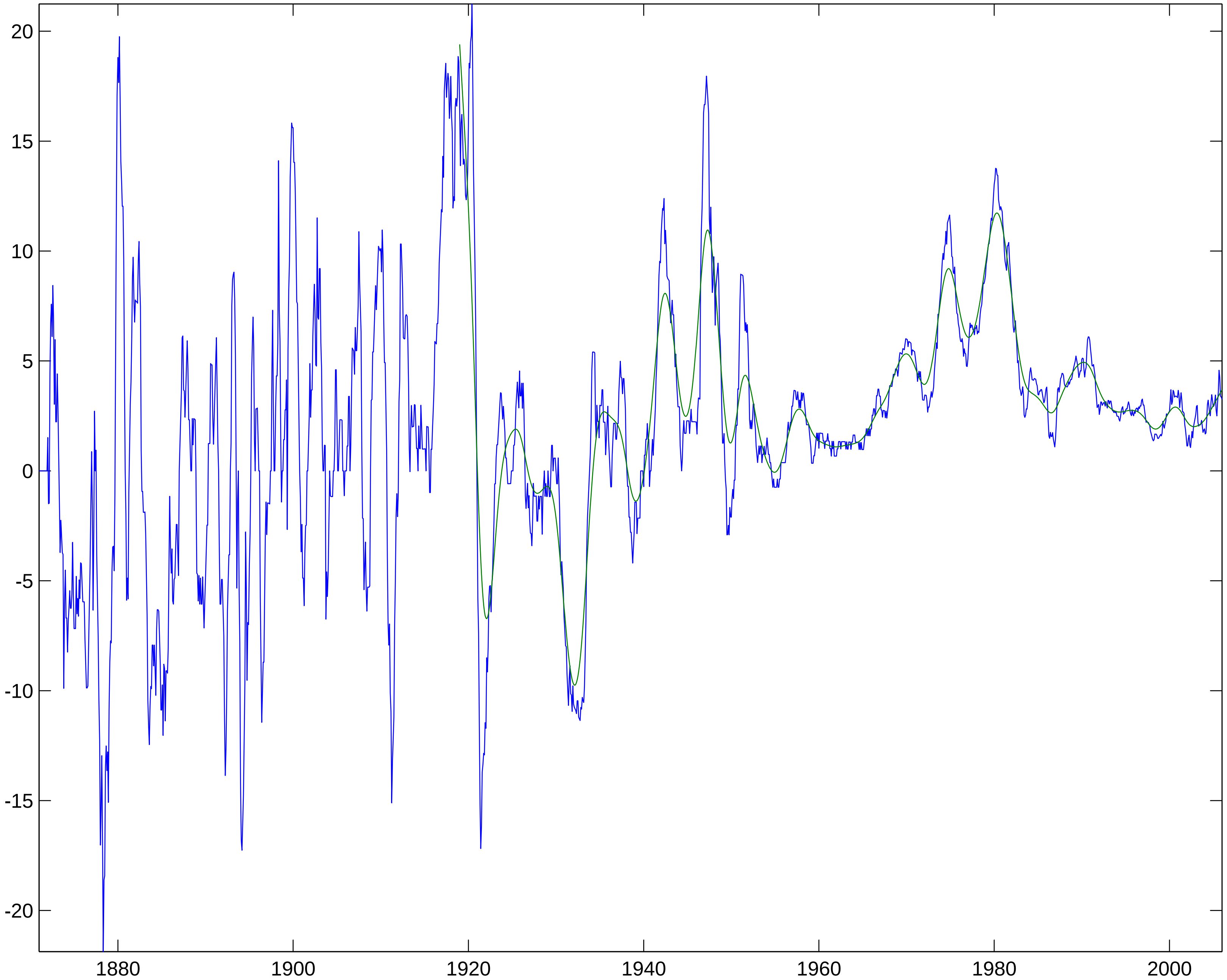



Figure 3: S&P500 and Smoothed Inflation (both variables scaled and mean-adjusted)
5
4
3
2
1
0
-1
-2
1920
1930
1940
1950
1960
1970
1980
1990
2000

Figure 4: Real Business Cycle Model with Habit and CEE Investment Adjustment Costs
Baseline - Tech Shock Not Realized, Perturbation - Tech Shock Realized in Period 5

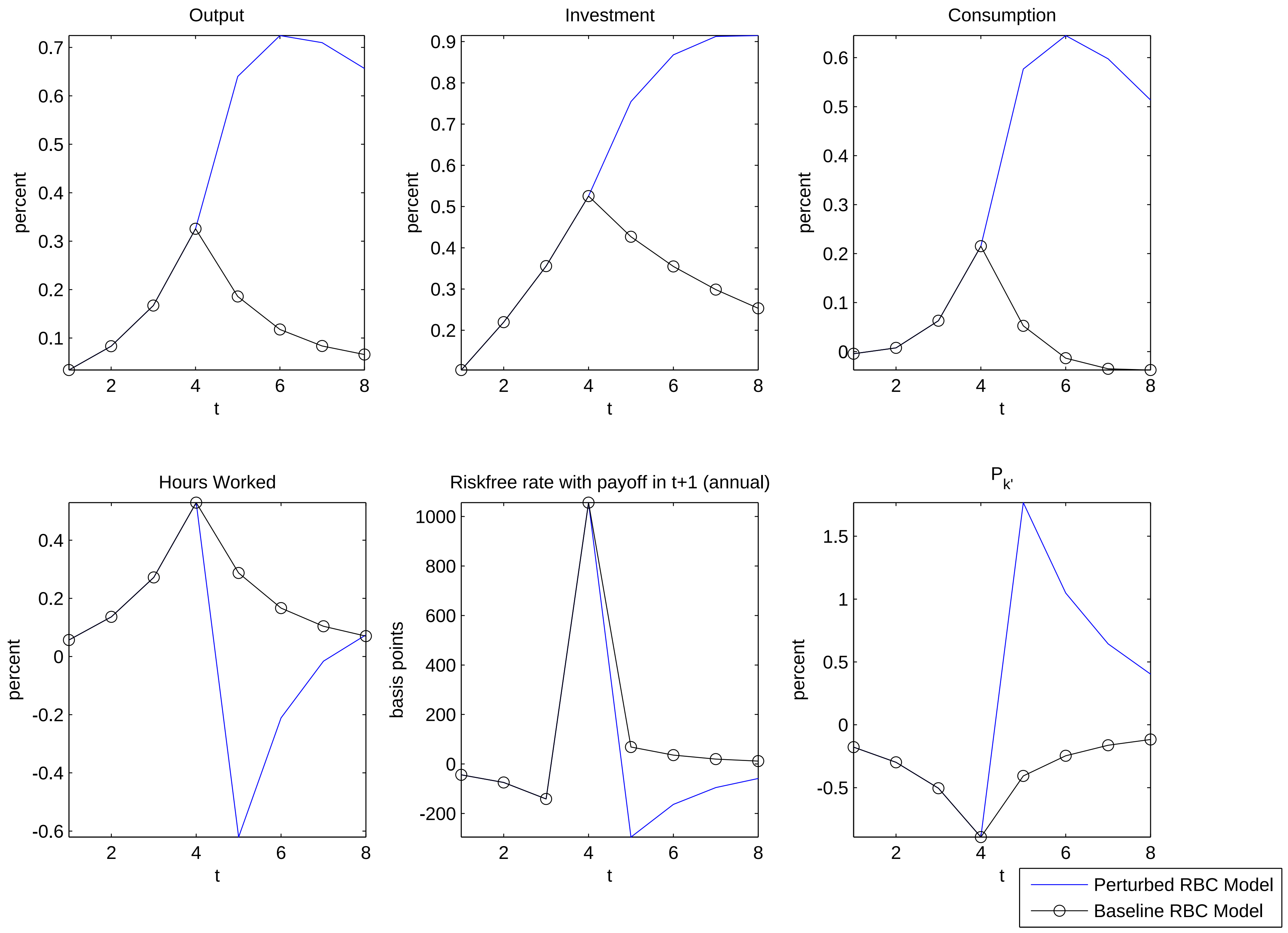


Figure 5: Real Business Cycle Model without Habit and with CEE Investment Adjustment Costs
Technology Shock Not Realized in Period 5

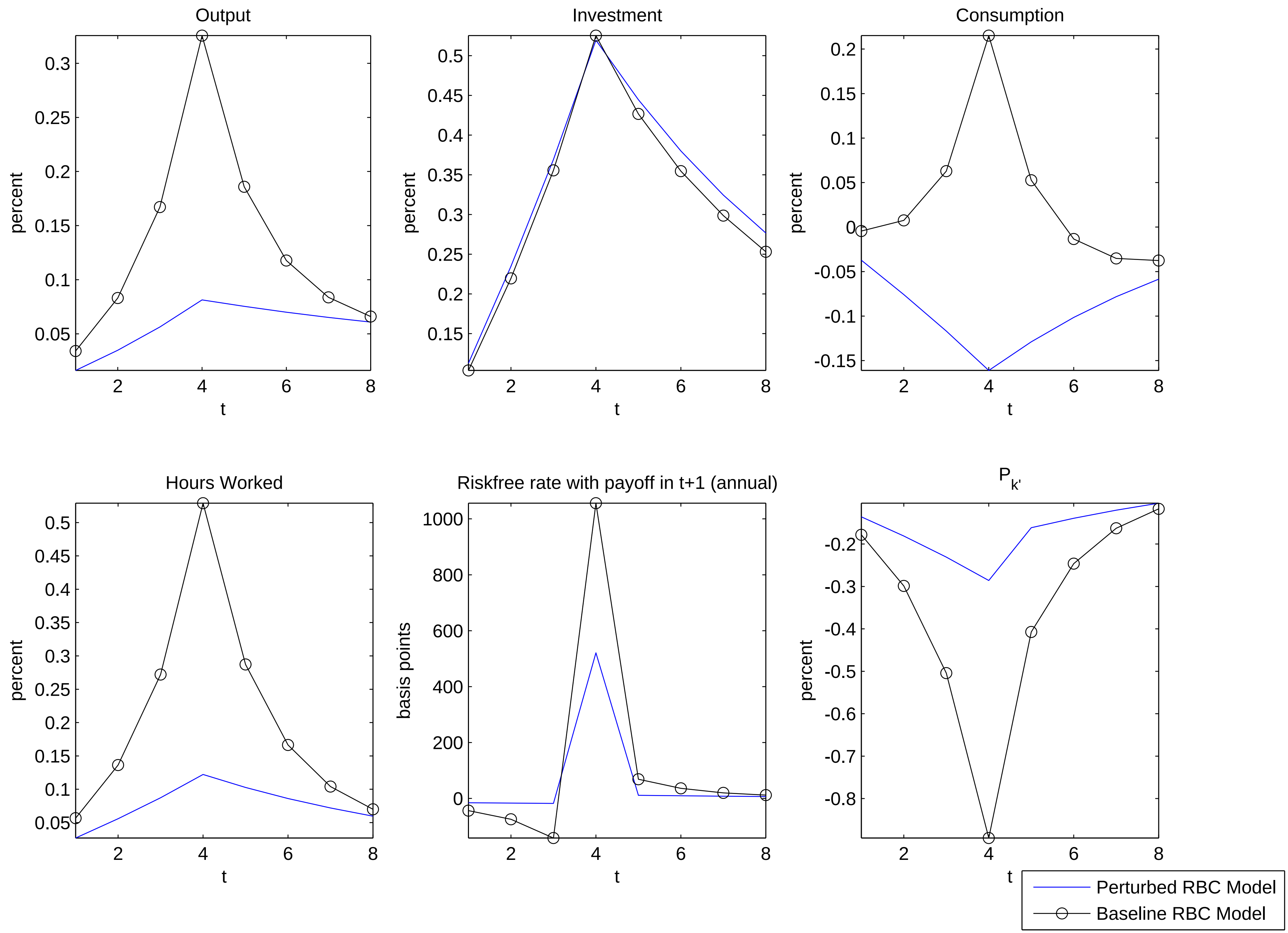


Figure 6: Real Business Cycle Model with Habit and Without Investment Adjustment Costs
Technology Shock not Realized in Period 5

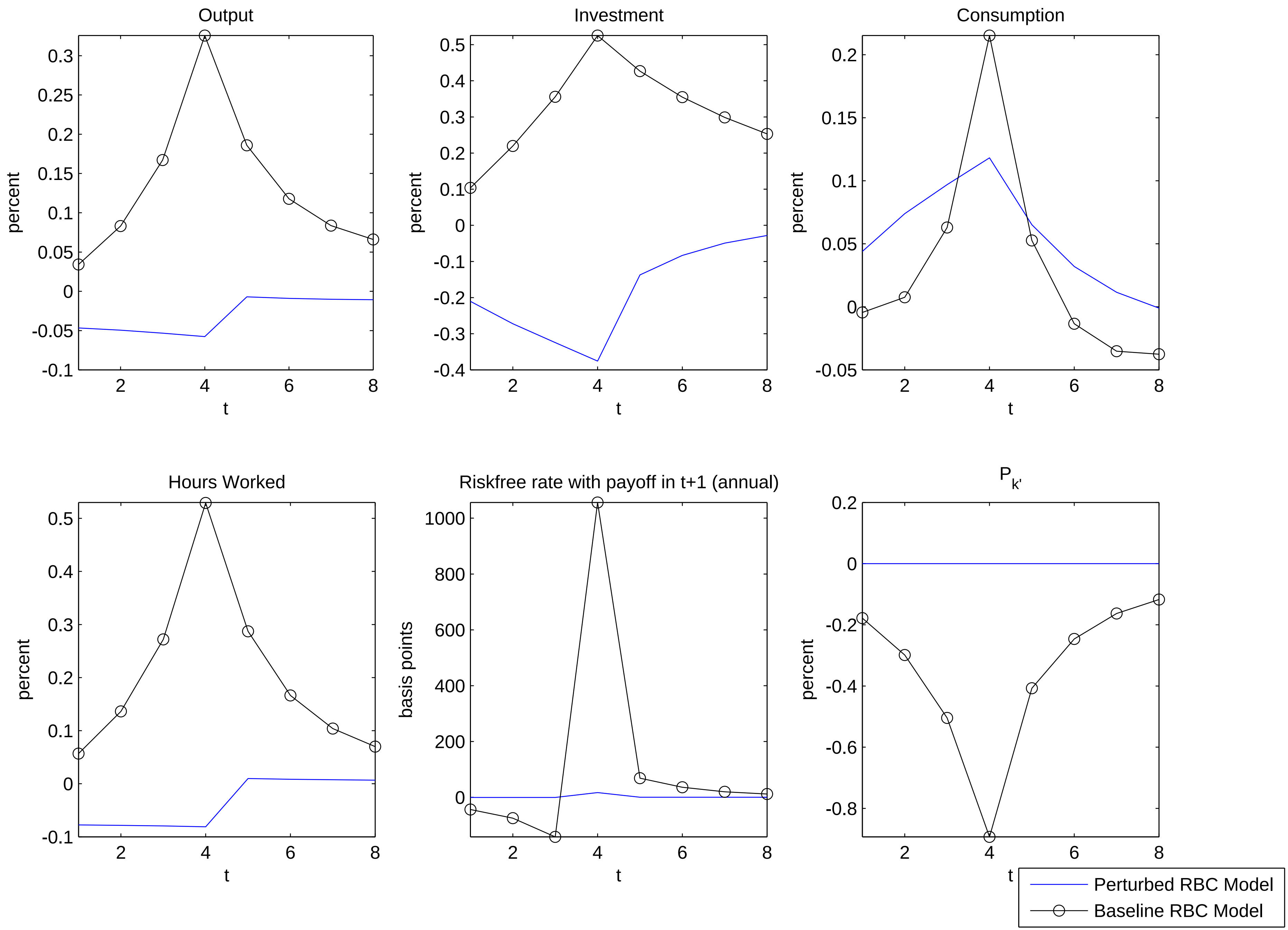


Figure 7: Real Business Cycle Model with Habit and with Level Investment Adjustment Costs
Technology Shock Not Realized in Period 5

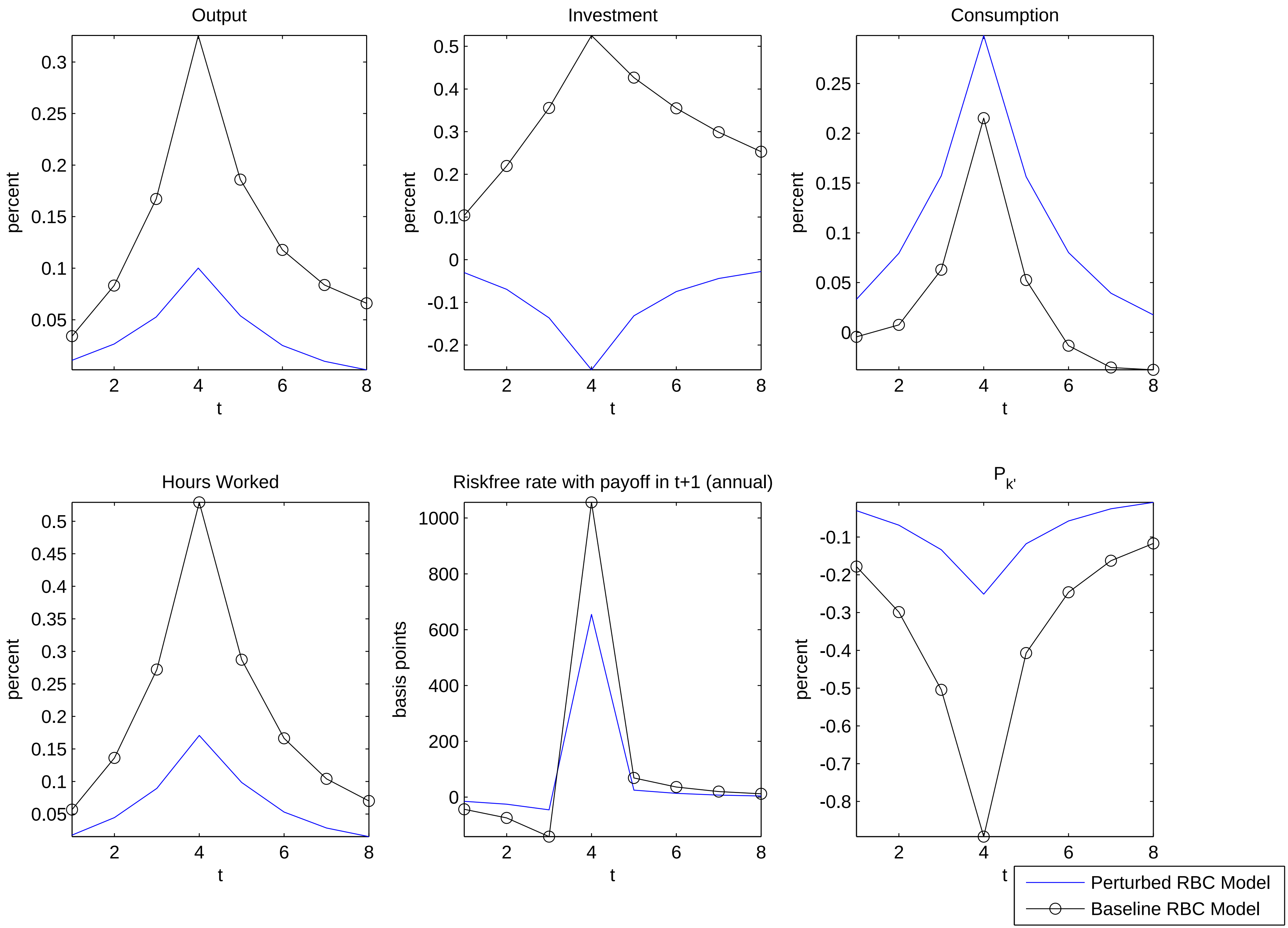


Figure 8: Real Business Cycle Model with Habit Persistence and Flow Adjustment Costs
Perturbed - Technology Shock Expected in Period 13, But Not Realized

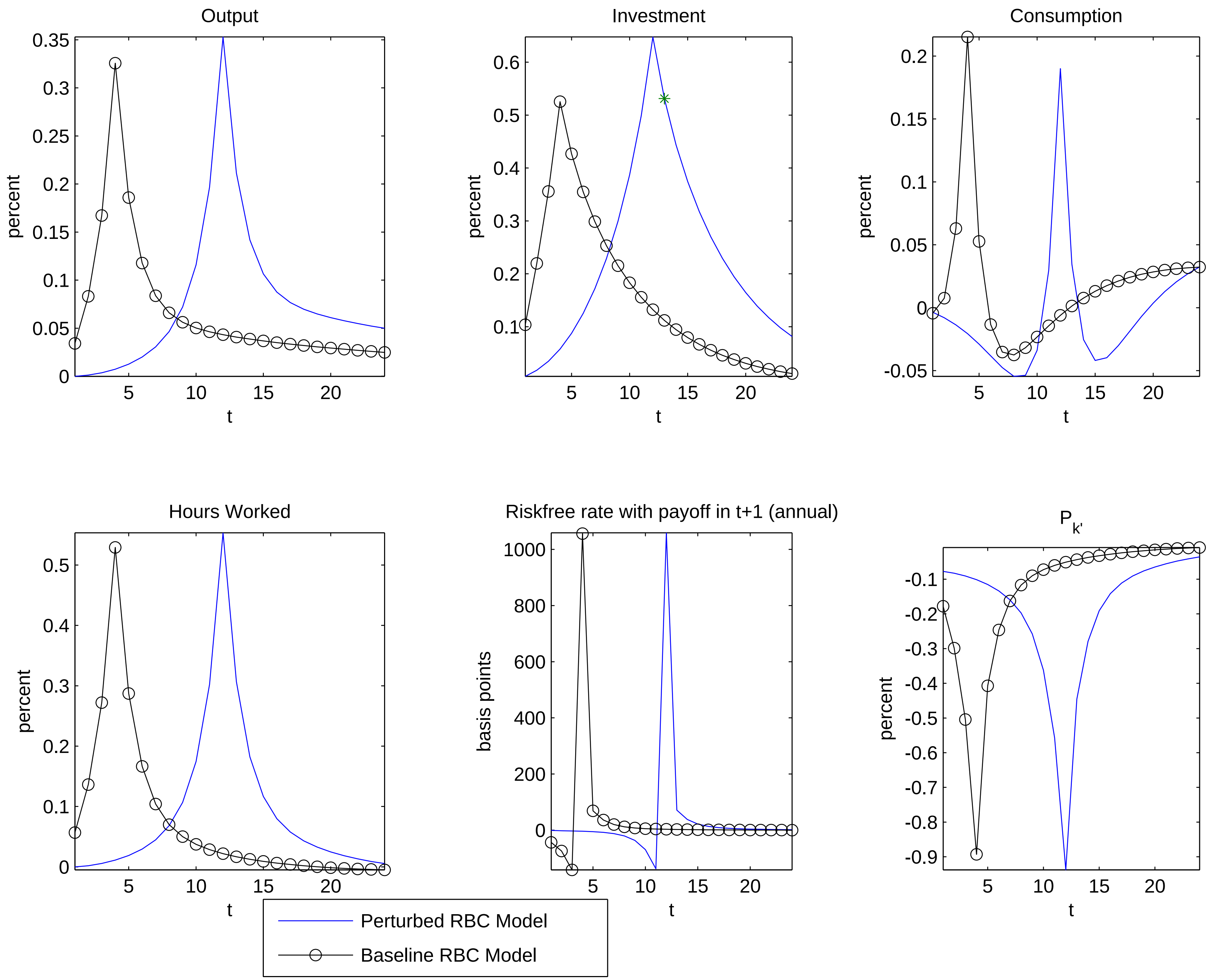
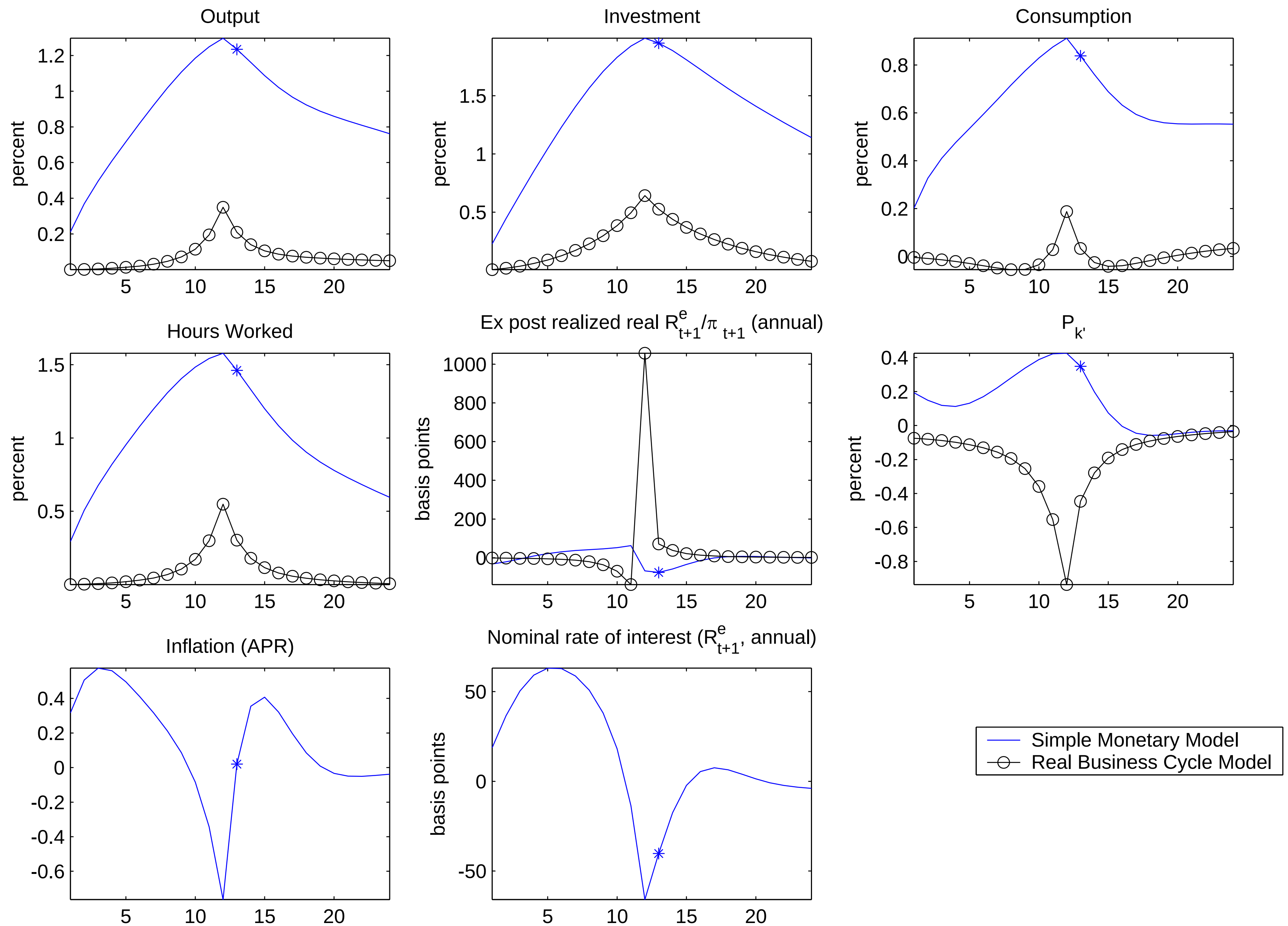
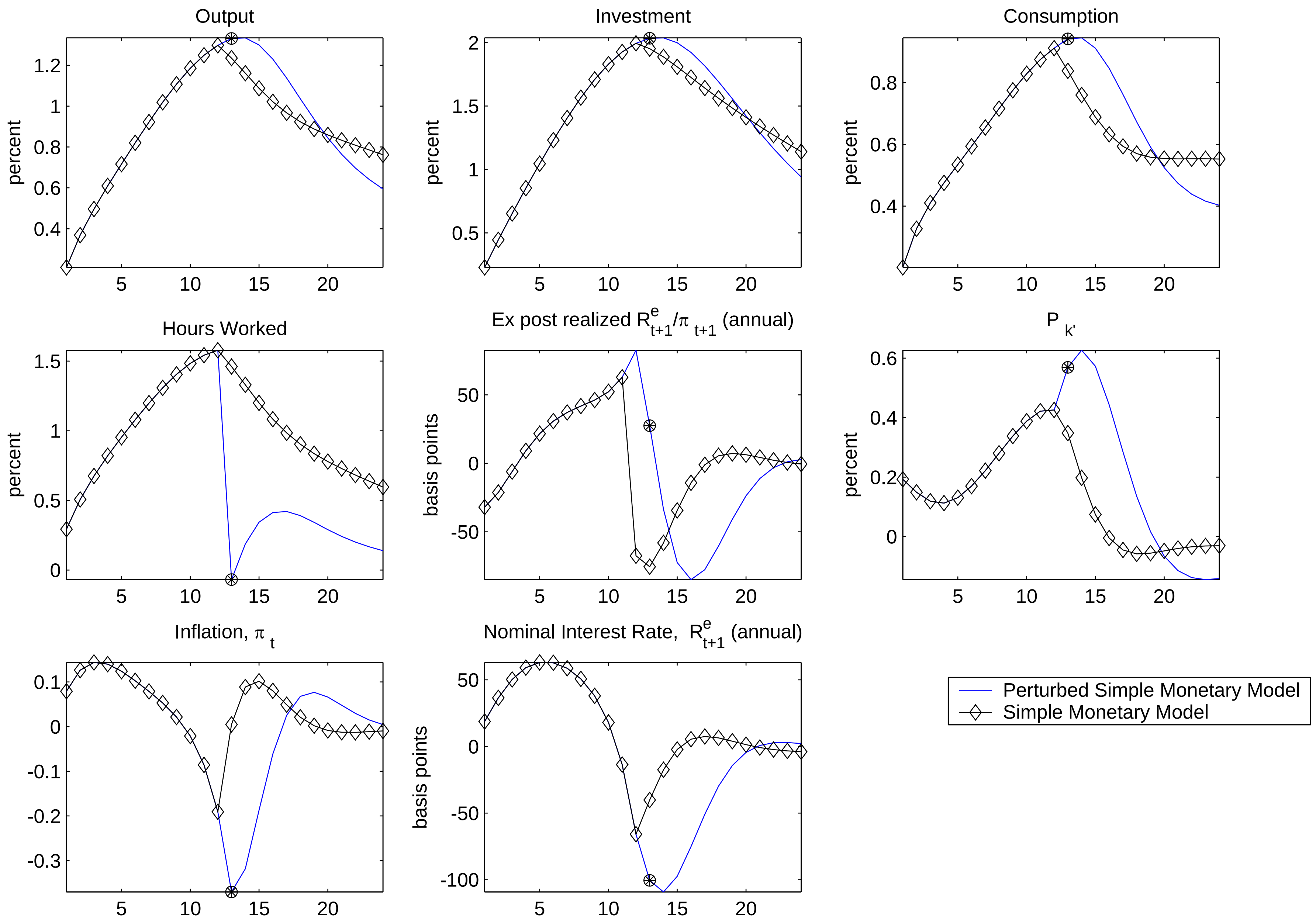


Figure 9: RBC and Simple Monetary Model
Expectation of Technology Shock in Period 13 Not Realized



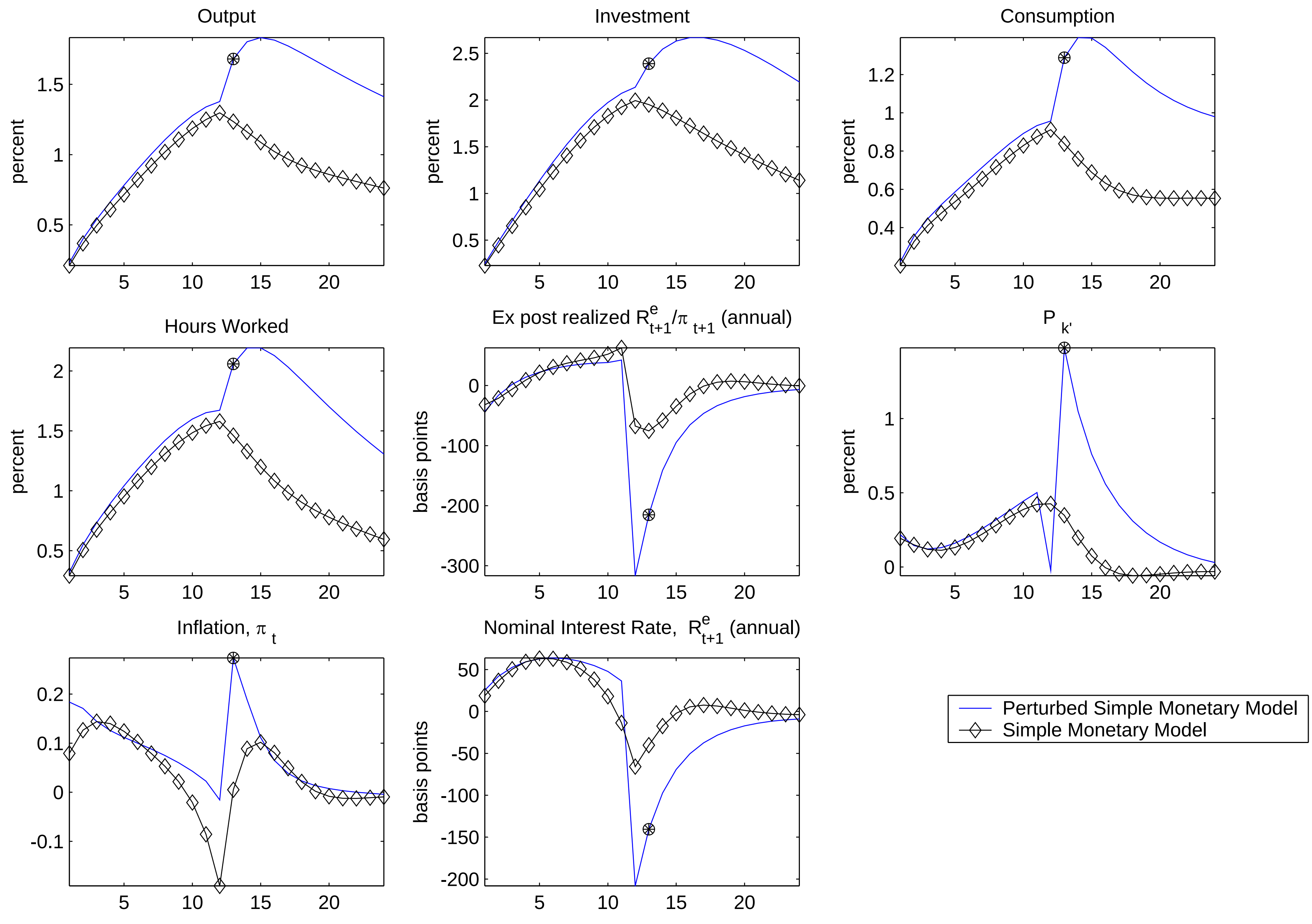
Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1

Figure 10 : Response of Simple Monetary Model and Perturbed Model to Signal Shock Perturbation - Technology Shock Realized in Period 13



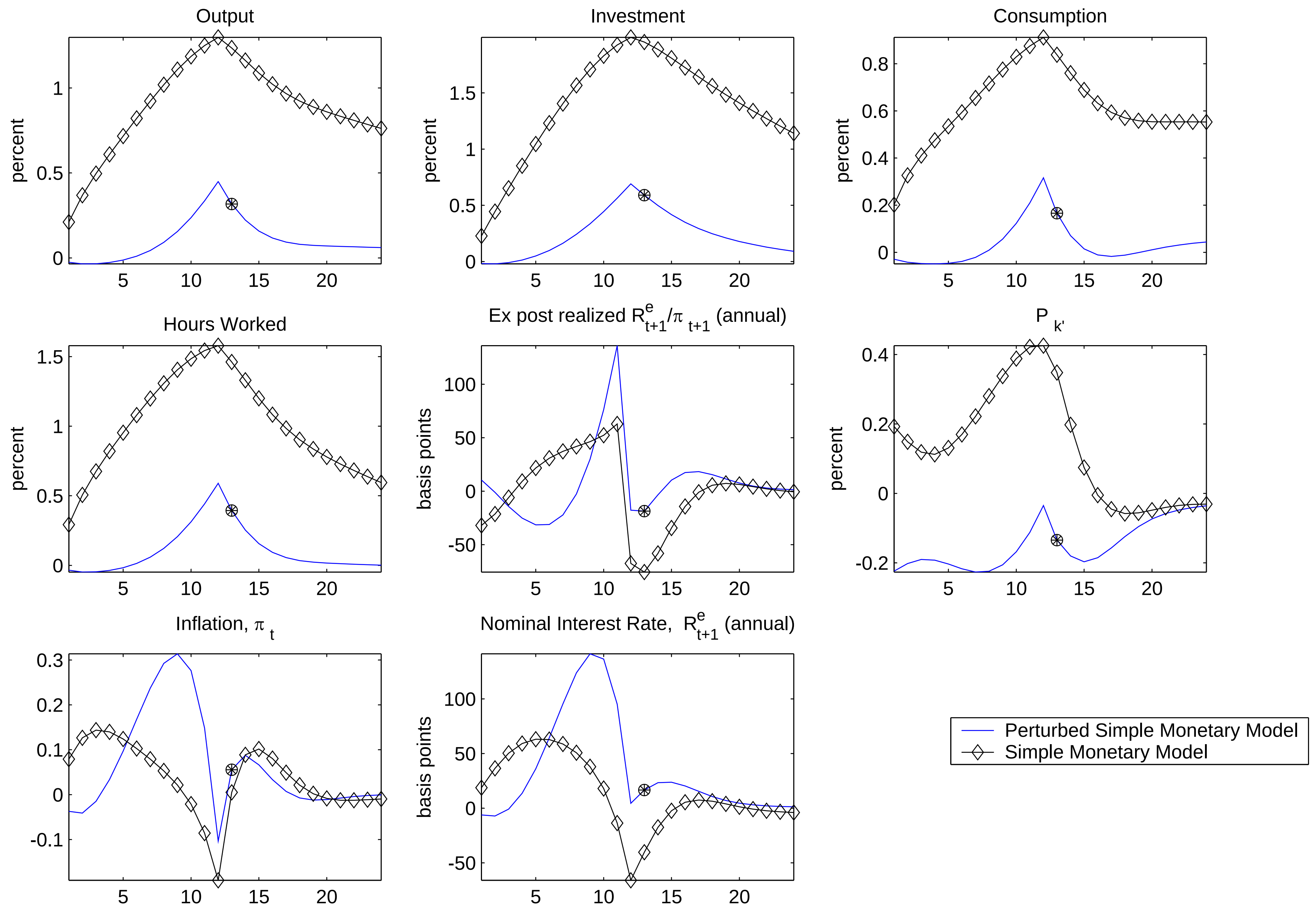
Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1 to t.

Figure 11: Response of Simple Monetary Model and Perturbed Model to Signal Shock
Perturbation - $\xi_p = 0.01$



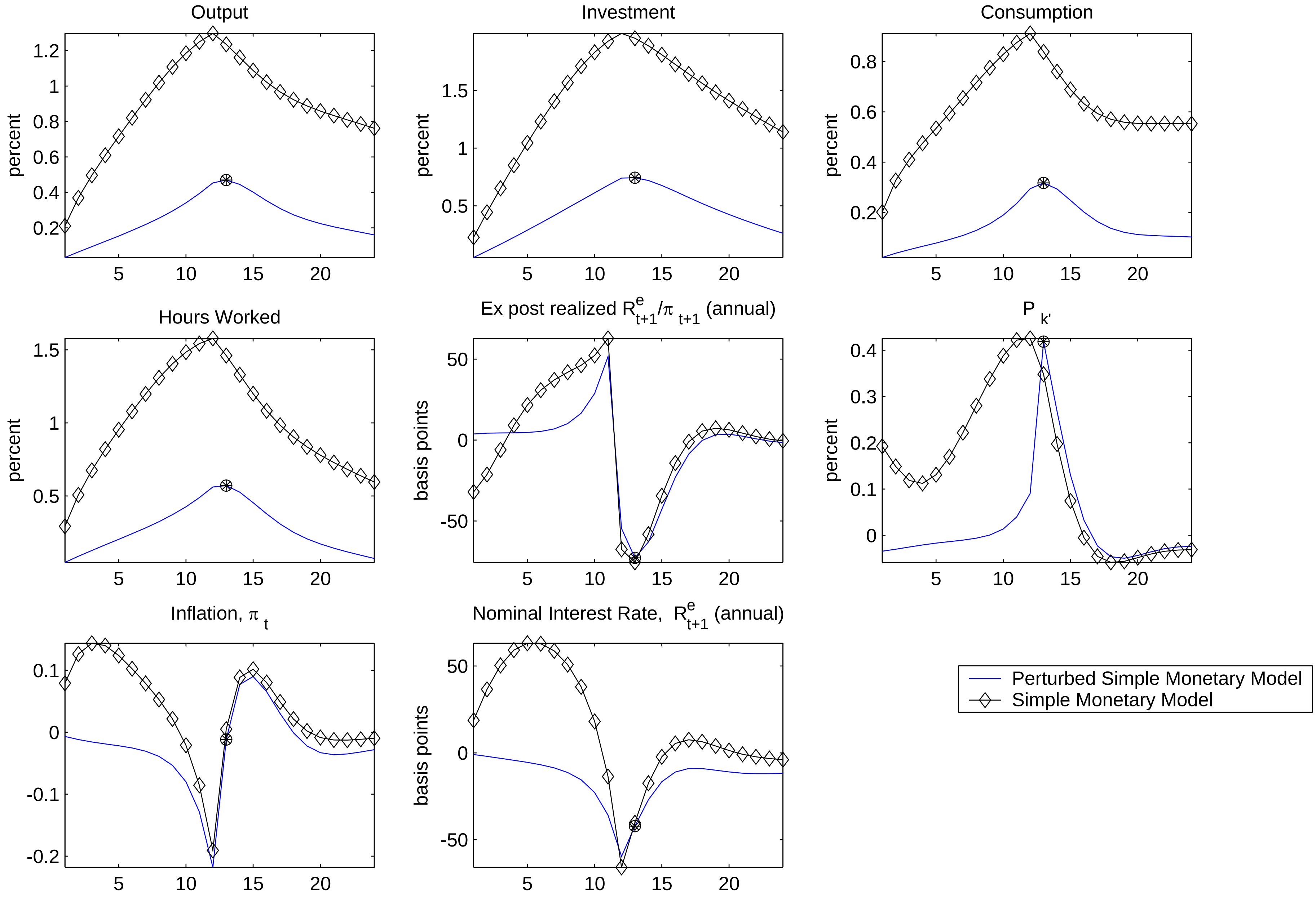
Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1 to t.

Figure 12: Response of Simple Monetary Model and Perturbed Model to Signal Shock
Perturbation - $\xi_w = 0.01$



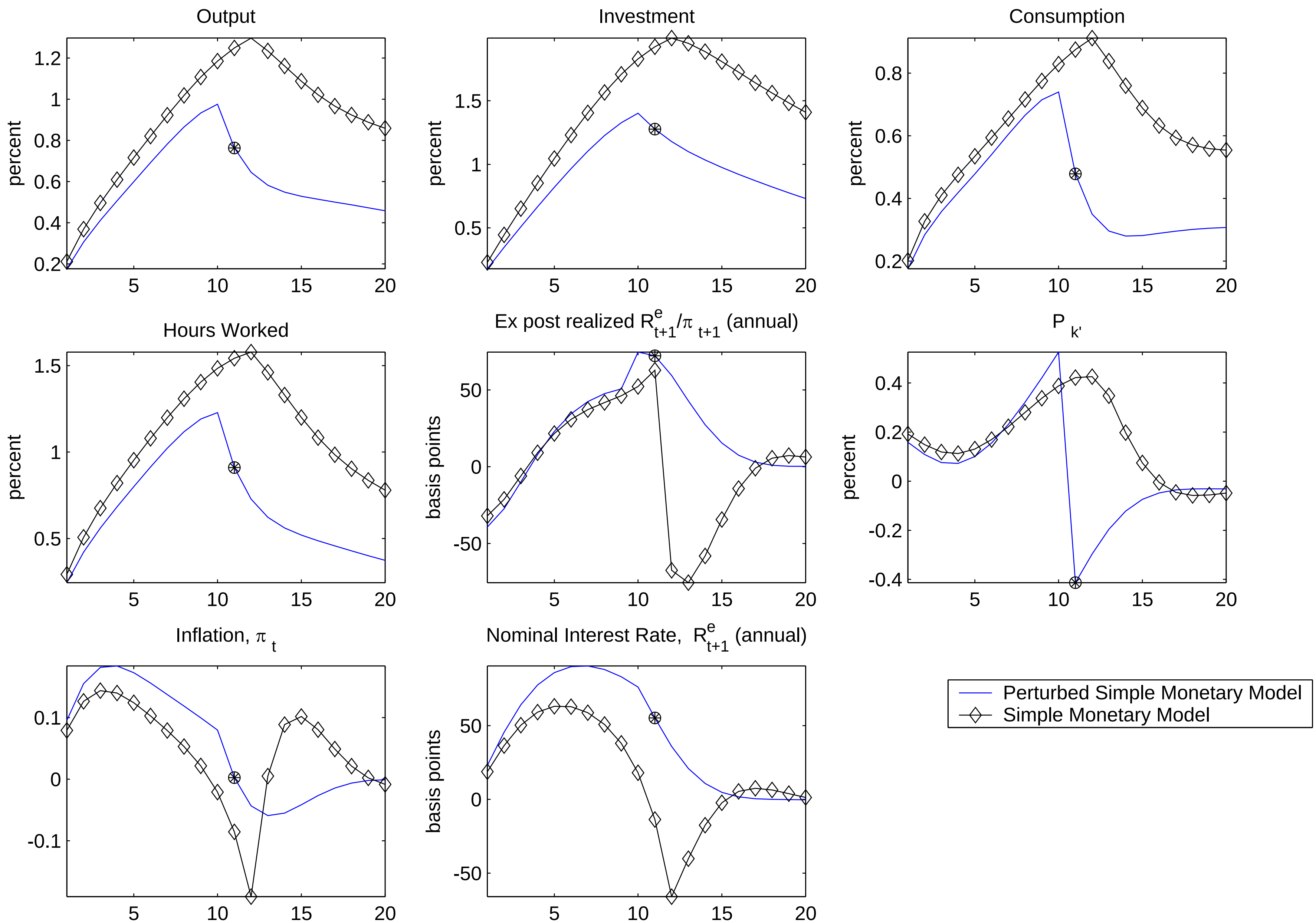
Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1 to t.

Figure 13: Response of Simple Monetary Model and Perturbed Model to Signal Shock
Perturbation - α_{π} = 1.05



Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1 to t.

Figure 14: Response of Simple Monetary Model and Perturbed Model to Signal Shock
Perturbation - 100 Basis Point Negative Policy Shock to Interest Rate in Period 11 that is Not Realized



Note: subscript on nominal rate of interest indicates date of payoff. R^e_{t+1} is graphed at date t. π_t indicates gross change in price level from t-1 to t.

Figure 15: Response of Full and Simple Monetary Model to Signal Shock

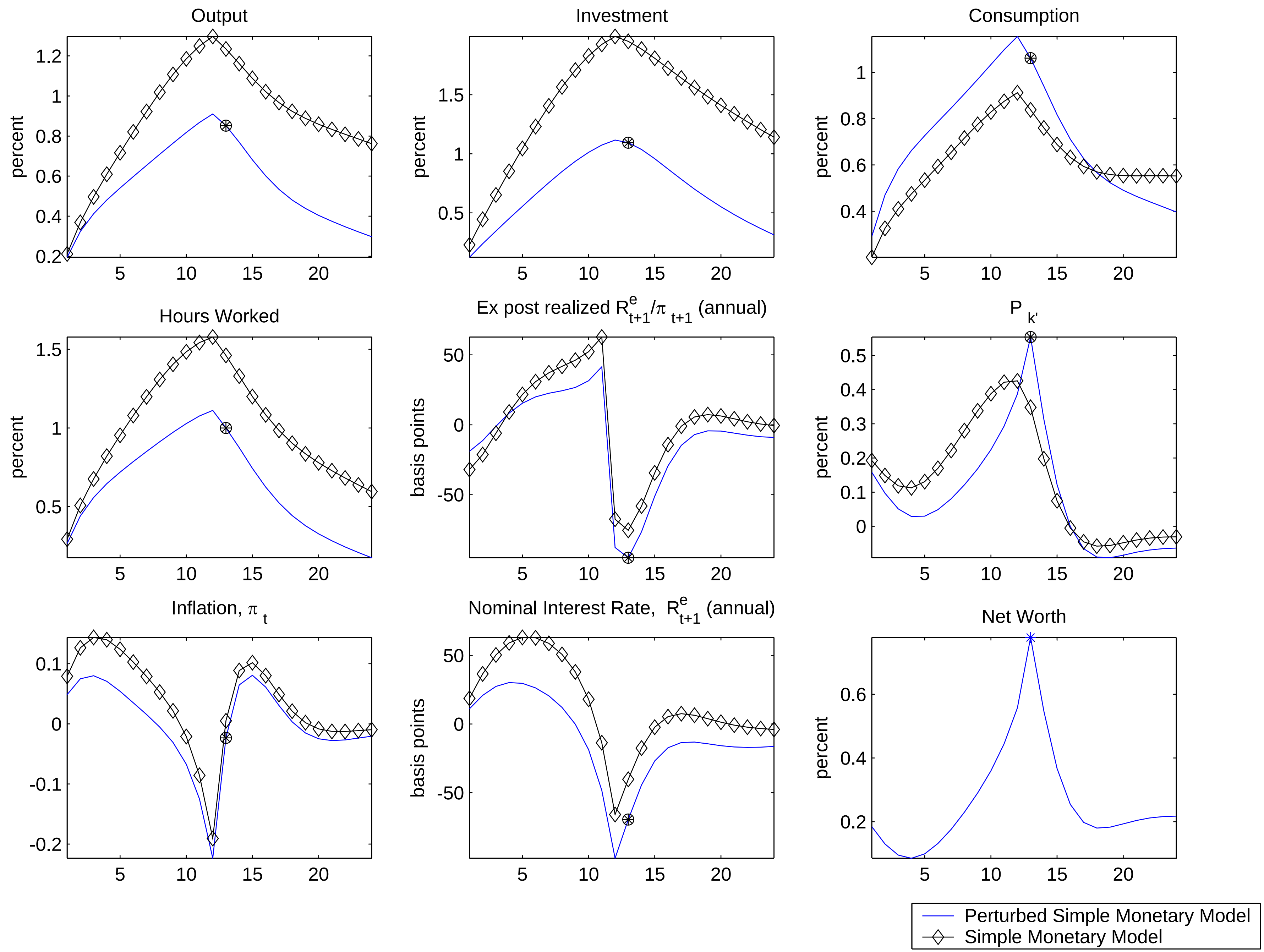


Figure 16: Behavior of Money and Credit in Full Monetary Model