How Should Monetary Policy Respond to Asset-Price Bubbles?

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We present a simple macroeconomic model that includes a role for an asset-price bubble. We then derive optimal monetary policy settings for two policymakers: a skeptic, for whom the best forecast of future asset prices is the current price; and an activist, whose policy recommendations take into account the complete stochastic implications of the bubble. We show that the activist's recommendations depend sensitively on the detailed stochastic properties of the bubble. In some circumstances the activist clearly recommends tighter policy than the skeptic, but in others the appropriate recommendation is to be looser. Our results highlight the stringent informational requirements inherent in an activist policy approach to handling asset-price bubbles.

JEL Codes: E32, E52, E60.

Asset-price bubbles pose difficult problems for monetary policy, and despite considerable debate, no consensus has yet emerged on the appropriate strategy for monetary policymakers in the presence of such bubbles.

Different views about the appropriate role of monetary policy in the presence of asset-price bubbles do not arise primarily

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because of differences about the objectives of monetary policy. These objectives, it is usually agreed, are to maintain low inflation and to limit the volatility of inflation and output, thereby contributing to stability in both the macroeconomy and the financial system. Rather, the different views are about how best to achieve these objectives.

One view is that monetary policy should do no more than follow the standard precepts of inflation targeting. Proponents of this view would acknowledge that rising asset prices often have expansionary effects on the economy, and might sometimes also provide a signal for incipient inflationary pressures, so that some tightening of monetary policy might be appropriate. According to this view, however, policy should only respond to observed changes in asset prices to the extent that they signal current or future changes to inflation or the output gap. There should be no attempt to use policy either to gently lean against a suspected asset-price bubble while it is growing or, more aggressively, to try to burst it. This view of the appropriate monetary policy response to asset-price bubbles has been put forth recently by Bernanke (2002).

An alternative view is that monetary policy should aim to do more than respond to actual and expected developments in inflation and the output gap. Cecchetti, Genberg, and Wadhwani (2003), prominent proponents of this alternative view, put the argument in these terms:

> Central banks seeking to smooth output and inflation fluctuations can improve . . . macroeconomic outcomes by setting interest rates with an eye toward asset prices in general, and misalignments in particular . . . *Raising interest rates modestly as asset prices rise above what are estimated to be warranted levels, and lowering interest rates modestly when asset prices fall below warranted levels, will tend to offset the impact on output and inflation of [asset-price] bubbles, thereby enhancing overall macroeconomic stability.* In addition, if it were known that monetary policy would act to "lean against the wind" in this way, it might reduce the probability of bubbles arising at all, which would also be a

> contribution to greater macroeconomic stability. (p. 429, italics added)[1]

We argue here that it is not clear that central banks should follow this advice. There is no universally optimal response to bubbles, and the case for responding to a particular asset-price bubble depends on the specific characteristics of the bubble process.

We present a simple model of the macroeconomy that includes a role for an asset-price bubble, and derive optimal monetary policy settings for two policymakers. The first policymaker, a skeptic, believes in the efficient markets hypothesis and makes no attempt to forecast future movements in asset prices when setting policy. His policy settings define the standard inflation-targeting benchmark in our model. The second policymaker, an activist, believes in the existence of the bubble and takes into account the complete stochastic implications of the bubble when setting policy.

Once the bubble has formed, it is assumed to either grow each year with some probability, or to collapse and disappear. Crucially, and realistically, monetary policy in the model affects the economy with a lag, so that policy set today has its initial impact on the economy next year, by which time the bubble will have either grown further or collapsed.

For an activist policymaker, it follows that there are two countervailing influences on monetary policy in the presence of the bubble. On the one hand, policy should be tighter than the standard inflation-targeting benchmark to counter the expansionary effects of future expected growth in the bubble and, in some formulations, to raise the probability that the bubble will burst. On the other hand, policy should be looser to prepare the economy for the possibility that the bubble may have burst by the time policy is having its impact on the economy.

Which of these two influences dominates? For intermediate and larger bubbles—which are of most importance to policymakers—we

[1] Cecchetti, Genberg, and Wadhwani are careful to argue that monetary policy should not target asset prices. To quote them again, "we are *not* advocating that asset prices should be *targets* for monetary policy, neither in the conventional sense that they belong in the objective function of the central bank, nor in the sense that they should be included in the inflation measure targeted by monetary authorities" (p. 429, italics in the original).

argue that it depends on the characteristics of the bubble process. There are circumstances in which the activist should recommend tighter policy than the skeptic. This is likely to be the appropriate activist advice when one or more of the following conditions applies: the probability that the bubble will burst of its own accord over the next year is assessed to be small; the bubble's probability of bursting is quite interest sensitive; efficiency losses associated with the bubble rise strongly with the bubble's size; or the bubble's demise is expected to occur gradually over an extended period, rather than in a sudden bust.

Alternatively, however, when these conditions do not apply, it is more likely that the activist should recommend looser policy than the skeptic. This result makes clear that there is no single optimal rule for responding to all bubbles, and also illustrates the high level of knowledge of the future stochastic properties of the bubble that is required to determine even the appropriate direction of activist policy.

1. Model

Our starting point is a simple, reduced-form model of the macroeconomy, which nevertheless captures the key stylized features of the interaction between monetary policy, output, and inflation. Augmented with an asset-price bubble, the model is deliberately illustrative rather than structural. It is designed to highlight the intuition behind our results, while ensuring that the insights that these results offer into the debate surrounding the appropriate response of monetary policy to asset-price bubbles are not obscured by modeling technicalities.

That said, many of the properties of the reduced-form model we outline below are qualitatively consistent with those of the structural model developed by Bernanke and Gertler (2000), while allowing for endogeneity of the bubble process. For example, monetary policy affects real activity with a lag, inflation has a backward-looking element, and nonfundamental movements in asset prices influence real activity. Furthermore, asset-price bubbles need not be "rational" in the sense of Blanchard and Watson (1982), with the potential for supranormal returns as long as the bubble survives.[2]

Formally, our model is an extension of a simple closed-economy model due to Ball (1999a) and Svensson (1997). In the Ball-Svensson model, the economy is described by two equations:

$$y_t = -\beta r_{t-1} + \lambda y_{t-1} \quad (1)$$

$$\pi_t = \pi_{t-1} + \alpha y_{t-1}, \quad (2)$$

where y is the output gap, r is the difference between the real interest rate and its neutral level, π is the difference between consumer-price inflation and its targeted rate, and α, β, and λ are positive constants (with $\lambda < 1$ so that output gaps gradually return to zero).

The Ball-Svensson model has the advantage of simplicity and intuitive appeal. It makes the simplifying assumption that policymakers control the real interest rate, rather than the nominal one. It assumes, realistically, that monetary policy affects real output, and hence the output gap, with a lag, and that the output gap affects inflation with a further lag. The values for the parameters α, β, and λ that Ball chose for the model, and that we will also use here, imply that each period in the model is a year in length.[3]

We augment the model with an asset-price bubble. We assume that in year 0, the economy is in equilibrium, with both output and inflation at their target values, $y_0 = \pi_0 = 0$, and that the bubble has zero size, $a_0 = 0$. In subsequent years, we assume that the bubble

[2]Our model can also be thought of as extending the earlier approach of Kent and Lowe (1997), by allowing for analysis of the appropriate response of monetary policy to endogenous bubbles over a multiperiod horizon. A detailed comparison of our results with those of Kent and Lowe is provided in appendix B of Gruen, Plumb, and Stone (2003). For a more extended discussion of the issue of the "rationality" of the asset-price bubbles we examine, see also section 2.2.5 below.

[3]Ball chose parameter values $\alpha = 0.4$, $\beta = 1$, and $\lambda = 0.8$ to fit the U.S. economy, based on previous studies by Ball (1994), DeLong and Summers (1988), and Rudebusch (1995). Ball (1999b) also used these parameter values in an open-economy version of the model which he noted was "meant to apply to medium-to-small open economies such as Canada, Australia and New Zealand" (although an increase in the real interest rate, for example, affects output through two channels in this open-economy model—directly and via the exchange rate—rather than just via the former channel). Finally, Ball and Svensson also add white-noise shocks to each of their equations, which we have suppressed for simplicity.

evolves as follows:

$$a_t = \begin{cases} a_{t-1} + \gamma_t, & \text{with probability } 1 - p_t \\ 0, & \text{with probability } p_t. \end{cases} \quad (3)$$

Thus, in each year, the bubble either grows by an amount, $\gamma_t > 0$, or bursts and collapses back to zero. For ease of exposition, in the rest of this section we will assume that γ_t is constant, $\gamma_t = \gamma$, but we will allow for a range of alternative possibilities in the results we report in the next section. We also assume that once the bubble has burst, it does not re-form. To allow for the effect of the bubble on the economy, we modify the Ball-Svensson two-equation model to read:

$$y_t = -\beta r_{t-1} + \lambda y_{t-1} + \Delta a_t \quad (4)$$

$$\pi_t = \pi_{t-1} + \alpha y_{t-1}. \quad (5)$$

In each year that the bubble is growing, it has an expansionary effect on the economy, increasing the level of output, and the output gap, by γ. The bubble is, however, assumed to have no direct effect on consumer-price inflation, although there will be consequences for inflation to the extent that the bubble leads the economy to operate with excess demand as it expands, and with excess supply when it bursts.

When the bubble bursts, the effect on the economy is, of course, contractionary—if the bubble bursts in year t, the direct effect on output, and the output gap, in that year will be $\Delta a_t = -(t-1)\gamma$. Thus, the longer the bubble survives, the greater will be the contractionary effect on the economy when it bursts.

We will assume that the evolution of the economy can be described by this simple three-equation system (equations [3], [4], and [5]). Before continuing, it is worth remarking on a number of aspects of this system.

The most notable feature of equations (3), (4), and (5) is that the treatment of both the asset-price bubble and the structure of the economy is extremely simple and stylized. For example, the model allows for no forward-looking element in the formation of inflation expectations, therefore limiting the scope for monetary policy to influence the economy through precommitment to a particular monetary policy path. Furthermore, the asset-price bubble in the model is treated in a simple, reduced-form fashion, in terms of its impact on real activity, without any attempt to model the bubble formation process itself.

These choices are deliberate. They reflect that much of the discussion about how monetary policy should react to asset-price bubbles focuses on the extreme informational difficulties that policymakers face in determining the properties of a given bubble (current size, likelihood of collapse, impact on the real economy) or whether a bubble even exists. These informational difficulties are often cited as a principal reason why an activist approach to monetary policy in the face of asset-price misalignments might be difficult or suboptimal in practice.

By using a highly simplified model of the economy, however, in which policymakers are also endowed with full knowledge of the stochastic properties of a developing asset-price bubble, it is possible to abstract from these informational issues. Doing so allows us to explore whether there may be other factors, besides informational constraints, which complicate an approach of actively responding to asset-price bubbles—to the point of sometimes making it problematic even to know whether policy ought to be set more tightly or more loosely than it would otherwise be.

In this spirit, for example, the reason that we do not attempt to provide a more explicit or detailed model of asset prices in this paper is simply that doing so is not a focus of the paper. Rather, we wish to study whether or not it is clear cut in what way policymakers ought to react to a developing asset-price bubble, even when in possession of an understanding of the stochastic properties of the bubble's future impact on the economy.[4]

Returning to the specification of our modeling framework, we next distinguish between two policymakers: a skeptic, who doesn't try to second-guess asset-price developments; and an activist, who

[4]The same rationale applies to our choice of a simple and transparent modeling framework which excludes any forward-looking element to the inflation expectations formation process. Excluding such an element does not imply that the management of expectations might not be an important tool in the armory of a central bank deciding how best to handle a growing asset-price bubble. Rather, it simply reflects that our aim in this paper is to highlight *other* factors which would—even were such management of future expectations possible—still complicate the task of policymakers trying to determine how to respond optimally to such a bubble.

believes that she understands enough about asset-price bubbles to set policy actively in response to them. To draw the distinction more precisely, both policymakers understand how the output gap and inflation evolve over time, as summarized by equations (4) and (5). The activist also understands, and responds optimally to, the stochastic behavior of the bubble, as summarized by equation (3). The skeptic, by contrast, responds to asset-bubble shocks, Δa_t, when they arrive, but assumes that the expected value of future shocks is zero.

Importantly, such a skeptic should not be thought of as naive or ignorant for adopting this position. As an asset-price bubble grows, there is always disagreement about whether the observed asset-price developments constitute a bubble, in which case expectations about future asset-price changes may be nonzero, or are instead consistent with an efficient market, in which case the expected value of future changes in the asset price is zero.[5] In holding that the expected value of future asset-price shocks is zero, the skeptical policymaker in our framework should therefore simply be viewed as a believer in the efficient markets hypothesis.

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[5]In the late 1990s, precisely this debate was occurring within the U.S. Federal Reserve in relation to the U.S. stock market, as the following quotation from Stephen Cecchetti makes clear.

> From August 1997 to June 1999 I sat on the backbench at the meetings of the FOMC and received all of the material distributed to the participants . . . The interesting thing is that during the period when I took part in this process, the Board staff preparing the forecasts invariably assumed that the US stock market would decline significantly — 10 to 20 per cent declines in the Wilshire 5000 index were commonly the basis for the forecasts. They clearly believed that the stock market was overvalued . . .
>
> At the time this was all happening, I confess that I was scandalised. I regularly ranted about the practice of forecasting a dramatic decline in the stock market. Like the vast majority of academics, I adhered to the efficient markets view . . . while we needed to assume something about the stock market, shouldn't we assume the equity index would stay constant at its current level indefinitely? . . .
>
> This happened five years ago (which is why I can talk about it now), and in the interim I have changed many of my views. (Cecchetti 2003)

The skeptical policymaker in our framework may be characterized as adhering to the approach of Cecchetti—before his change of view!

Continuing, we assume that the policymakers observe in each year whether the bubble has grown further, or collapsed, before setting the interest rate for that year. Given the nature of the lags in the model, this year's interest rate will have no impact on real activity until next year, and no impact on inflation until the year after that.

We also assume that the two policymakers have the same preferences, and that they care about the volatility of both inflation and output. Thus we assume that in each year t, policymaker p (activist or skeptic) sets the real interest rate, r_t, to minimize the weighted sum of the expected future squared deviations of inflation and output from their target levels, or in symbols, sets r_t to minimize

$$L = \sum_{\tau=t+1}^{\infty} \left[E_t^p \left(y_\tau^2 \right) + \mu E_t^p \left(\pi_\tau^2 \right) \right], \tag{6}$$

where μ is the relative weight on the deviations of inflation and E_t^p is the year t expectation of policymaker p. In the results we show in the paper, we set $\mu = 1$, so that policymakers are assumed to care equally about deviations of inflation from target and output from potential.

In setting policy each year, the skeptical policymaker ignores the future stochastic behavior of the bubble. Since certainty-equivalence holds in the model in this setting, Ball shows that, for the assumed parameter values, optimal policy takes the form

$$r_t = 1.1y_t + 0.8\pi_t, \tag{7}$$

which is a more aggressive Taylor rule than the "standard" Taylor rule introduced by Taylor (1993), $r_t = 0.5y_t + 0.5\pi_t$.

As the bubble grows, the skeptical policymaker raises the real interest rate to offset the bubble's expansionary effects on the economy. But he does so in an entirely reactive manner, ignoring any details about the bubble's future evolution. Once the bubble bursts, output falls precipitously and the skeptical policymaker eases aggressively, again in line with the dictates of the optimal policy rule, equation (7).[6]

[6]We implicitly assume that the zero lower bound (ZLB) on nominal interest rates is not breached when policy is eased after the bubble bursts, so that the

We assume that the activist policymaker learns about the bubble in year 0, and hence takes the full stochastic nature of the bubble into account when setting the policy rate, r_t, from year 0 onward. Once the bubble bursts, however, there is no further uncertainty in the model, and the activist policymaker simply follows the modified Taylor rule, equation (7), just like the skeptical policymaker.

2. Results

In this section, we present optimal policy recommendations through time, assuming that the bubble survives and grows. Specifically, for each period t we compute optimal policy recommendations for both the skeptic and activist conditional on, first, the bubble having survived to period t, and secondly, actual policy in each prior period having been set by the skeptic.

We focus on the growth phase of the bubble's life because it is of most policy interest, as it generates the most disagreement about which policy approach is preferable. Once the bubble bursts, by contrast, there is general agreement that it is appropriate to ease aggressively to offset the contractionary effects of the bust.[7]

As for our assumption that the skeptic has actually set policy in each prior period, our main aim is to compare the optimal policy recommendations of the skeptic with those of an activist, over a range of plausible alternative assumptions about the stochastic nature of the bubble. To do so in a meaningful way, it is necessary that the two policymakers face an economy in the same state in each year. Since the current state of the economy depends on previous policy settings (as well as on the evolution of the bubble), some assumption along these lines is clearly necessary, and this seems a convenient and natural choice.

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real interest rate can be set as low as required by equation (7). The model can readily be extended, however, to explore the implications—both for policymakers' choice of target inflation rate and for the operation of policy for a given inflation target—in the event that a ZLB constraint is imposed. In this case, policymakers who wish to react preemptively to a growing bubble must now take into account whether their actions might result in them being unable to set the real interest rate optimally in subsequent periods, whenever the bubble bursts. For a detailed discussion of this case, see Robinson and Stone (2005).

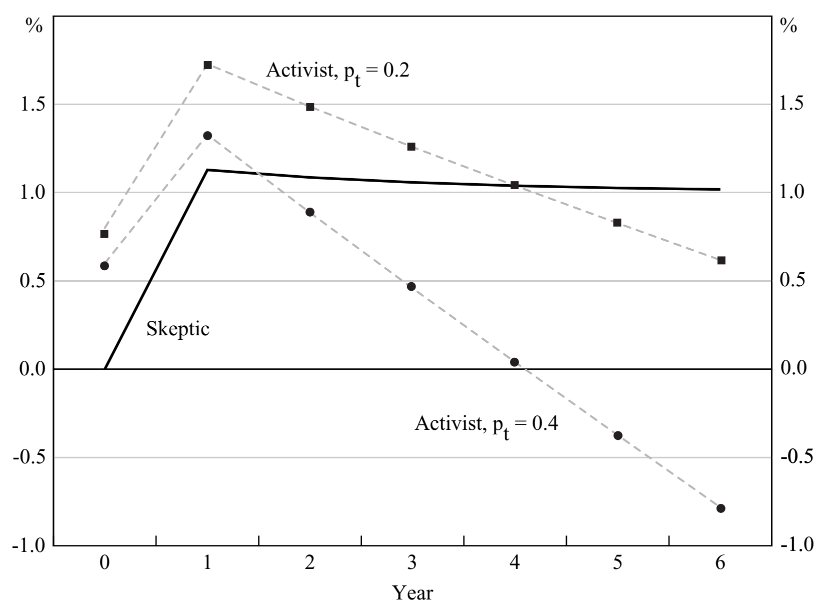
[7] For completeness, the appendix shows optimal interest-rate recommendations both before and after the bursting of the bubble.

With these two assumptions, we can then meaningfully ask each year: Given the state of the economy, what are the current optimal policy recommendations made by the different policymakers? The activist's recommendations will depend on the assumptions she makes about the future possible paths of the bubble, while the skeptic's will not, since he assumes that future asset-price shocks have no expected effects.

2.1 Baseline Results: Policy Cannot Affect the Bubble

We begin with some simple baseline results. For these results, we assume that the bubble's direct expansionary effect on output in each year of its growth is a constant 1 percent (i.e., $\gamma_t = 1$). Figure 1 shows the optimal policy choices made by the skeptic and two activists. We focus first on the skeptic, and then on the activists.

Figure 1. Real Interest Rate Recommendations While the Bubble Survives: Policy Has No Effect on the Bubble



Note: The skeptic implements policy in each year. Real interest rates are deviations from neutral.

Since the skeptic assumes that future asset-price shocks have no expected effects, he responds to the bubble only when its initial expansionary effects are manifest in year 1. As time proceeds and the bubble grows, he sets the policy interest rate in line with equation (7), which is optimal given his beliefs about future asset-price shocks. Of course, were the bubble to burst, he would ease immediately (see appendix for further details).

An activist, deciding on optimal policy in year t, understands that if the bubble continues to grow, its direct effect on output next year will be +1 percent, while if it bursts, the direct effect next year will be $-a_t$ percent. If the probability of bursting each year is a constant, p^*, the bubble's expected direct effect on output next year is $(1 - p^*) - p^* a_t$.

Certainty equivalence applies to this baseline version of the model.[8] It follows that the difference between the policy interest rates recommended by the activist, r_t^{ac}, and the skeptic, r_t^{sc}, depends only on their different assessments of the expected effect of the bubble on output next year. With the skeptic assuming that the bubble will have no expected effect on output next year, it follows that

$$r_t^{ac} - r_t^{sc} = (1 - p^*) - p^* a_t. \tag{8}$$

Equation (8) implies that the activist will recommend tighter (easier) policy than the skeptic whenever, in probability-weighted terms, the expansionary effect on real activity from the bubble surviving is greater (less) than the contractionary effect from the bubble collapsing.

For the results shown in figure 1, we assume that the only difference between the two activists is that one assesses the probability that the bubble will burst each year as $p_t = p^* = 0.2$

[8]The model setup is more complex than the standard setup in which certainty equivalence applies. This is because, once the bubble bursts, there are no further asset-bubble shocks and hence, ex ante, the distribution of shocks is not independent through time. It is therefore not straightforward to demonstrate certainty equivalence. Nevertheless, equation (8) in the text does follow and can be generalized to allow for alternative parameter values, and for time-varying bubble growth and/or probabilities of bubble collapse, provided that the evolution of the bubble remains independent of the actions of the policymakers. The generalized equation is $r_t^{ac} - r_t^{sc} = \beta^{-1}[(1 - p_{t+1})\gamma_{t+1} - p_{t+1} a_t]$ which, in particular, implies that $(r_t^{ac} - r_t^{sc})$ does not depend on α, λ, or μ. A proof of this equation is provided in Gruen, Plumb, and Stone (2003).

(the "durable-bubble activist"), while the other assesses it as $p_t = p^* = 0.4$ (the "transient-bubble activist").[9]

In terms of their optimal policy recommendations, the two activists agree that policy should be tighter than the settings chosen by the skeptic for the first couple of years of the bubble's growth (including year 0, since that is when they learn about the bubble). Although they disagree about the details, they share the assessment that the continued probable growth of the bubble is a more important consideration for policy than the bubble's possible collapse.

The activists both understand, however, that as time proceeds, the bubble is getting bigger and the size of the prospective bust is also getting bigger. As a consequence, if the bubble survives for more than a year or two, the two activists no longer agree about whether policy should be tighter or looser than the modified Taylor-rule settings chosen by the skeptic. The durable-bubble activist recommends tighter policy because she assesses the probability of the bubble bursting to be small, but the transient-bubble activist recommends looser policy because her assessment is that this probability is larger.

If the bubble survives for long enough, the two activists will again concur at least in the direction of their policy advice—they will both recommend looser policy than the skeptic because the possibility of the by-now-bigger bubble collapsing eventually dominates for them both.

In this case, then, the policy recommendations of an activist—and even whether she recommends tighter or looser policy than the benchmark settings chosen by the skeptic—depend crucially on her assessment of the probability that the bubble will collapse of its own accord. This is an important example of the general point that the activist's policy advice will depend critically on the detailed assumptions she makes about the stochastic properties of the bubble. This is the central insight of the paper. We now show the relevance of this insight across a wide range of alternative assumptions about the bubble's stochastic behavior.

[9] Assuming $p_t = 0.2$ implies an average remaining life for the bubble of five years, while $p_t = 0.4$ implies an average remaining life of two and one-half years.

2.2 Sensitivity Analysis

2.2.1 Policy Affects the Probability That the Bubble Will Burst

An obvious extension to the model is to assume that by setting tighter policy *this year*, the policymaker can raise the probability that the bubble will burst *next year*.[10] For simplicity, we initially assume a linear relationship between the interest rate and the probability of the bubble bursting:

$$p_t = p^* + \delta(r_{t-1} - r^*_{t-1}) \, . \tag{9}$$

We assume that $\delta = 0.1$, so that a 1 percentage point rise in the real interest rate this year raises the probability of the bubble bursting next year by 0.1, subject to the constraint that $0 \leq p_t \leq 1$. The path of interest rates, r^*_t, $t \geq 0$, is the optimal path chosen by the skeptical policymaker.[11]

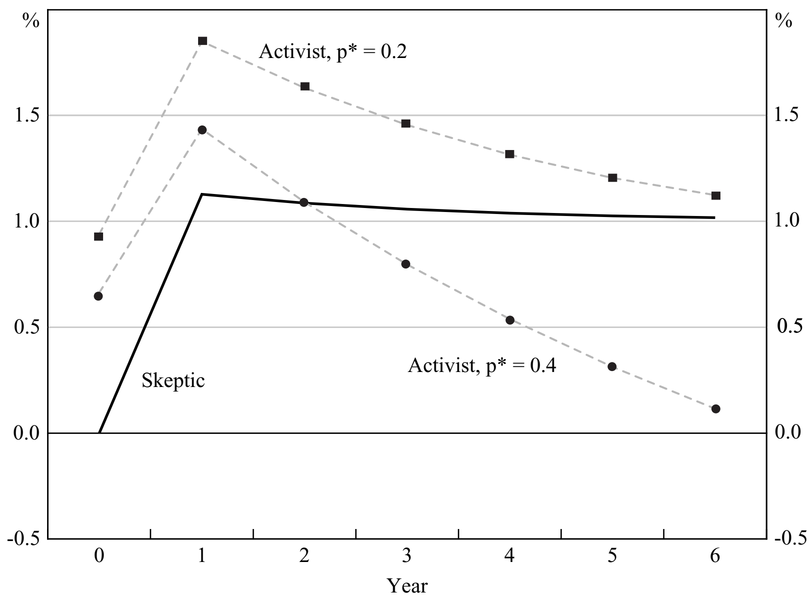
As before, we assume that the bubble's direct expansionary effect on output in each year of its growth is a constant 1 percent (i.e., $\gamma_t = 1$). Figure 2 shows the optimal policy recommendations made by the skeptic and two activists. The two activists again differ only in their assessment of the bubble's probability of collapse. Both believe that this probability is given by equation (9), but the durable-bubble activist believes that $p^* = 0.2$, while the transient-bubble activist believes that $p^* = 0.4$.

The skeptic's optimal policy profile is the same as in figure 1, because he ignores the future stochastic details of the bubble. By contrast, it is optimal for the activists to recommend tighter policy

[10] Most of the extensions we examine as part of our sensitivity analysis imply that certainty equivalence no longer applies to the model (the exceptions are the bubble that collapses over two or more years and the rational bubble), in which case the results must be derived by numerical optimization. To simplify the numerical problems, we assume that if the bubble survives until year 14 (which is a very unlikely event for all the parameter values we consider), then it bursts with certainty in that year. For earlier years, this assumption is only relevant for the policy choices of the activist policymaker. Where numerical solutions are used, these were obtained using the "Solver" function in Microsoft Excel, which employs the Generalized Reduced Gradient (GRG2) nonlinear optimization algorithm. These results were also checked using the BFGS algorithm in Gauss.

[11] We choose the functional form in equation (9) so that, for the benchmark policy settings chosen by the skeptic, $p_t = p^*$ for all t. The results generated using an alternative functional form, $p_t = p^* + \delta r_{t-1}$, are qualitatively very similar to those shown.

Figure 2. Real Interest Rate Recommendations While the Bubble Survives: Policy Affects the Bubble's Probability of Bursting



Note: The probability of the bubble bursting is given by equation (9) with $\delta = 0.1$. The skeptic implements policy in each year. Real interest rates are deviations from neutral.

than they would recommend if they had no influence on the bubble, as can be seen by comparing the activist profiles in figures 1 and 2. By tightening somewhat, the activists reduce the probability that the bubble will grow further and be more disruptive to the economy when it ultimately bursts. Nevertheless, the optimal policy continues to depend, sensitively, on the activist's assessment of the bubble's probability of collapse, just as it did when the activists could not affect the bubble.

It is also of interest to see how the results change when we vary the sensitivity to interest rates of the bubble's probability of collapse. For this exercise, we assume a monotonically increasing, but nonlinear, relationship between interest rates and this probability, to avoid a corner-solution problem with the linear form (explained shortly). The relationship we assume is

$$p_t = \frac{1}{1 + e^{a(r_{t-1} - r^*_{t-1}) + b}}, \tag{10}$$

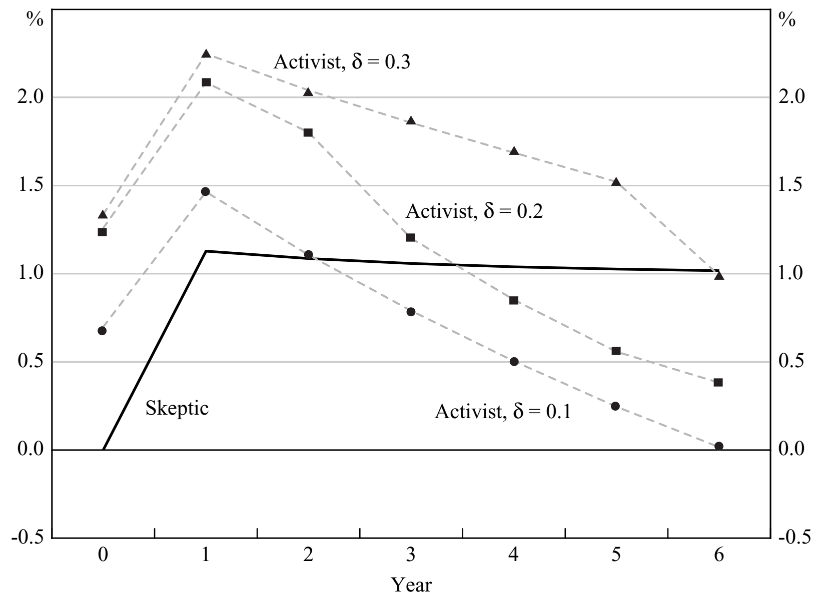
where $a = -\delta/(p^*(1 - p^*))$ and $b = ln((1 - p^*)/p^*)$. For this functional form, $p_t = p^*$ when $r_{t-1} = r^*_{t-1}$ and $\partial p_t/\partial(r_{t-1} - r^*_{t-1}) = \delta$ when this derivative is evaluated at $r_{t-1} = r^*_{t-1}$. These two features are also features of the linear form, equation (9). The advantage of the nonlinear form, equation (10), is that, while raising last year's interest rate, r_{t-1}, raises the probability that the bubble will burst this year, p_t, it cannot drive that probability to one, as can occur with the linear form.[12]

Figure 3 shows a comparison of optimal interest rate recommendations for the skeptic and three activists. The activists assume that the bubble's probability of bursting is given by equation (10) with $p^* = 0.4$ (except $p_{14} = 1$), but they assume three different degrees of interest-rate sensitivity: $\delta = 0.1$, $\delta = 0.2$, or $\delta = 0.3$.

The pattern of optimal interest rate recommendations is somewhat similar to those in figures 1 and 2. When the bubble is very small, the activists all agree that policy should be tighter than the setting chosen by the skeptic. But this consensus among the activists evaporates as the bubble gets bigger, and from year 2 onward, first one and then two of the three activists recommend looser policy than the skeptic, while the activist who believes that the bubble is highly interest sensitive ($\delta = 0.3$) continues to recommend tighter policy, at least until year 6.

[12]It seems implausible that moderate rises in the real interest rate would burst the bubble with certainty, yet that is an implication of the linear form, equation (9). Simulations of the linear model with $\delta > 0.1$ do indeed generate this outcome (results not shown). It is for this reason that we use the nonlinear form for simulations with $\delta > 0.1$. As argued by Stockton (2003) in comments on this paper, one could also imagine that the relationship between the bubble's probability of collapse and the policy interest rate might be nonmonotonic, with small interest-rate rises *lowering* the subsequent probability of collapse. This could occur if investors came to view potential market gains as larger or more durable than they had previously believed, were the bubble to survive a modest policy tightening. This would undoubtedly further complicate the optimal policy recommendations of an activist.

Figure 3. Real Interest Rate Recommendations While the Bubble Survives: Varying the Interest Sensitivity of the Probability of Bursting



Note: The probability of the bubble bursting is given by equation (10) with $p^* = 0.4$. The skeptic implements policy in each year. Real interest rates are deviations from neutral.

2.2.2 Allowing for Efficiency Losses

A second natural extension is to allow for efficiency losses associated with the bubble. There are two broad ways to motivate the idea of efficiency losses. They can be motivated in terms of the economically inefficient physical overinvestment that is put in place in response to asset-price rises that are not based on fundamentals, or in terms of the damage done to the financial system when the bubble bursts.

Either way, it seems plausible that efficiency losses rise with the size of the bubble. To account for these losses, we reformulate the policy problem as setting r_t to minimize

$$L = E_t^p \left[\max(a_\tau)\right]^\kappa + \sum_{\tau=t+1}^{\infty} \left[E_t^p \left(y_\tau^2\right) + E_t^p \left(\pi_\tau^2\right)\right], \qquad (11)$$

where we assume that the efficiency losses rise either linearly with the maximum size of the bubble ($\kappa = 1$) or with the square of this maximum size (quadratic case, $\kappa = 2$).[13] We also assume, as before, that the relative weight on inflation deviations, μ, takes a value of one. Since the skeptic ignores the bubble, we assume for him that $E_t^{sc}\left[\max(a_\tau)\right]^\kappa = 0$.

Figure 4 shows a comparison of optimal interest rate settings for the skeptic and three activists. The activists all assume that the bubble's probability of bursting is given by equation (10) with $p^* = 0.4$, and with interest-rate sensitivity, $\delta = 0.2$. The first activist, however, makes no allowance for efficiency losses, and hence minimizes the standard loss function, equation (6). The second activist assumes linear efficiency losses, while the third assumes quadratic losses, and so they minimize the loss function, equation (11), assuming appropriate values for κ.

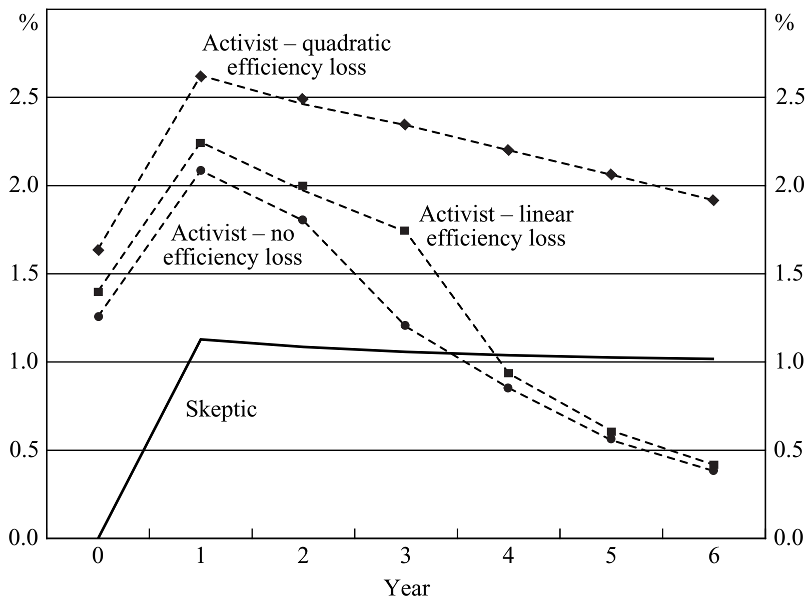
As previous figures have shown, being able to raise the probability of the bubble bursting gives an incentive to the activist policymaker to tighten policy somewhat. Figure 4 shows that taking account of efficiency losses associated with an asset-price bubble raises this incentive further, and therefore further raises the optimal interest rate recommendations of the activist. Moreover, if efficiency losses associated with the bubble are assumed to rise sufficiently rapidly with the maximum size of the bubble, then the incentive for the activist to recommend tighter policy than the skeptic is a strong one.

2.2.3 Policy Affects the Bubble's Growth

A further natural extension to the simple version of the model involves assuming that, rather than affecting the probability of the bubble bursting, the activist policymaker can, by setting tighter policy this year, reduce the extent of the bubble's growth next year if it survives. For the simulations we show for this case, we assume that

[13] An alternative way to capture these efficiency losses would be to leave our policymakers' loss function unchanged, and instead allow for *additional* contractionary effects on the real economy from the collapse of the bubble, over and above those implicit in equation (3), with the magnitude of these additional effects increasing with the maximum size of the bubble. A modeling approach along these lines was considered in Kent and Lowe (1997)—see, for example, their equation (1). However, for simplicity we have chosen to incorporate efficiency losses directly into our policymakers' loss function.

Figure 4. Real Interest Rate Recommendations While the Bubble Survives: Allowing for Efficiency Losses Associated with the Bubble



Note: The probability of the bubble bursting is given by equation (10) with $p^* = 0.4$ and $\delta = 0.2$. The skeptic implements policy in each year. Real interest rates are deviations from neutral.

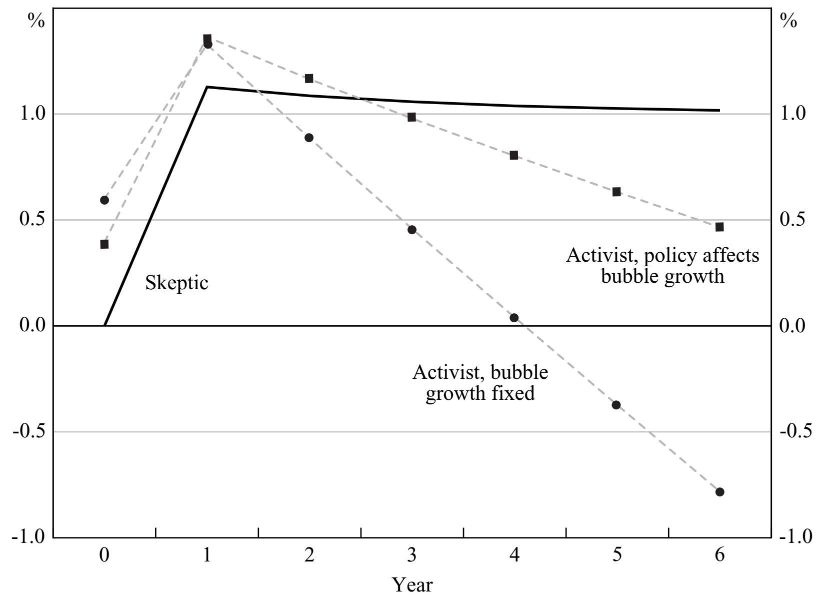
$p_t = p^* = 0.4$ (except $p_{14} = 1$) and that

$$\gamma_t = 1 - \phi(r_{t-1} - r^*_{t-1}) \,. \tag{12}$$

For reasons we discuss shortly, only large values of the parameter ϕ generate significantly changed behavior by the activist policymaker. We therefore assume that $\phi = 1$, so that by setting policy 1 percentage point higher than the skeptic this year, the bubble's growth next year is reduced from 1 percent to nothing.[14] As above, the path of

[14] If the bubble survives, it would again be necessary to set policy 1 percentage point higher than the skeptic to ensure that the bubble did not grow in the subsequent year. Given the effects of continually tight policy on the rest of the economy, it is perhaps not surprising that being able to raise the probability that the bubble will burst has more influence on optimal policy than simply being able to reduce its growth each year by setting tighter policy in each previous year.

Figure 5. Real Interest Rate Recommendations While the Bubble Survives: Policy Affects the Bubble's Growth



Note: The probability of the bubble bursting is $p_t = 0.4$. The skeptic implements policy in each year. Real interest rates are deviations from neutral.

interest rates defined by r_t^*, $t \geq 0$, is the optimal path chosen by the skeptical policymaker assuming $\gamma_t = 1$.

Figure 5 shows a comparison of optimal interest rate recommendations for the skeptic and two activists. Both activists assume that the bubble's growth is given by equation (12), but one assumes no interest-rate sensitivity, $\phi = 0$, while the other assumes high sensitivity, $\phi = 1$.[15]

For every year apart from year 0, being able to reduce the bubble's growth induces the activist policymaker to recommend tighter policy than she otherwise would. The differences in the policy recommendations induced by this expectation are, however, less pronounced than the differences that arise when an activist

[15]The results assuming no interest-rate sensitivity are equivalent to the baseline results shown in figure 1 for the activist assuming $p_t = 0.4$.

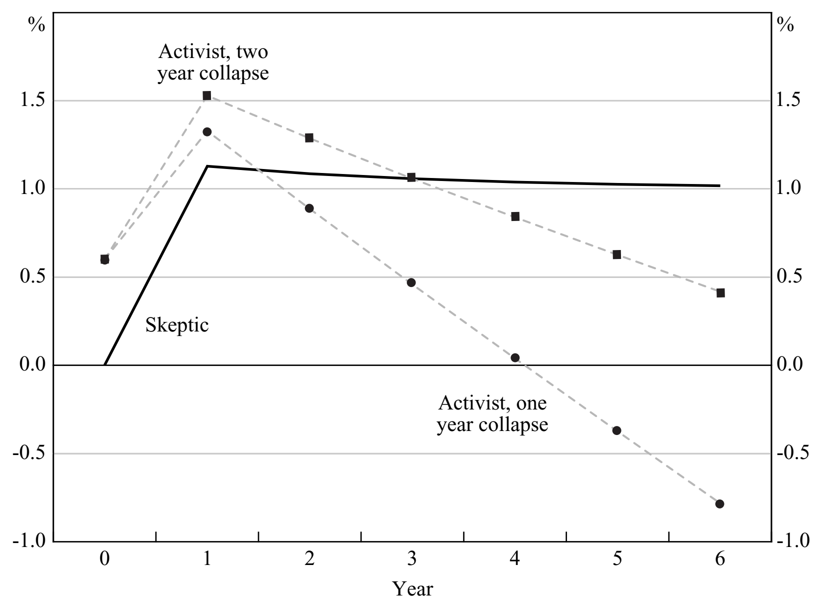
policymaker assesses the probability that the bubble will burst each year at $p_t = 0.2$ rather than $p_t = 0.4$, as can be seen by comparing figures 1 and 5.

2.2.4 Bubbles That Take Two or More Years to Collapse

Another extension to the basic model involves assuming that, when the bubble collapses, it does so evenly over two or more years, rather than suddenly in one. In the examples we have examined until now, the activist must always confront the problem that, owing to the lag structure of the Ball-Svensson model, policy can only respond to a collapsing bubble after the collapse is complete. This problem is reduced by assuming that the collapse occurs over two or more years rather than one.

Figure 6 shows results for the skeptic and two activists (one who assumes gradual, even, two-year collapse; the other, sudden),

Figure 6. Real Interest Rate Recommendations While the Bubble Survives: Bubble Takes Two Years to Collapse



Note: The probability of the bubble bursting is $p_t = 0.4$. The skeptic implements policy in each year. Real interest rates are deviations from neutral.

assuming that $p_t = p^* = 0.4$ (except $p_{14} = 1$) and that $\gamma_t = 1$. The activist who assumes that the bubble will collapse only gradually recommends tighter policy than the one who assumes that it will be sudden, because of their different assessments of the bubble's expected effect on next year's output.

Nevertheless, the overall pattern of policy recommendations remains similar to earlier cases. As the size of the bubble grows, the "gradually bursting" activist eventually recommends looser policy than the skeptic does, for reasons that are by now familiar.

In cases in which the bubble is expected to collapse evenly over three or more years, the activist would recommend tighter policy than the skeptic for longer, while the bubble is growing, a result that follows from a straightforward extension to equation (8).

2.2.5 A Rational Bubble

In the baseline results presented at the beginning of the section, we assumed that the asset-price bubble grew at a uniform rate, $\gamma_t = 1$, and that the probability of the bubble's collapse was constant through time. This seems to us a simple and intuitively appealing baseline case.

In this case, however, there is no arbitrage condition ruling out unexploited profit opportunities in the assets whose price rises constitute the bubble. Our baseline case is therefore not a "rational" bubble. We do not see this as a shortcoming—to our minds, there is much evidence that the asset-price bubbles we see in modern industrial economies are not rational in this sense (see, for example, Shiller 2000). Nevertheless, it is of interest to derive results for the case of a rational bubble.

Such a bubble arises from the actions of a rational investor who buys the relevant assets up to the point at which expected profits are driven to zero.[16]

If the probability of collapse is constant, p^*, and the capital gain to the investor in year $t + 1$ if the bubble collapses is $-a_t$, then a rational risk-neutral investor will be indifferent to holding the asset when the expected growth of the bubble, if it survives,

[16]We assume that the assets yield an annual return equal to the real interest rate, so that the expected profit relative to holding one-year government bonds is determined by the expected capital gain on the assets.

is $\Delta a_{t+1} = a_t p^*/(1 - p^*)$. This is a geometrically growing bubble, rather than the constant-growth bubble that constituted our baseline case.[17]

The arbitrage condition that defines this rational bubble implies that the bubble's expected growth over the next year, $E_t^{ac}\Delta a_{t+1}$, is zero. In this case, however, the activist and the skeptic are making identical assumptions about the bubble's expected effect on next year's output. It follows that the activist will always recommend the same policy interest rate as the skeptic for a rational bubble, provided she believes that the stochastic properties of the bubble are not affected by the actions of policymakers, so that certainty equivalence holds.[18]

This result for a rational bubble is interesting in its own right. However, it suggests another possible critique of our earlier choice of baseline bubble. This critique runs as follows.

An activist policymaker in our model economy, observing what she believes to be a developing asset-price bubble, must think the assets in question to be overvalued or they would not constitute a bubble. In this case, however, she would presumably always expect the probability-weighted value of the change in asset prices next period to be negative, while the bubble survives. Yet then, in view of the generalization of equation (8) discussed in footnote 8, such an activist would always (at least for an exogenous bubble) recommend looser policy than a skeptic while such a bubble was growing. This, however, would run counter to the central thrust of our earlier results—that the direction in which an activist approach to responding to asset-price bubbles would shift policy is not uniform, and depends sensitively on the detailed stochastic properties of the bubble.

[17]Note that, if the probability of collapse is not constant, a rational bubble need not grow at a constant geometrical rate.

[18]This result relies on a number of implicit, simplifying assumptions about the economy. In particular, it relies on the assumptions that the effect on the output gap of changes in asset prices is proportional to the size of those changes, and that rational investors and the activist policymaker agree on the exact stochastic details of the bubble. Relaxing either of these assumptions could generate different policy recommendations by the activist. For example, for a geometrically growing bubble, it could account for an activist policymaker assessing the bubble's growth rate to be faster (slower) than "rational"—say, $\Delta a_{t+1} = \chi a_t p^*/(1 - p^*)$, with $\chi > 1$ ($\chi < 1$)—in which case the activist's policy recommendations would always be tighter (looser) than the skeptic's for as long as the bubble survived.

Fortunately for our analysis, we believe there is a flaw in this chain of reasoning. The critical link is the presumption that, if an activist policymaker believes asset prices to be currently overvalued, she will necessarily judge the expected value of the change in these prices next period to be negative. We do not believe this need be so.

Specifically, such an activist may regard the current level of asset prices as irrational, *in the sense of having become unmoored from fundamentals*, yet still judge it likely that these prices will continue to rise next period, with sufficient probability to make the bubble's expected excess return next period positive. Such an assessment merely requires a view that enough market participants do not yet share her view as to the overvaluation of the relevant asset prices—together with a belief, which the empirical evidence would seem to support, that asset-price misalignments can often persist for extended periods.[19] As such, a bubble process along the lines of our baseline bubble seems to us quite a natural and plausible benchmark from which to have begun our analysis in this section.

3. Discussion

As discussed at the outset, there are two competing schools of thought in the literature regarding the appropriate response of monetary policy to asset-price bubbles. The first, often associated with Bernanke and Gertler (2000), argues that monetary policy should only respond to observed changes in asset prices to the extent that they signal current or future changes to inflation or the output gap. The second, advanced by Cecchetti, Genberg, and Wadhwani (2003), argues that raising interest rates modestly as asset prices rise above what are estimated to be warranted levels can reduce the effects

[19]This point can be strikingly illustrated by considering the case of a pyramid scheme, for which there may be no underlying assets whatsoever. An observer who becomes aware of such a scheme in its early stages need not necessarily conclude that it will collapse next period, even though there is no doubt that it is fundamentally irrational. Rather, it may be perfectly rational to expect that such a scheme will continue to grow for several periods, until enough people become wary of its unsustainable nature that it suddenly fails some time down the track. For a detailed model in which it may be rational for speculators to buy into a market which they understand to be experiencing a bubble, see DeLong et al. (1990). More generally, regarding the distinction in our setting between policymakers' assessments of asset-price developments and those of market participants, see also the earlier discussion in footnote 18.

Table 1. Activist's Policy Recommendations While the Bubble Survives

Scenario	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Policy can't affect bubble						
$p_t = 0.2$	+	+	+	=	−	−
$p_t = 0.4$	+	−	−	−	−	−
Policy affects probability of bursting						
$p^* = 0.2$, $\delta = 0.1$	+	+	+	+	+	+
$p^* = 0.4$, $\delta = 0.1$	+	+	−	−	−	−
$p^* = 0.4$, $\delta = 0.2$	+	+	+	−	−	−
$p^* = 0.4$, $\delta = 0.3$	+	+	+	+	+	−
Linear efficiency losses	+	+	+	−	−	−
Quadratic efficiency losses	+	+	+	+	+	+
Policy affects bubble growth	+	+	−	−	−	−
Bubble bursts over two periods	+	+	+	−	−	−
Rational bubble	=	=	=	=	=	=

Key: Tighter (+), looser (−), or the same as (=) the skeptic's recommendation

of asset-price bubbles on output and inflation, thereby enhancing macroeconomic stability.

Our paper does not resolve this debate. However, the results of our simulations do serve to highlight the information required to successfully implement activist policy, thereby bringing the debate closer to the policy arena. These results are summarized in table 1. For each set of assumptions, this table shows, as time proceeds and the bubble grows, whether the activist in our model setting would recommend tighter (+), looser (−), or the same (=) policy settings as the skeptic.

There are several broad lessons worth highlighting from this summary. When the asset-price bubble is small enough, the activist policymaker always (except in the case of the rational bubble) recommends tighter policy than the skeptic who ignores the future possible paths of the bubble. However, this result is of limited practical relevance. Although we have assumed that activist policymakers learn about the nature of the bubble at its inception, in reality there is likely to be much doubt in the early stages about whether rising asset prices constitute a bubble. Asset-price bubbles rarely arise out of thin air—instead, they usually occur when the evolving economic fundamentals are consistent with some rise in asset prices. While there will always be some doubt about whether rising asset prices constitute a bubble, these doubts would seem particularly acute when the suspected deviation of asset prices from fundamentals remains small and has been short-lived. For these reasons, there would seem to be no strong case for central banks to respond to small asset-price misalignments.[20]

As the bubble grows, however, there are two developments with potentially conflicting implications for appropriate activist policy. On the one hand, an activist policymaker should become increasingly confident that the observed asset-price rises *do* constitute a bubble, which should strengthen the case for responding actively to them. On the other hand, as the bubble grows, the potential negative effects from its eventual bursting will increase. Whether this constitutes an argument for tighter or looser policy will depend on the nature of the bubble.

The case for tightening is to offset the expansionary effects of future expected growth of the bubble and, in some formulations, to reduce the bubble's growth or help to burst it. As we have seen, there are circumstances in which this case is particularly compelling—in particular, when the probability that the bubble will burst of its own accord over the next year is assessed to be small, the bubble's probability of bursting is quite interest sensitive, efficiency losses associated with the bubble rise strongly with the bubble's size, or the bubble's demise is expected to occur gradually over an extended period, rather than in a sudden bust. Conversely, the case for

[20]Cecchetti, Genberg, and Wadhwani (2003, 440) also make this point when they say, "Our proposal [to raise interest rates modestly as asset prices rise above what are estimated to be warranted levels] does not call for central banks to respond to small misalignments. We agree that these are difficult to detect and are unlikely to have very strong destabilizing effects in any case."

loosening is strongest when these conditions are reversed, since in those circumstances it becomes increasingly important to allow for the contractionary impact that arises when the bubble bursts.[21] The stochastic process driving the bubble is thus crucial to determining which of these considerations predominates.[22]

4. Conclusions

The appropriate strategy for policymakers faced with an asset-price bubble depends sensitively on the stochastic properties of the bubble, which highlights the stringent informational requirements inherent in an activist approach. Where sufficient information about the bubble process is not available to policymakers, a robust approach, something along the lines of the standard inflation-targeting approach used by our skeptic, may be the best that can be achieved. Given sufficient information about the bubble process, an activist approach may be feasible, but our results suggest that the appropriate response to bubbles is not uniform. In particular, it may be optimal to "lean against" some bubbles but not others, and hence the formulation of an activist strategy requires judgments to be made about the process driving the bubble and its likely sensitivity to monetary policy.

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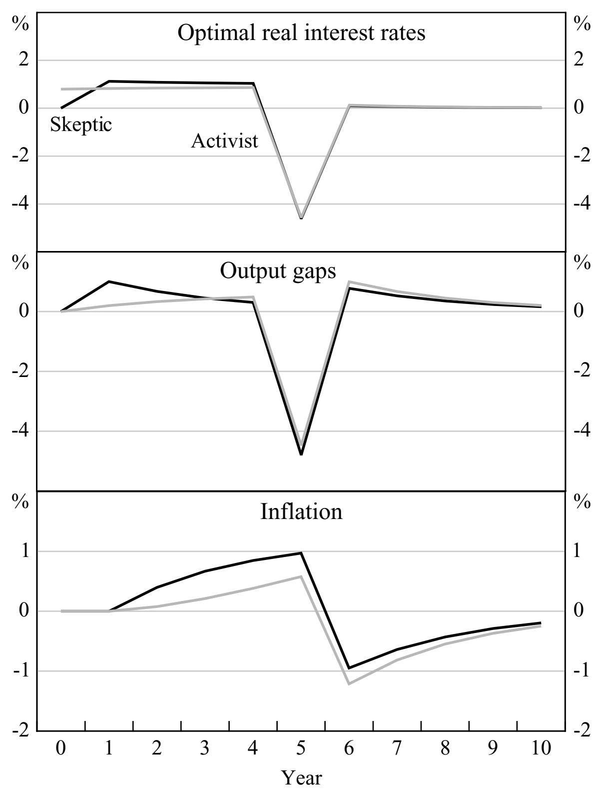
[21]In a passage immediately following the one quoted in the previous footnote, Cecchetti, Genberg, and Wadhwani (2003) say, ". . . There are clearly times when egregious misalignments exist. Recent examples include Japanese stock and land prices in 1989, and the NASDAQ in late 1999 and early 2000. While some portion of these high price levels may have been justifiable based on fundamentals, few people would deny that a significant component was due to asset market disturbances. Ultimately, in terms of reducing inflation and output volatility, *it is important that central bankers respond to these large relatively 'obvious' misalignments.*" (p. 440, italics added) When misalignments are large and relatively obvious, however, our results suggest that it may be unclear whether the appropriate policy response is to raise interest rates modestly or to lower them, unless the policymaker has specific knowledge about the stochastic process driving the bubble.

[22]It is also possible that the probability of the bubble bursting of its own accord over the next year might rise as the bubble gets larger. If so, the case for looser, rather than tighter, policy by the activist is further strengthened, a point also made by Kent and Lowe (1997). For most of our simulations, we have assumed $p^* = 0.4$, implying an average remaining life for the bubble of two and one-half years, which may be a more plausible assumption for intermediate and larger bubbles than $p^* = 0.2$, which implies an average remaining life of five years.

Appendix. Policy Settings for a Bubble That Bursts in the Fifth Year

We assume a constant probability $p_t = 0.2$ that the bubble bursts in each year. In contrast to the simulations reported in the text, we allow both the skeptic and the activist to implement policy through time—so that the state of the economy depends on the identity of the policymaker. Figure 7 shows results assuming that, as events turn out, the bubble grows for four years, during which time it has

Figure 7. Results for Bubble That Happens to Burst in the Fifth Year



Note: Bubble's ex ante probability of bursting in each year is $p_t = 0.2$. Real interest rates are deviations from neutral; inflation rates are deviations from target.

a direct expansionary effect on output of $\gamma = 1$ percent in each year, and then bursts in the fifth year, with a direct contractionary effect on output of 4 percent in that year.[23] The top panel shows the real interest-rate profiles, r_t, set by the two policymakers; the second and third panels show the outcomes for the output gap, y_t, and the inflation rate, π_t.

While the bubble is growing, the paths for output and inflation generated by the skeptic's policy settings reflect the continued expansionary effects of the bubble. The activist responds more aggressively to these expansionary effects because she anticipates them, but nevertheless she does not offset them completely because of the possibility that the bubble may be about to burst. Therefore, even with the activist's optimal policy settings, output and inflation remain above target while the bubble survives.

The bursting of the bubble in year 5 generates a severe recession. Output falls by more than the direct contractionary effect of the bubble bursting, because policy in the previous year has been tighter than neutral to offset the bubble's expansionary effects. In response to the bubble's collapse, policy is eased aggressively. Despite using the same policy rule after the bubble bursts—namely the modified Taylor rule, equation (7)—the paths for the policy interest rate, output, and inflation are somewhat different for the two policymakers because they have set different policy interest rates in earlier years.

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[23] A bubble with a probability of bursting each year of $p_t = 0.2$ bursts on average in the fifth year.

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