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Asset Price Bubbles and Monetary Policy: A Multivariate Extension

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While views range widely about whether it is appropriate to use monetary policy to try to curb an asset price boom, there appears to be less disagreement about the prescription of easing monetary policy in the aftermath of a sharp break in an equity price bubble. This paper considers the monetary policy tradeoffs in a multivariate bubble setting, where such conventional wisdom could lead policymakers astray. The tradeoffs appear particularly complex when the collapse of the equity price bubble coincides with expansion of a housing price bubble. Technically, the optimal monetary policy model in this paper is an extension of the earlier work of Filardo (2003d) into endogenous univariate bubbles in the context of a fully dynamic model. This approach contrasts with the existing literature which has emphasised the question of whether monetary authorities should simply respond to univariate asset price movements using an exogenous bubble approach or the one-shot endogenous bubble approach. The model is sufficiently flexible to allow for uncertainty about the nature of the bubble as well as other relevant policy issues.

I. Introduction

The debate about whether central banks should respond to asset price bubbles has evolved considerably over the past decade. Initially, there was general scepticism about the efficacy of policy reactions and even considerable doubt about the putative existence of bubbles. While doubts still abound, there is much more acceptance of the fact that central banks should seriously consider the possible ramifications of asset price booms and busts and how central banks might optimally calibrate their policy settings. Prudence advises hoping for the best but preparing for the worst.

Views about the relevance of asset price bubbles have been greatly influenced by the movement in equity prices over the past decade. These views have become more complicated in recent years as housing prices have taken a more prominent role in monetary policy discussions. In part, the simultaneous collapse of equity prices and strong boost in housing prices deepened our understanding of the possible forces affecting disparate financial markets. Indeed, the steady rise in real estate prices may have reinforced the notion that even if some asset prices might appear to be priced "correctly" cross-sectionally, they might nonetheless show persistent intertemporal mispricing and even apparent and persistent disconnects across markets.

Concerns about linkages between boom-bust behaviour in equity prices and housing prices naturally arose during the period (eg see Borio and McGuire 2004). Were bubbles in different markets linked? Did the peaks have a temporal ordering and did the collapse of the equity price bubble increase, or decrease, the likelihood of a housing price collapse? Of particular importance was the question of whether the monetary policy response to the collapse of the equity price bubble could have unexpectedly led to the subsequent size and longevity of the housing price bubble. Some progress has been made in understanding the nature of the relationship but our understanding remains fairly rudimentary. This gap in our understanding leaves plenty of room for more speculative "what if" modelling exercises to explore some of the monetary policy tradeoffs, under various plausible assumptions. In particular, such exercises can shed light on the conjecture that central banks might prefer to respond to the collapse of an asset price bubble in an ex post fashion, rather than "leaning" against it in an ex ante fashion during the boom phase so as to prevent the build up of risk of a downward economic and financial cascade.

The paper addresses these important monetary policy questions with a model that explicitly incorporates multivariate asset price bubbles and a channel by which a monetary authority can influence the evolution of asset price bubbles. In the model, high output and low interest rates produce a fertile environment for multivariate asset price bubbles to expand simultaneously. This of course leaves open the possibility that central banks may optimally prefer to affect the longevity and size of asset price bubbles by taking actions. The advantage of the modelling approach over previous efforts is that the question of the optimality of pricking asset price bubbles can be addressed directly. To anticipate the conclusions of the paper, the possibility of multiple bubbles reduces the attractiveness of ex post versus ex ante monetary policy strategies to address asset price bubbles. In particular, the delay in reacting to the expansion of one bubble may extend its longevity, size and ultimately the disorderliness of its collapse, which might require a much more aggressive ex post monetary policy reaction; in turn, this response could perpetuate cycles of boom-bust behaviour in other bubbles. This conclusion from the model has implications for recent history. It would suggest that the aggressive and persistent easing of monetary conditions in the wake of the stock market collapse in the past decade might have helped pump up, unwittingly for central banks around the globe, a real estate price boom.

Technically, the model in this paper is an extension of earlier work into endogenous univariate bubbles by Filardo (2003d).[1] This contrasts with the existing literature which places emphasis on the question of whether monetary authorities should simply respond to univariate asset price movements, as explored by Bernanke and Gertler (1999, 2001), Cecchetti, Genberg, Lipsky and Wadhwani (2000), Filardo (2001), Dupor (2001) and others using an exogenous bubble approach.[2] The monetary policy model of the economy is adapted from Rudebusch and Svensson (1999) and optimal monetary policy is calculated. In addition, the model allows for uncertainty about the nature of the bubble process–in the limit, whether there is a bubble or not. Implications of uncertainty about the bubble for monetary policy are explicitly explored, along with broad monetary and regulatory policy implications.

This paper begins with some stylised facts about multivariate bubbles and raises some general modelling issues related to asset price bubbles and monetary policy. Section III then lays out the particular specifications of interest and characterises the inherent nonlinearities, first using a simpler univariate asset price bubble to illustrate some of the complex dynamics and then focusing on a multivariate extension of the model. Section IV discusses policy implications and draws conclusions for future research.

II. Thinking about bubbles

Writing down a monetary policy model with asset price bubbles in it is not an uncontroversial exercise. One first must assume that bubbles exist and that one can characterise the evolution of the bubbles. The existence of bubbles is still quite controversial, owing in large part to the lack of consensus about their definition and the inability to observe them with certainty. Various definitions have been suggested, which are reviewed in Filardo (2003c). The notion closest to the spirit of the exercise in this paper is that of an irrational bubble (Meltzer (2003), Allen and Gale (1999)). The

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[1] Earlier research efforts into endogenous bubbles include Bordo and Jeanne (2002), Kent and Lowe (1997) and Gruen, Plumb and Stone (2003). These models tended to examine one-shot bubbles instead of a fully dynamic solution.

[2] Other efforts to explore the trade-offs include Akram et al (2006), Christiano and Rostango (2005), Disyatat (2005), Roubini (2006), Berger, Kissmer and Wagner (2005) and Zampoli (2006).

irrational bubble largely reflects the statistical properties of boom-bust behaviour that can be seen in asset prices from time to time across a wide range of countries.[3] In many respects, the definition of an irrational bubble sweeps under the rug many intriguing questions about how bubbles arise, what sustains them and what triggers a collapse. From a macroeconomic point of view, these questions may be of second order importance at this point in time, relative to the questions about what policymakers might want to do about them.

A starting point of reference for this study is the empirical behaviour of various asset prices over the past few decades. While there is considerable latitude to disagree with any particular characterisation of the swings in key asset prices, there is a set of reasonable economists, both inside and outside the central banking community, who have labelled these wide swings as being symptomatic of asset price bubbles. For practical purposes, this paper will focus on equity price and housing price developments. Graph 1 shows that equity prices and housing prices have exhibited behaviour that is arguably consistent with bubble behaviour, ie persistent expansion in prices and subsequent sharp declines. Also noteworthy is the co-movement of housing and equity prices as well as a tendency for equity price peaks to precede housing price peaks.[4]

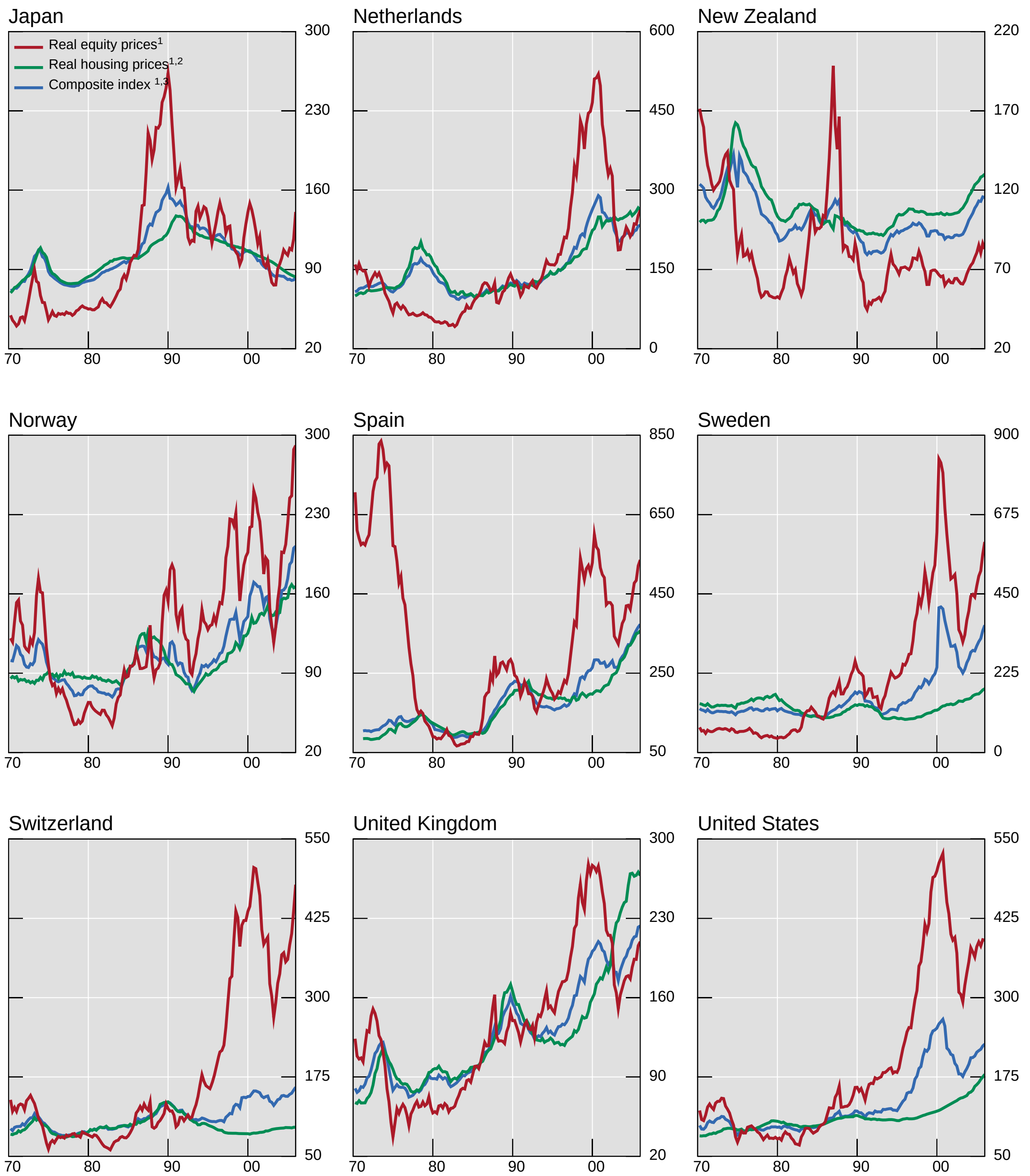
Various modelling challenges follow from these observations. In a nutshell, the key challenge is to write down a representation of multivariate bubbles that replicates the time-series behaviour of what is evident in the historical records. To this end, hypothetical bubbles should exhibit gradual expansions followed by sharp contractions. The trigger of the collapse should not be deterministic but rather stochastic in nature. Moreover, in contrast to many existing models of endogenous bubbles, the bubbles should not be static one-shot games but rather dynamic, recurring processes. This dynamic aspect enriches the types of tradeoffs central bankers face because strategies to fight a given bubble may have implications for the evolution (eg likelihood, longevity and size) of subsequent bubbles. The stochastic processes on the bubbles are necessary but not sufficient for a complete analysis. Of critical importance is the assumed influence on key macroeconomic variables. At this point in time, this aspect of the problem is the most speculative because of considerable uncertainty about how consumers, investors and workers factor asset price bubbles into their behaviour. In some episodes

[3] The label "irrational" may be somewhat unfortunate because this type of boom-bust behaviour might be quite consistent with a weaker form of rationality than is generally the case when assuming rational expectations. For example, see models of De Grauwe and Grimaldi (2006) and Kurz (1998).

[4] For a more detailed analysis of these booms and busts, see for example, Case and Shiller (2003), Detken and Smets (2004) and ECB (2006). For a less favourable bubble interpretation, see for example Himmelberg et al (2005), McCarthy and Peach (2004) and Smith and Smith (2006).

Graph 1 – Cross-country equity, housing and composite asset prices

Equity and housing prices

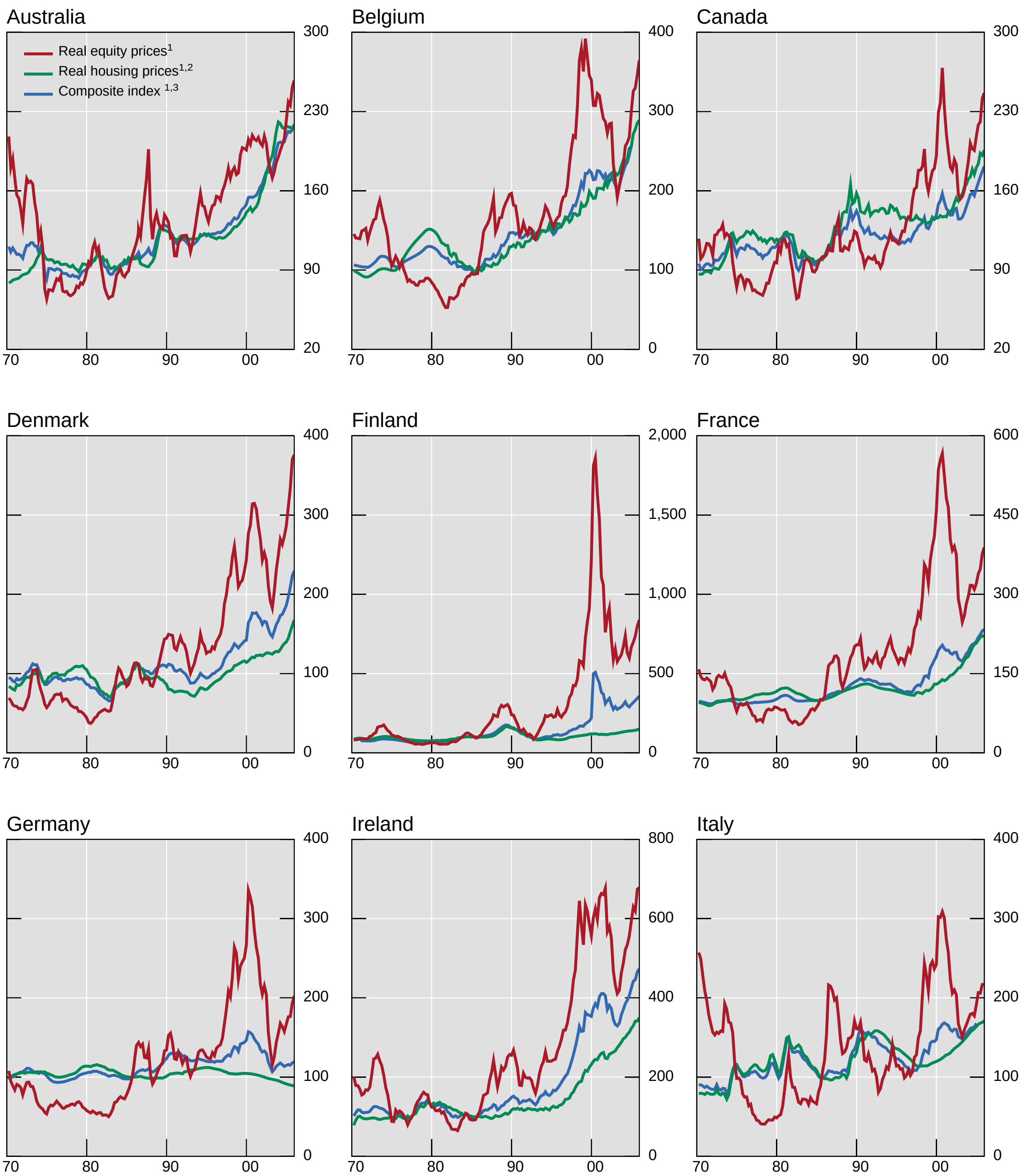


[1] 1985 = 100; nominal prices deflated by the personal consumption. [2] National benchmark indices. [3] Real aggregate asset price index; defined as weighted average of national price indices for equities and residential and commercial real estate.

Sources: Various private real estate associations; national data; BIS calculations.

Graph 1 – Cross-country equity, housing and composite asset prices (con't)

Equity and housing prices



¹ 1985 = 100; nominal prices deflated by the personal consumption. ² National benchmark indices. ³ Real aggregate asset price index; defined as weighted average of national price indices for equities and residential and commercial real estate.

Sources: Various private real estate associations; national data; BIS calculations.

there is evidence that economic agents can "look through" the asset price booms; in such a situation the excesses in one market need not spillover into other markets, thereby muting the nonlinearities, or contagion, that might arise in the aftermath of a collapse.

The model in this paper does take a stand on these key features, to varying degrees of satisfaction. As will be seen, the model does address the possibility of complex nonlinearities. Further exploration of these types of nonlinearities might shed important light, but at this stage they should be seen as being more stylised than a convincing replication of reality. Another important departure from much of this literature is that this paper focuses on optimal monetary policy strategies in the presence of information constraints. In this way, the results in this paper provide some guidance about how to think about the policy tradeoffs in a more disciplined way, ie one that provides a positive analysis rather than the mixture of both positive and normative elements as has been the case in many papers on this subject of late. Finally, the paper attempts to understand how the optimal monetary policy strategies might change when there is uncertainty associated with the identification of asset price bubbles in real time and clarifies what type of uncertainties are of prime importance.

III. Modelling multivariate asset price bubbles

There are many ways to model multivariate asset price dynamics. This paper extends the basic framework of Filardo (2003d), which admittedly is based on a fairly stylised model of the policy trade-offs faced by a monetary authority. The model economy can be described by three blocks of equations: a macroeconomic block, an asset price block and a monetary policy block. In many respects, this is a stripped down version of a much larger-scale model but nonetheless highlights the key policy tradeoffs arising from the possibility of multivariate asset price bubbles.

Macroeconomic block

The macroeconomic block is an extension of the Rudebusch and Svensson (1997) model incorporating a vector of asset prices. The demand side of the model is assumed to have a standard *IS* curve specification. Inflation fluctuations are modelled as a standard backward-looking Phillips curve with an additional source of inflation coming from asset prices.[5] As specified, it is only the non-

[5] This can be generalized to be forward-looking but there are a few good reasons in this paper to suppress this dimension of the policy problem. First, it helps to focus on the set of information variables relevant to policymakers. In a forward-looking specification, variables such as the fundamental and non-fundamental components of asset prices might be thought of as instrumental variables; hence, from a practical point of view such variables would be important but their practical importance might be obscured by focusing on the valid claim that asset prices only matter to the extent that they help to predict future inflation and output. Second, as long as the relevant policy experiments in the paper are roughly immune from the Lucas critique, a backward-looking representation might be deemed a reasonable approximation. Third, the backward-looking assumption

fundamental, or bubble, component of asset prices that contributes to inflation, above and beyond what is already captured in the output gap or past inflation rate. Algebraically, the first block of the system is represented compactly as follows:

Macro block

$$
\begin{aligned}
&(IS) \quad y_t &&= -\gamma r_{t-1} &&+ \theta y_{t-1} + \boldsymbol{\varphi}\left(\boldsymbol{\pi}_{AP,t-1} - \boldsymbol{\pi}_{t-1}\right) + \varepsilon_t \\
&(PC) \quad \pi_t &&= \pi_{t-1} &&+ \alpha y_{t-1} + \boldsymbol{\beta}\boldsymbol{\pi}_{NF,t-1} + \eta_t
\end{aligned}
\tag{1}
$$

where $\boldsymbol{\varphi} = \left(\phi_e, \phi_h\right)$ and $\boldsymbol{\beta} = \left(\beta_e, \beta_h\right)$; y is the output gap, r is the interest rate controlled by the monetary authority, π is the inflation rate, $\boldsymbol{\pi}_{AP}$ is a vector of the rates of asset price appreciation, which in turn is a function of $\boldsymbol{\pi}_F$ (the rate of change in asset prices attributable to fundamentals) and $\boldsymbol{\pi}_{NF}$ (the rate of change in asset prices attributable to the bubble component of asset prices). Without loss of generality, it is assumed for simplicity that the bubble is bivariate.

To be more specific, the real return on asset prices in the IS equation captures the potential channels of asset prices, eg equity and housing price inflation, on consumption (via a real or perceived wealth effect), investment (via a cost of capital effect) and government spending (via a tax revenue effect). The linkages are kept fairly simple and linear in order to keep this block of equations relatively easy to manipulate and interpret. The error terms in the *IS* and *PC* equations are assumed to be normally distributed with mean zero and a fixed variance.

Asset price block

The simplicity of the first two equations has the additional benefit of allowing us to focus closely on the implications of the nonlinear asset price dynamics and hence the monetary policy tradeoffs, in the overall system of equations. To investigate the nature of the macroeconomic dynamics in this system it is useful to spell out the details of how asset prices evolve in this hypothetical economy. Without loss of generality, we assume a bivariate asset price specification; clearly this can be easily extended to a greater number of asset prices. In light of recent history, it is natural to think in terms of equity price and housing price developments. The components of the asset price block have the following specification:

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simplifies the model sufficiently to use the solution algorithm proposed in the paper, which admits a very flexible specification of multivariate asset price bubbles.

(2) $$\begin{gathered}\textit{Asset price block} \\ (AP)\ \boldsymbol{\pi}_{AP,t} = \boldsymbol{\pi}_{F,t} + \boldsymbol{\pi}_{NF,t}\end{gathered}$$

where

(3) $$\begin{aligned}(F)\quad \boldsymbol{\pi}_{F,t} &= \begin{pmatrix}\pi^e_{F,t} \\ \pi^h_{F,t}\end{pmatrix} = i\pi_{t-1} + \begin{pmatrix}\lambda^e \\ \lambda^h\end{pmatrix} y_{t-1} + \begin{pmatrix}\nu^e_t \\ \nu^h_t\end{pmatrix} \\ (B)\quad \boldsymbol{\pi}_{B,t} &= \begin{pmatrix}\pi^e_{B,t} \\ \pi^h_{B,t}\end{pmatrix} = \zeta_t(y_{t-1}, r_{t-1})\end{aligned}$$

where i is a unit vector, (λ^e, λ^h) are coefficients and $(\nu^e, \nu^h) \sim N(0, \sigma^2_j), j = \{e, h\}$.

The fundamental components of asset prices (F) are assumed to have a simple structure. The real growth rate of housing and equity prices is proportional to output, y. More complicated functions can be constructed but this is suppressed for simplicity. The nonfundamental, or bubble, components are modelled as nonlinear random functions of output and interest rates. The details of the $\zeta(y_{t-1}, r_{t-1})$ are described in more detail below. As will be seen, the nonlinearity implied by this assumption will introduce interesting nonlinear dynamics of the model and enrich the types of trade-offs that the hypothetical monetary authority face in such an environment.

Monetary policy block

Given this structure of the macroeconomy and asset price dynamics, the monetary authority's challenge is to choose a policy interest rate in order to minimize the weighted average of the variance of output, inflation and the change in interest rates, that is, the monetary authority's loss function,[6]

(4) $$L = \operatorname{var}(y) + \mu_\pi \operatorname{var}(\pi) + \mu_r \operatorname{var}(r - r_{-1}).$$

The theory of stochastic optimal control problems states that the optimal monetary policy can be characterized as a function of the state space. In this paper, we will limit the search of the function to the class of linear feedback rules of the form[7]

[6] The variance of the change in the interest rate is included to reflect the general desire of central banks to smooth interest rate fluctuations.

(5) $$r_t = a_y y_t + a_\pi \pi_t + \mathbf{a}_F \boldsymbol{\pi}_{F,t} + \mathbf{a}_{NF} \boldsymbol{\pi}_{NF,t}\,.$$

This full mathematical statement of the model can be summarized in the state-space representation to highlight the simple dynamic structure:

(6) $$\underset{\{a_y, a_\pi, \mathbf{a}_F, \mathbf{a}_{NF}\}}{\operatorname{argmin}} L$$

subject to

(7) $$X_t = AX_{t-1} + BE_t$$

where

(8) $$X_t = \begin{pmatrix} y_t \\ \pi_t \\ \pi^e_{F,t} \\ \pi^h_{F,t} \\ \pi^e_{B,t} \\ \pi^h_{B,t} \end{pmatrix}$$

$$A = \begin{bmatrix} \theta - \gamma a_y & -\gamma a_\pi - \phi^h - \phi^e & -\gamma a^e_F + \phi^e & -\gamma a^h_F + \phi^h & -\gamma a^e_{NF} + \phi^e & -\gamma a^h_{NF} + \phi^h \\ \alpha & 1 & 0 & 0 & \beta^e & \beta^h \\ \lambda^e & 1 & 0 & 0 & 0 & 0 \\ \lambda^h & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \text{ and } E_t = \begin{pmatrix} \varepsilon_t \\ \eta_t \\ \upsilon^e_t \\ \upsilon^h_t \\ \zeta^e_t \\ \zeta^h_t \end{pmatrix}.$$

In the paper, it is not only interesting to examine the results corresponding to the optimal policy rule (equation 5) but also to look at rules that do not require the ability of the central bank to identify the fundamental and non-fundamental components. In particular, rules will be calculated that assume

[7] See, eg, Chow (1978).

that the monetary authority responds to observable asset price growth ($y, \pi, \boldsymbol{\pi}_{AP}$) and to the more conventional rule based on (y, π). In this way, we can evaluate the marginal benefits, if any, of reacting to asset price developments above and beyond the conventional case.

Benchmark model

This paper also explores various specifications of the non-fundamental, or bubble, process. The benchmark case is that of a two-sided, exogenous multivariate bubble with Markov probabilities governing the transitions across states. The process is considered two-sided because there is a possibility of positive as well as negative bubbles. A positive bubble represents geometric growth in an asset price, where the rate of expansion is taken to be constant, without loss of generality. It is multivariate owing to the bivariate asset price assumption. These two features will not vary across the alternative specifications. The exogeneity assumption, however, will be relaxed in the alternatives. The assumption of exogeneity implies the transition probabilities are independent of the evolution of the other state variables in the model, ie the transition probabilities are fixed. From the point of the hypothetical monetary authority, the evolution of the bubbles is independent of what happens in the economy and its own actions in setting the interest rate.

In this case the fixed transition probabilities (FTP) can be written as

(9) $$\mathbf{P}_{-1,0,1} = \left(\begin{array}{c|c} P^{e}_{1-,0-1} & \mathbf{0} \\ \hline \mathbf{0} & P^{h}_{-1,0,1} \end{array} \right)$$

where the diagonal elements of the partitioned transition probability matrix are

(10) $$\mathbf{P}^{i}_{-1,0,1} = P(I^{i}_{t} \mid I^{i}_{t-1}) = \begin{pmatrix} p^{i}_{-1,-1} & p^{i}_{-1,0} & 0 \\ p^{i}_{0,-1} & p^{i}_{0,0} & p^{i}_{0,1} \\ 0 & p^{i}_{1,0} & p^{i}_{1,1} \end{pmatrix}, \text{ for } i \in \{e, h\}.$$

In this case, the stochastic process for the asset price bubble can be written as a multinomial distribution that is dependent on the previous realisation of the state of the bubble but independent of all other variables in the system:

$$(11)\qquad \pi^i_{B,t}=\zeta^i_t=\begin{cases}\theta^i_p & \textit{with probability } p^i_{1,1},\ \textit{given } s^i_{t-1}=1\\ -\theta^i_p\tau^i_{t-1} & \textit{with probability } 1-p^i_{1,1},\ \textit{given } s^i_{t-1}=1\\ \theta^i_p & \textit{with probability } p^i_{0,1},\ \textit{given } s^i_{t-1}=0\\ 0 & \textit{with probability } p^i_{0,0},\ \textit{given } s^i_{t-1}=0\\ \theta^i_n & \textit{with probability } p^i_{0,-1},\ \textit{given } s^i_{t-1}=0\\ \theta^i_n & \textit{with probability } p^i_{-1,-1},\ \textit{given } s^i_{t-1}=-1\\ -\theta^i_n\tau^i_{t-1} & \textit{with probability } 1-p^i_{-1,-1},\ \textit{given } s^i_{t-1}=-1\end{cases}\quad \text{, for } i\in\{e,h\}.$$

In a positive bubble state, the bubble grows by an increment θ^i_p. In a negative bubble state, the bubble grows by an increment θ^i_n. Otherwise the bubble collapses to zero.

Alternative transition probability specifications

Two other specifications are considered. Each represents a different perspective to which the multivariate bubble processes are interrelated.

The *first alternative* allows the time-varying transition probabilities (TVTP) for the two asset price bubbles to depend on common state variables contained in *X*. In a sense, the interrelationships between the bubbles are *indirect*, and hence the alternative is labelled the *weakly interacting multivariate bubble* specification.

$$(13)\qquad \mathbf{P}_{-1,0,1}\left(X_{t-1}\right)=\left(\begin{array}{c:c} P^e_{-1,0,1}\left(X_{t-1}\right) & 0\\ \hdashline 0 & P^h_{-1,0,1}\left(X_{t-1}\right)\end{array}\right)$$

$$(14)\quad \mathbf{P}^i_{\mathbf{-1,0,1}}\left(X_{t-1}\right)=P^i(I_t\mid I_{t-1},X_{t-1})=\begin{pmatrix} p^i_{-1,-1}\left(X_{t-1}\right) & p^i_{-1,0}\left(X_{t-1}\right) & 0\\ p^i_{0,-1}\left(X_{t-1}\right) & p^i_{0,0}\left(X_{t-1}\right) & p^i_{0,1}\left(X_{t-1}\right)\\ 0 & p^i_{1,0}\left(X_{t-1}\right) & p^i_{1,1}\left(X_{t-1}\right)\end{pmatrix}\ \text{for } i\in\{e,h\}.$$

(15) $$\pi_{B,t}^{i} = \zeta_t^{i} = \begin{cases} \theta_p^i & \textit{with probability } p_{1,1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = 1 \\ -\theta_p^i \tau_{t-1}^i & \textit{with probability } 1 - p_{1,1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = 1 \\ \theta_p^i & \textit{with probability } p_{0,1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = 0 \\ 0 & \textit{with probability } p_{0,0}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = 0 \\ \theta_n^i & \textit{with probability } p_{0,-1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = 0 \\ \theta_n^i & \textit{with probability } p_{-1,-1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = -1 \\ -\theta_n^i \tau_{t-1}^i & \textit{with probability } 1 - p_{-1,-1}^i\left(X_{t-1}\right), \textit{ given } s_{t-1}^i = -1 \end{cases}$$

where θ_p^i and θ_n^i represents the rate at which the bubble grows in the positive and negative bubble states, and τ_{t-1}^i tracks the duration of the bubble phase. The bubble is parameterized so that $\left(\theta_p^e = 0.3,\ \theta_n^e = 0.3, \theta_p^h = 0.3,\ \theta_n^h = 0.3\right)$

The general specification of the time-varying transition probabilities is

(16) $$P_{j,k}^i\left(\tilde{X}_{t-1}\right) = G\left(\frac{\exp\left(\mu_{0,I_{t-1}} + \mu_{I_{t-1}}\tilde{X}_{t-1}\right)}{1+\exp\left(\mu_{0,I_{t-1}} + \mu_{I_{t-1}}\tilde{X}_{t-1}\right)}\right), \qquad \tilde{X}_{t-1} = \left(y_{t-1}, r_{t-1}, \boldsymbol{\tau}\right).$$

(17) $$P_{0,0}^i\left(\tilde{X}_{t-1}\right) = 0.96 - 1.92 \times \left|\frac{\exp\left(0.5 y_{t-1}\right)}{1+\exp\left(0.5 y_{t-1}\right)} - 0.5\right|$$

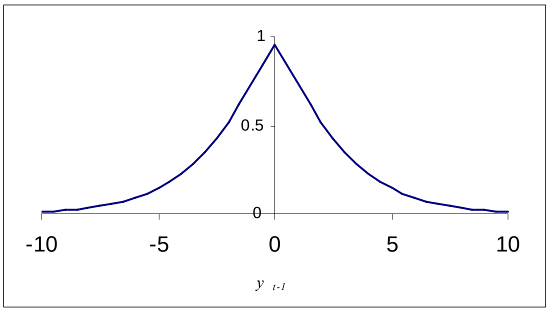
$$P_{0,1}^i\left(\tilde{X}_{t-1}\right) = \left(1 - P_{0,0}^i\left(\tilde{X}_{t-1}\right)\right) \times \frac{\exp\left(y_{t-1}\right)}{1+\exp\left(y_{t-1}\right)}, \quad P_{0,-1}^i\left(\tilde{X}_{t-1}\right) = 1 - P_{0,0}^i\left(\tilde{X}_{t-1}\right) - P_{0,1}^i\left(\tilde{X}_{t-1}\right)$$

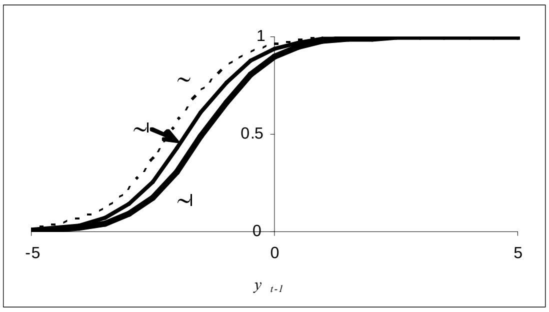
(18) $$P_{1,1}^i\left(\tilde{X}_{t-1}\right) = \frac{\exp\left(2.5 + 1.1 y_{t-1} - 0.4 r_{t-1} - 0.1\tau_{t-1}^i\right)}{1+\exp\left(2.5 + 1.1 y_{t-1} - 0.4 r_{t-1} - 0.1\tau_{t-1}^i\right)}, \quad P_{1,0}^i\left(\tilde{X}_{t-1}\right) = 1 - P_{1,1}^i\left(\tilde{X}_{t-1}\right)$$

(19) $$P_{-1,-1}^i\left(\tilde{X}_{t-1}\right) = \frac{\exp\left(2.5 - 1.1 y_{t-1} + 0.4 r_{t-1} - 0.1\tau_{t-1}^i\right)}{1+\exp\left(2.5 - 1.1 y_{t-1} + 0.4 r_{t-1} - 0.1\tau_{t-1}^i\right)}, \quad P_{-1,0}^i\left(\tilde{X}_{t-1}\right) = 1 - P_{-1,-1}^i\left(\tilde{X}_{t-1}\right).$$

These functional forms are chosen more for their analytical tractability than for any other reason. The general shapes of these are illustrated in Graph 2.

Graph 2: Functional forms for the no-bubble (left) and bubble (right) transition probabilities





A comment on the economic and policy significance of these equations is warranted. As noted above, the key difference between the benchmark and this alternative is the endogeneity of the asset price bubbles. There are no direct linkages between the size, longevity or collapse of one bubble on the other. This characteristic is consistent with the fact that despite the boom, collapse and subsequent expansion of equity prices, the path of housing prices appears to have been little affected across a wide range of countries. This putative behaviour, however, does not necessarily mean that the equity and housing price dynamics do not share common factors. In this specification, the common factors are the behaviour of output and interest rates on the transition probabilities. Given the parameterisation, strong economic activity would tend to raise the transition probability of an asset price boom for both housing and equity prices. Similarly, an increase in interest rates would have a negative impact on the transition probabilities. By design, the magnitudes of the impacts of output and interest rates on the transition probabilities for the negative bubble transition probabilities are opposite.

In addition, these transition probabilities are subject to negative duration dependence, namely, as an asset price boom of one type or another continues the probability of exiting such a boom rises. For technical reasons, this helps to simplify the solution algorithm (ie produces a large number of bubble configurations that guarantees a well-defined likelihood function). This also helps to match the fact that asset price bubble sequences do not go on forever – they might collapse of their own weight, or policy actions (or mistakes) may end them. Policy interpretations of duration dependence are left until later in the paper.

The no-bubble transition probabilities are only functions of output; the steady state transition probabilities are highest when output deviations are zero. This means that, in the absence of shocks, the state of the system tends to settle down to the no-bubble state. Note, however, that the no-bubble steady state transition probability does not reach 1. So, even in the best case scenario, this system is not immune from bubbles arising sporadically.

The *second alternative* specification of the transition probabilities for the asset price bubbles allows for a more direct interaction. This alternative is motivated by the apparent lagging relationship between equity price bubbles and housing price bubbles, where on average peaks in equity prices precede peaks in housing prices by a few years (Borio and McGuire (2003)). Far from being a mechanical linkage, the distribution of peaks suggests that there is considerable uncertainty associated with the lags. To address the general tendency for housing price peaks to lag (in a stochastic sense), this alternative strongly interacting multivariate bubble specification allows the duration of the equity price bubble to influence the transition probabilities of the housing price bubble but not vice versa.

In this alternative, equations (20) and (21) are replaced with the following for the time-varying transition probabilities influencing the housing price bubble:

$$(20) \quad P_{1,1}^{i}\left(\tilde{X}_{t-1}\right)=\frac{\exp\left(2.5+1.1y_{t-1}-0.4r_{t-1}-0.1\tau_{t-1}^{i}+0.1\tau_{t-1}^{j}\right)}{1+\exp\left(2.5+1.1y_{t-1}-0.4r_{t-1}-0.1\tau_{t-1}^{i}+0.1\tau_{t-1}^{j}\right)},\ P_{1,0}^{i}\left(\tilde{X}_{t-1}\right)=1-P_{1,1}^{i}\left(\tilde{X}_{t-1}\right)$$

$$(21) \quad P_{-1,-1}^{i}\left(\tilde{X}_{t-1}\right)=\frac{\exp(2.5-1.1y_{t-1}+0.4r_{t-1}-0.1\tau_{t-1}^{i}+0.1\tau_{t-1}^{j})}{1+\exp(2.5-1.1y_{t-1}+0.4r_{t-1}-0.1\tau_{t-1}^{i}+0.1\tau_{t-1}^{j})},\ P_{-1,0}^{i}\left(\tilde{X}_{t-1}\right)=1-P_{-1,-1}^{i}\left(\tilde{X}_{t-1}\right).$$

The asymmetry implied by these equations reflects not only the general patterns of peaks in the data but also the possibility of an asymmetric economic link between equity price booms and housing prices via a collateral effect. A rise in equity prices would tend to increase the availability of collateral for households who need to raise a down payment for a house purchase. The relaxation of the collateral constraint would generally raise demand for existing houses and hence the price. In contrast, an increase in housing prices would not generally have the same type of influence on equity prices. In this way, the positive influence of equity price bubbles on the transition probabilities of the housing price bubble would generate the tendency for housing price peaks to follow equity price peaks.

However, this is not the whole story in this model. The output response and, more importantly from the point of this paper, the monetary policy response to the subsequent decline in equity prices following a peak would affect the overall impact. The output effect would reinforce the impact. But the monetary policy response would generally moderate the impact, owing to the fact that the interest rate would decline; a decline in interest rates, all else the same, would tend to increase the housing bubble transition probability. The net effect is summarised below in the expected duration calculations.

Results

To better understand the marginal contribution of the multivariate nature of asset price bubbles, we first review the dynamics of a simpler model, ie one with a univariate version of the Markovian bubble described above. Then, we turn to the bivariate specification. As noted in the introduction, the model is purposefully stylized and meant to highlight the monetary policy tradeoffs that a central bank might face in the presence of such asset prices.

Univariate bubble model results

Table 1 presents the results for loss function parameters of ($\mu_\pi = 2, \mu_r = 0.1$).[8] The first three columns are generated from a time-varying transition probability version of the model, assuming different functional forms for the monetary authority's policy reaction function. The first column assumes that the monetary authority does not respond to asset price movements. The second column assumes that the monetary authority does not respond differentially to the fundamental and bubble components of asset prices. One can also think of this as an economic environment where the monetary authority cannot distinguish between the two asset price components; the comparison of the first two columns addresses the question about whether the monetary authority can do better by responding to asset prices even if the monetary authority cannot identify separately the asset price bubble. In general, the monetary authority achieves a lower loss when it responds to asset price bubbles.

Table 1: Estimates of the Optimal Policy Parameters ($\mu_\pi = 2, \mu_r = 0.1$)

	TVTP specification			FTP specification*
	No asset price response	Constrained response to asset price components	Differential response to fundamental and non-fundamental asset prices	
a_y	1.80 (.03)	1.71 (.04)	1.70 (.06)	1.76 (.001)
a_π	2.64 (.07)	1.86 (.12)	1.11 (.12)	2.12 (.01)
a_F	–	.63 (.07)	1.18 (.06)	.91 (.001)
a_{NF}	–	.63 (.07)	.10 (.006)	.09 (.002)

Note: The standard error (ie the numerical precision) of the estimate is in parentheses. The coefficients correspond to the following policy rules: (col. 2) $r_t = a_y y_t + a_\pi \pi_t$;

(col. 3) $r_t = a_y y_t + a_\pi \pi_t + a_{AP} \pi_{AP,t}$; and (col. 4) $r_t = a_y y_t + a_\pi \pi_t + a_F \pi_{F,t} + a_B \pi_{B,t}$. The fixed transition probability (FTP) version of the model sets $P_{0,0}$ = exp(.154)/(1+exp(.154)), $P_{0,1}$ = $P_{0,-1}$=0.5*(1-$P_{0,0}$), $P_{1,1}$ =$P_{-1,-1}$= exp(2.5)/(1+exp(2.5)).

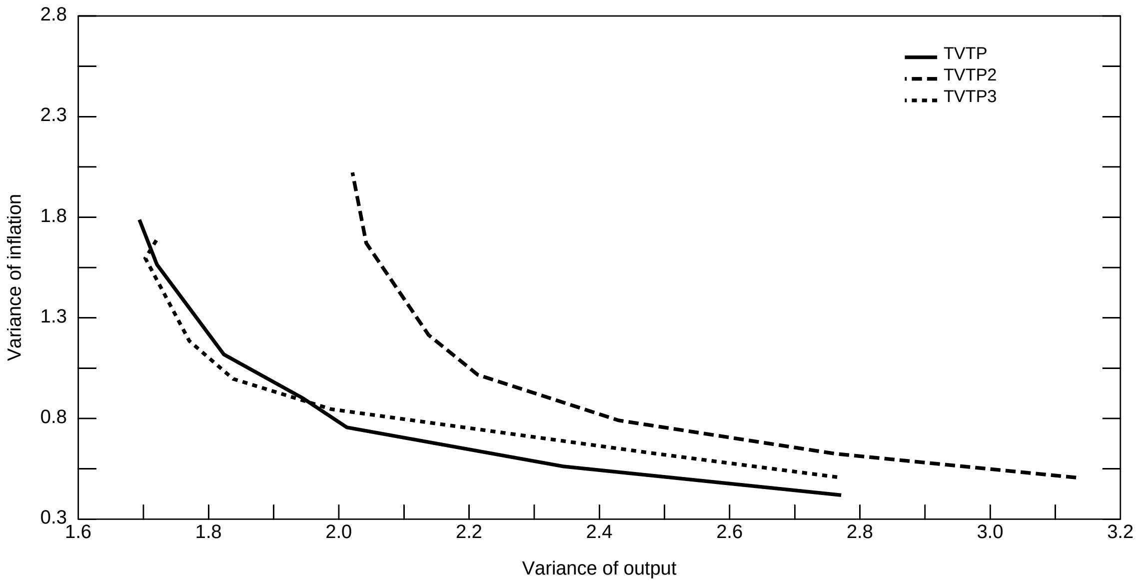
[8] For a monetary authority that does not put weight on the variability of interest rate changes in its loss function (ie μ_r = 0 in equation 4), the value of being able to respond to asset prices is higher. Since asset prices are quite variable, responding to them will generally increase variability in the monetary authority's policy rate. As a consequence, adding a penalty for interest rate fluctuations in the monetary authority's loss function will provide an incentive to reduce the weight on the information in asset price movements.

The second and third columns highlight the marginal contribution of being able to distinguish the fundamental and non-fundamental movements in asset prices. As might be expected from the difference in the parameter values, the value of being able to distinguish the bubble component may be high. This benefit, of course, has to be weighed against the ability to identify asset price bubbles, which may be exceedingly difficult in practice.

Reading across the first three rows indicates that the response coefficient for inflation is affected most by the differential responses to asset prices. Without a response to asset prices, the monetary authority would react more aggressively than when it can respond. The degree of aggressiveness declines when a monetary authority does distinguish between asset price movements due to fundamentals and those due to bubbles. When unable to distinguish, the reaction parameter is 0.63. When the monetary authority can distinguish, the coefficient on the fundamental component rises but that for the bubble falls. This suggests that if a monetary authority cannot distinguish fundamentals from bubbles, the weight on asset price movements is greater, on average, than if it could identify the bubble alone. This is somewhat at odds with the conventional intuition that the inability to distinguish fundamentals and bubbles would generally suggest that little, if any, weight be placed on asset price movements.

Graph 2 summarizes monetary policy tradeoffs resulting from the model using various values of μ_π , the weight that the monetary authority places on the variance of inflation in its preferences. The curves have their standard bowed shape. The location of the curves also provides useful information about the tradeoffs. The closer the curves are to the origin, the lower the value of the monetary authority's loss function because, all else the same, the point represents a smaller variance of output and inflation. The graph illustrates the benefits of changing the policy rate in reaction to asset price developments. The curve to the right represents the locus of points generated from a monetary authority that does not respond to asset prices. The curve to the immediate left is the one that represents the tradeoff for a monetary authority that is constrained to respond to overall asset price movements without being able (or willing) to discriminate between the fundamental component and the bubble component. The left-most curve represents the locus of points associated with a monetary authority that discriminates between the fundamentals and the bubbles.

Graph 2: Optimal policy frontiers



Responding to different types of asset price bubbles

The last two columns in Table 1 compare the monetary policy response across economies characterized by two different types of asset price bubbles–one governed by time-varying transition probabilities where the state of economic activity influences the bubble, and the other by fixed transition probabilities where the probabilities are independent of the state of the economy. The comparison provides insights into the marginal value of being able to prick asset prices relative to simply being able to respond. Even though some of the coefficients are fairly close, there are some important differences that will affect the time-series behaviour of the two different economies.

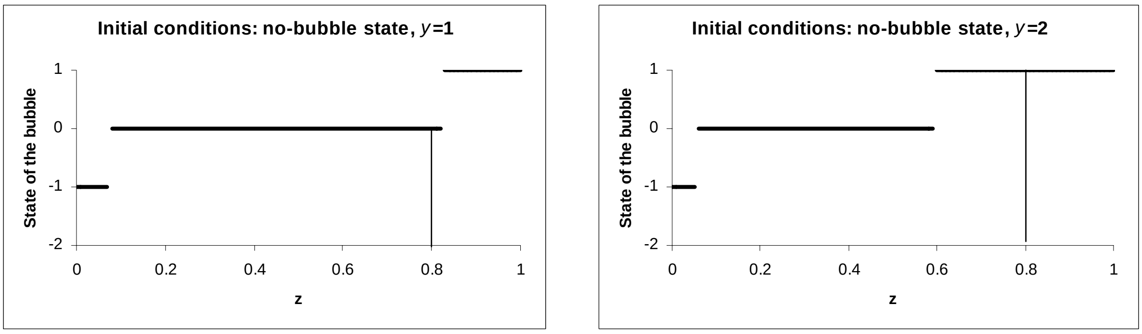
There is a tendency for the optimal reaction function parameters in the TVTP case to be smaller than those in the FTP case. Part of the reason is that the interest rate has an important role in affecting the TVTPs. From a policy vantage point, it beneficial to have the interest rate fall in the immediate aftermath of the collapse of a positive bubble and rise in the immediate aftermath of a negative bubble. Consider the case where output and inflation are close to the steady state. Then the monetary authority's behaviour helps to keep the economy from overshooting the no-bubble state after a bubble collapses and therefore lowers the probability of persistent oscillations between positive and negative bubbles. By responding in such a way, the monetary authority is less likely to incite bubbles or create overshooting conditions.

Impulse responses and nonlinear dynamics

It is sometimes argued that one of the complications in calibrating monetary policy responses to asset price booms and busts is the nonlinear behaviour of the economy. Clearly, conventional linear models provide poor guidance. But, one attractive feature of the above model along this dimension is that complicated cycles are possible. Indeed, the model can generate long, drawn-out cycles as well as behaviour consistent with limit cycles and chaotic cycles.

To gain some insight into the rich dynamic properties of this model, it is useful first to review the statistical assumptions behind the Markovian process. In contrast to a linear model with normally distributed random error terms, the Markov process is somewhat more complicated. The appendix explains how simulating the bubble requires drawing from the inverse cumulative distribution function of the transition probability function using a z random variable defined over the unit interval. Graph 3 provides a graphical description of the link between z and the transition probabilities. This graph shows how, for a given draw of z, there is an assigned state of the bubble. The assignment function will change with changes in the transition probabilities due to either changes in y or r. The key point to observe is that the draw of z will determine the state of the bubble, given the transition probability functions defined above.

Graph 3: Changes in the inverse cumulative distribution function to changes in y



Note: The z is the random variable that determines the probabilistic draws from the Markov process for the states. As y changes, the length of the line segments change, which then determines the likelihood that a particular state will be realised. See the technical appendix for more details.

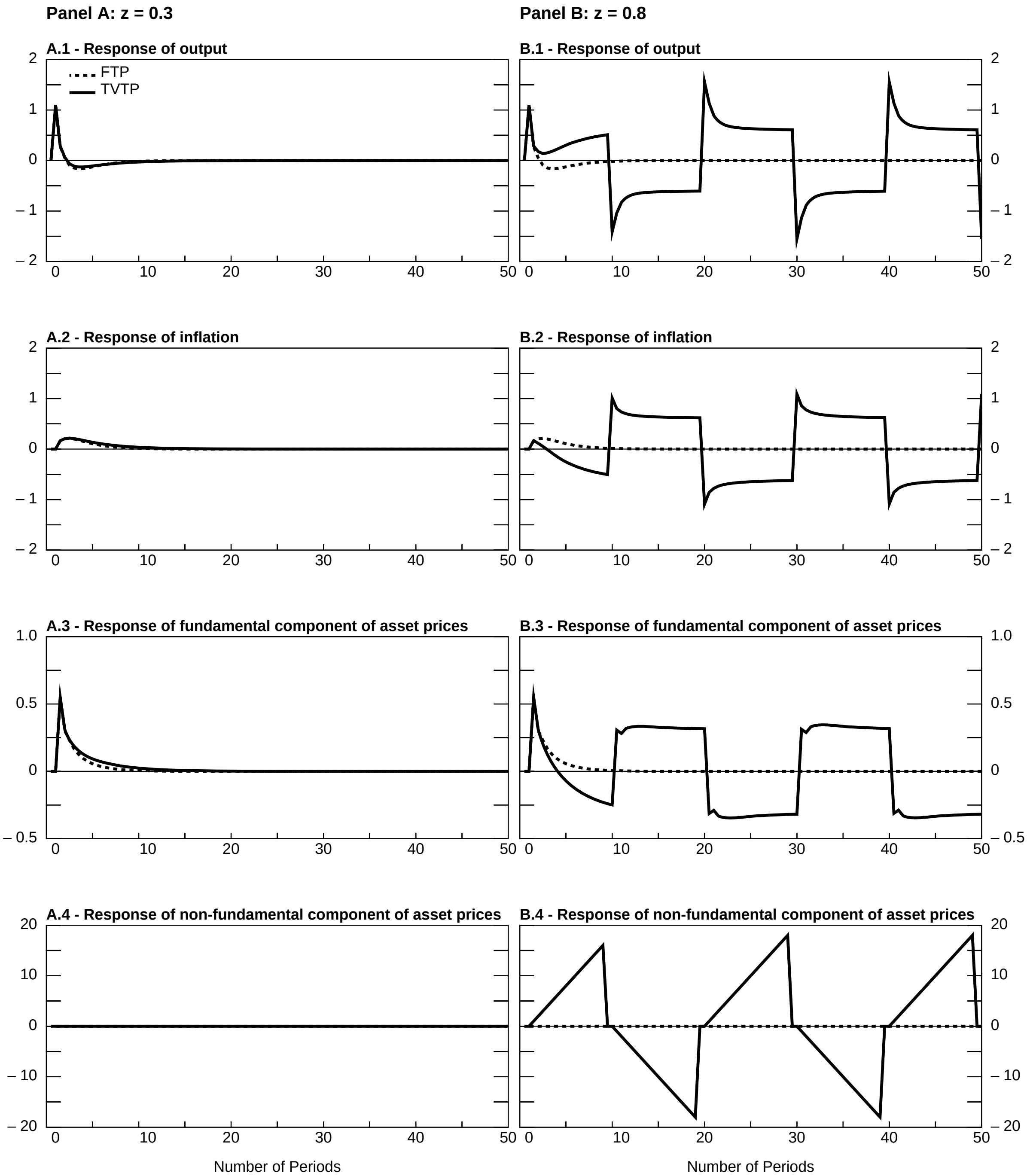
The relationships among z, the transition probabilities and the state of the bubble make it more difficult to summarise the nature of the impulse responses than in the case of a linear system of equations with i.i.d. errors. In the model, for example, a one-standard error shock to output not only feeds through the IS-PC-AP equations in the conventional way but also affects the transition probabilities and hence the path of the bubble. One way to analyse the consequences is to hold the value of z fixed and graph the results. Graph 4 does just this and displays the nonlinear impulse responses, assuming a fixed value of the stochastic variable, z.[9]

Graph 4 illustrates three types of nonlinear behaviour that are possible in this model. These impulse responses are associated with three different values of z =.3, .8 and .89, and with a 1-standard deviation output shock and the economy initially in the no-bubble state. In Panel A, z is assumed to be 0.3 and corresponds to an economy that remains in the no-bubble state. As might be expected, in the no-bubble state the impulse responses look like those from a linear model. Panels B and C, however, indicate just how nonlinear the system is. Panel B shows that the TVTP model can generate complicated dynamics because the state of the bubble oscillates between positive-bubble and negative-bubble states. Panel C offers an intermediate case for the TVTP model where the output shock causes the bubble state to oscillate for a while before settling back to the no-bubble state fairly quickly.

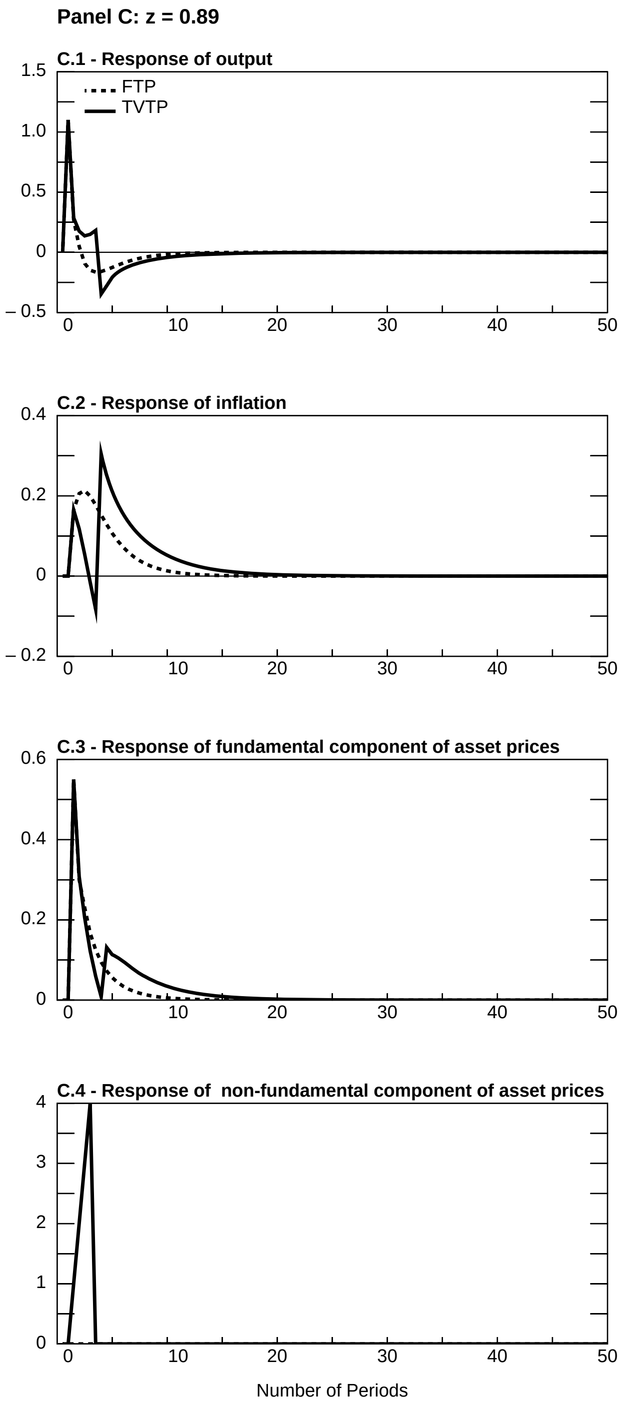
As for the monetary policy implications, these types of dynamics suggest additional tradeoffs for central banks. Given the variance possibilities arising from the nonlinearities, the optimal policy parameters are likely to produce rules that try to prevent the extremes. Evidence supports this conclusion but these consequences are explored in more depth through the lens of the expected duration calculations.

[9] Technically, the impulse responses assume $z_t = \bar{z}$. They are consistent with the approach of Gallant, Rossi and Tauchen (GRT, 1993); that is, that the impulse response function is defined as $\frac{\partial X_{i,t+s}(\bar{z})}{\partial e_{j,t}} = \frac{\partial X_{i,t+s}(z_{t+s} = \bar{z},\ldots,z_t = \bar{z})}{\partial e_{j,t}}$ and $\frac{\partial X_{i,t+s}(\bar{z})}{\partial e_{j,t}}$ is shorthand notation for the effect on the i-th component of the state variable, X, to an innovation of one of the error terms (ε,η,ν). This type of response does not display shock linearity, symmetry, or path independence. A second type of impulse response is explored in Filardo (2003), which can provide additional insight into the dynamics of the model. This impulse response is consistent with the alternative approach in Koop, Pesaran and Potter (KPP, 1996). Instead of holding fixed a particular value of z, the influence of z is integrated out of the impulse responses, ie $\frac{\partial X_{i,t+s}}{\partial e_{j,t}} = \int_{z\in[0,1]} \frac{\partial X_{i,t+s}(z_{t+s},\ldots z_t)}{\partial e_{j,t}} f(z)dz$.

Graph 4: Nonlinear impulse responses, fixed z



Graph 4–con't: Nonlinear impulse responses, fixed *z*



Effect of monetary policy on the expected duration of the bubble

Monetary policy in this environment can also be used *opportunistically* to influence bubble formation. With policy actions being able to influence the bubble, a monetary authority might be interested in using this ability to pursue its goals of output and inflation stabilization. To be sure, such an approach would have its potential downsides. The link between monetary policy actions and economic outcomes might be much less predictable than is assumed in the model, hence opening up the possibility of such actions backfiring.

In a broad sense, such pro-active policies can be thought of as operating through animal spirits. As Blanchard (2000) argued, if non-fundamentals are generally thought to be driven by animal spirits, monetary policy can be used to excite or dampen such spirits. Arguably, a monetary authority can occasionally take actions that by themselves are not considered sufficient to have a large impact on aggregate demand, but nonetheless are expected to provide a catalyst to private sector expectations and confidence. In the model, such behaviour would correspond to situations in which the monetary authority exploits its influence on the non-fundamentals to smooth output and inflation. For example, in an economy where economic activity appears subpar relative to fundamentals, the monetary authority might take actions to generate a positive bubble, ie try to boost confidence. Conversely, when economic times are somewhat frothy, upward moves in the policy rate may dampen attitudes sufficiently and contribute to the slowing of economic activity toward trend. In either case, the monetary authority might find it advantageous to boost the likelihood of positive and negative bubbles in an opportunistic manner when the bubbles reinforce other channels of monetary policy to stabilize economic activity.

One way to measure the importance of pro-active policies is to evaluate why monetary policy makers may want to affect the expected duration and, as a consequence, the expected amplitude of an asset price bubble. This question can be answered using methods described in the technical appendix. In the case of asset prices, conditional on being in one of the three bubble states, a monetary authority might consider how its optimal monetary policy will affect the expected duration compared to that in a model where the bubble is assumed to evolve independently of the state of the economy.

The conditional expected duration of any bubble type D_j, where j = {-1, 0, 1}, can be calculated by exploiting the Markovian nature of the asset price bubble. The conditional probability of distribution of D_j for the negative-bubble, the no-bubble and positive-bubble states can be written generally as

(22) $$E_t(D \mid I_t = j) = \sum_{i=1}^{\infty} D_i \times F(D_i \mid I_t = j) = \sum_{i=1}^{\infty} i \times (1 - p_{j,j,t+i}) \prod_{k=1}^{i-1} p_{j,j,t+k}$$

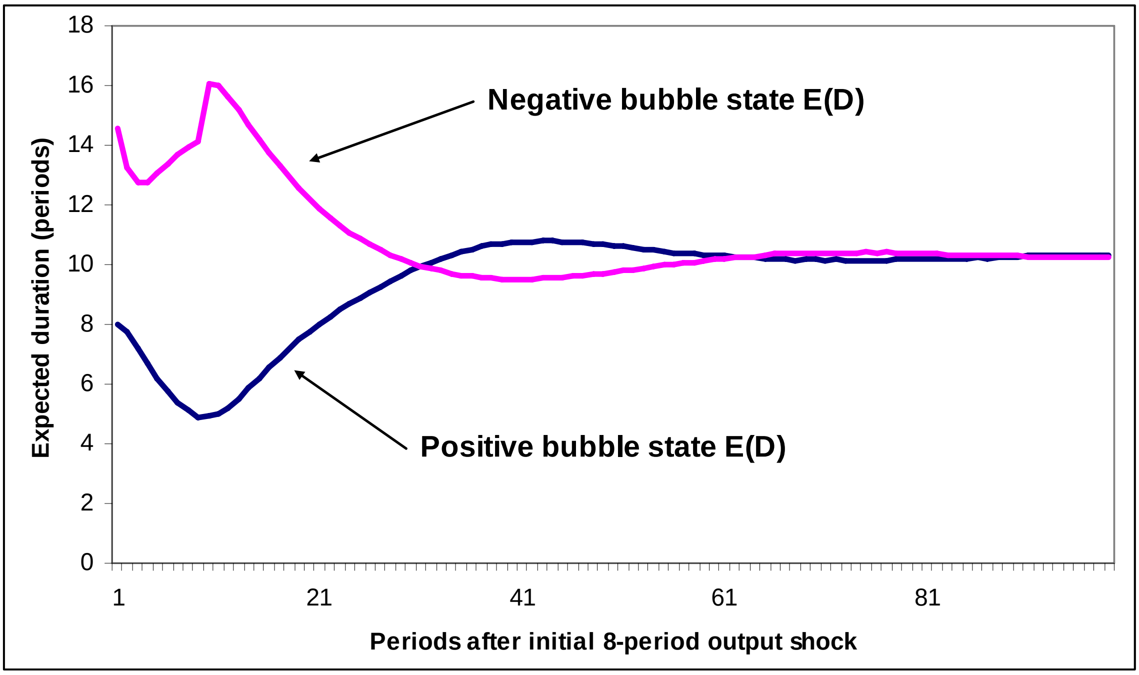
where the duration events are D_j = {1, 2, 3,...}, the probability distribution function over these events is

(23) $$F(D_j \mid I_t = j) = (1 - p_{j,j,t+i}) \prod_{k=1}^{i-1} p_{j,j,t+k}$$

and $p_{-1,-1}$, $p_{0,0}$, and $p_{1,1}$ correspond to the transition probabilities for the negative-bubble to negative-bubble, the no-bubble to no-bubble and the positive-bubble to positive-bubble states, respectively, in equation (3).[10] The coefficient of 2.5 implies that the conditional expected duration of a bubble is roughly eight quarters, assuming that a new bubble just began and that $y = 0$ and $r = 0$ (see below for formulae to calculate the conditional expected durations).

Graph 5 shows variation in the expected duration of the asset price bubble in response to a persistent output shock. In particular, output is boosted by a 1 standard deviation shock for 8 consecutive periods. The monetary authority is assumed to respond both to fundamental and non-fundamental asset price fluctuations. The solid line represents the conditional expected duration left in the bubble if the economy stays in a positive-bubble state. The higher output generally leads to a higher expected duration initially. But the higher interest rate response of the monetary authority leads to a rapid decline in the expected duration. In contrast, the expected duration of the negative-bubble state is higher.

Graph 5: Conditional expected durations in response to positive output innovation



[10] Additional details on how to calculate the expected duration is described in the technical appendix.

This may seem to be a puzzle in the sense that a stronger economy would, all else the same, increase the expected duration of a positive bubble and lower the expected duration of a negative bubble. The key to the intuition, however, is the behaviour of monetary policy. When the economy is subject to a series of positive output shocks, the monetary authority raises rates to moderate aggregate demand. This moderation along with the direct impact on the transition probabilities via the interest rate channel is sufficient to lower the expected duration of a positive bubble state and boost the expected duration of a negative bubble state. From an analytic point of view, the ability of expected duration to shed light on the monetary policy tradeoffs illustrates the usefulness of this type of statistic as a diagnostic in this class of models.

This next section addresses further complications for monetary maker that arise from the consideration of an additional asset price bubble.

The multivariate bubble extension

Table 2 presents the results from the multivariate bubble version of the model in this paper. The weakly interacting alternative and the strongly interacting alternative yield similar quantitative results; the results for the latter are only reported for concision. There are several interesting findings. First, the output response is fairly similar across specifications. This is true not only for the strongly interacting alternative with the three different monetary policy rules but also for the FTP (or independent multibubble) alternative. The similarity in the coefficients suggests that there is a robustness tendency in this model with respect to responding to output.

Second, the coefficient on the inflation response is much more sensitive to the particular specification of the model. Using a traditional Taylor-type rule (only responding to output and inflation), the hypothetical central bank optimally responds aggressively to output innovations. In other words, an economy subject to asset price bubbles would generally lead the central bank to act as if it is very averse to inflation developments. Part of the explanation for this finding may reflect the timing conventions in the macroeconomic block of equations. If it does not respond to the asset price developments, the central bank would fall farther behind the inflation curve, on average, than when responding. As a consequence, the central bank optimally responds more aggressively to rising inflation pressures so as not to fall further and further behind the curve. This line of reasoning was also seen in the univariate bubble case.

Third, responding to the housing bubble or to the overall increase in housing prices (ie the combination of the fundamental and nonfundamental components) does not seem to make that much of a difference. The coefficients on the housing components in columns 3 and 4 are nearly identical. This similarity in response seems to arise from the particular specification than from a general property of the model.

Fourth, in contrast, the coefficients on the equity price components differ across the columns. This suggests that responding to the bubble component in equity prices is small. But, it also suggests that if the coefficient in column 3 were used when most of the equity price was driven by the bubble component, the monetary authority would unwittingly respond too aggressively to equity developments. Hence there are potential payoffs in trying to identify equity price bubbles in real time, while the marginal gain for housing bubbles is small – in this model.

Table 2: Optimal policy parameters ($\mu_\pi = 2, \mu_r = 0.1$), strongly interacting alternative

	TVTP specification			FTP specification*
	No asset price response	Constrained response to asset price components	Differential response to fundamental and non-fundamental asset prices	
	(col 2)	(col 3)	(col 4)	(col 5)
a_y	1.30 (.01)	1.28 (.01)	1.28 (.01)	1.28 (.01)
a_π	2.18 (.05)	1.31 (.12)	1.30 (.12)	1.03 (.04)
a_F^e	–	.49 (.01)	.55 (.01)	.58 (.01)
a_{NF}^e	–	–	.05 (.02)	.58 (.01)
a_F^h	–	.55 (.01)	.55 (.01)	
a_{NF}^h	–	–	.55 (.02)	

Note: The standard error (ie the numerical precision) of the estimate is in parentheses. The coefficients correspond to the following policy rules: (col. 2) $r_t = a_y y_t + a_\pi \pi_t$;

(col. 3) $r_t = a_y y_t + a_\pi \pi_t + a_{AP}^e \pi_{AP}^e + +a_{AP}^h \pi_{AP}^h$; and

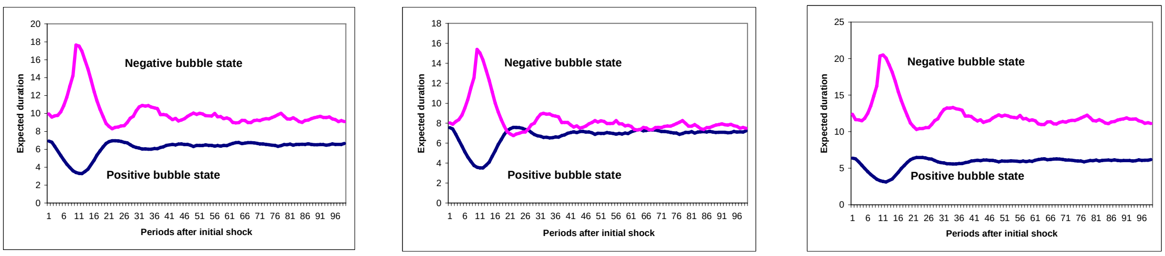
(col. 4) $r_t = a_y y_t + a_\pi \pi_t + a_F^e \pi_{F,t}^e + a_{NF}^e \pi_{NF,t}^e + a_F^h \pi_{F,t}^h + a_{NF}^h \pi_{NF,t}^h$.

Overall, these results suggest that multivariate bubbles create several important tradeoffs for monetary authorities. First, responding to asset prices in general is a good approach – even if you can't identify the bubble in real time. This assumes, however, that you understand the stochastic processes driving the asset prices and the consequences for the macroeconomy. This is an important point highlighted in Filardo (2003c). Moreover, all bubbles are not alike and hence information learned about responding to one type of bubble need not apply to other bubbles. In this case, the difference in the optimal responses to the fundamental component of the housing bubble or the bubble component is not particularly significant. This certainly simplifies the signal extraction problem that a central banker faces. But this rule of thumb would lead to problems if applied to equity prices. Looking forward, this should suggest that policymakers should be somewhat cautious in reading the history of dealing with bubbles over the past decade. With respect to the equity market collapse earlier this decade, the macroeconomic consequences were fairly mild. A housing market collapse, however, may be much more disorderly and costly. Casting our gaze farther back in time to earlier housing price collapses, the macroeconomic consequences were often much more debilitating. The experiences of Japan, Scandinavian countries and others provide a cautionary reminder of what is possible.

Conditional expected durations

The conditional expected durations in this model exhibit many of the characteristics of the univariate version. Most important, the expected duration of a positive bubble in an expansionary economy falls, as can be seen in Graph 6. In Graph 6, the economy is hit with an 8-period positive shock to output. This initially drives output and inflation up. In general, aggressive monetary policy tightening aimed at stabilising output and inflation leads expected durations of positive bubbles to fall and expected durations of negative bubbles to rise during expansions. Why is that? It is because the monetary authority is not only trying to burst asset price bubbles in this model but is also trying to use asset price bubbles to achieve its macroeconomic stabilisation goals. This feature of the model is not specific to the multi-bubble specification; it was also seen in the univariate case.

Graph 6: Conditional expected duration for housing bubble (weakly interacting multi bubble model)
[left: assumes no equity bubble; middle: assumes positive equity bubble; right: assumes negative equity bubble]

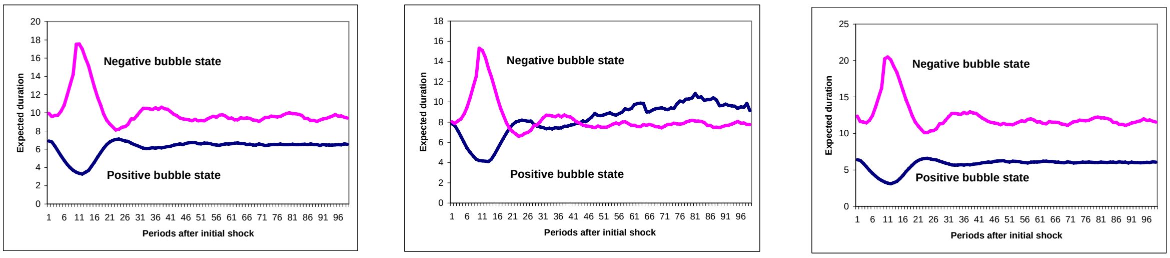


Note: Assumes an initial 8-period output shock of roughly 1 standard error per period.

Turning to the strongly interacting multibubble alternative, the conditional expected durations look remarkably similar. This may reflect the possibility that the degree of interaction was fairly moderate. More research along this dimension is called for. One distinctive difference, however, is the upward drift in the middle panel of Graph 7. In this panel the conditional expected duration of the positive housing bubble continues to rise over the time horizon. This reflects the fact that jointly positive equity and housing bubbles are mutually reinforcing in this model as time goes on. This suggests the possibility that, despite a monetary policy that stabilises output and inflation, the persistence of bubbles may grow during periods of *apparent* stability.

This possibility should be of concern to a monetary authority. In such a situation, a central bank only interested in the variance of output and the variance of inflation might find itself becoming complacent, despite anomalous behaviour in housing and equity prices. If imbalances were left to grow unabated, the central bank might ultimately find itself in an undesirable situation. In some respects this finding seems to support the general concerns of White (2005) that the goal of price stability alone may not simply be enough in a world of financial imbalances.

Graph 7: Conditional expected duration for housing bubble (strongly interacting multibubble model)
[left: assumes no equity bubble; middle: assumes positive equity bubble; right: assumes negative equity bubble]



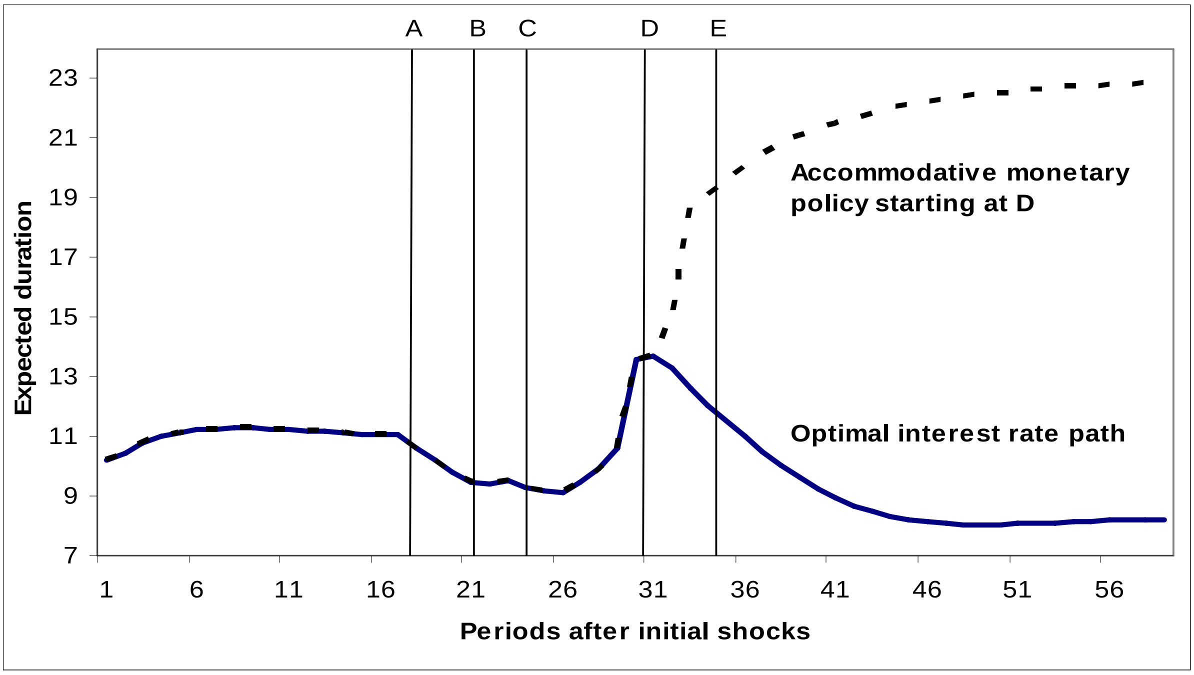
Note: Assumes an initial 8-period output shock of roughly 1 standard error per period.

Calibrated simulation

The conditional expected durations for the housing bubble in the previous section were based on three different assumptions about the state of the equity price bubble. The equity price bubble was either in a positive state, a negative state or a no-bubble state. The previous section did not examine the consequences of a collapse of an equity price bubble on the conditional expected duration of a housing price bubble. To this end, a conditional expected duration is estimated under the assumption that an equity price bubble expands for a while, then collapses and rises again. In the middle of this equity price bubble sequence a recession is also assumed to occur. This conditioning information might seem somewhat arbitrary but it is arguably consistent with a reading of US history from 1995 to the present, as can be seen in Graph 1. The chronology is, of course, highly stylised and used for illustrative purposes only.

The results of this simulation are striking. Graph 8 presents the time line and the developments in the conditional expected duration of the housing bubble. The simulation begins with an equity price bubble that starts in period one and proceeds. As a result, the expected durations creep up as the length of the equity price bubble grows. At point A, a housing bubble finally develops. The expected duration begins to fall because the combined equity and housing price bubbles lead to a strong increase in output which elicits an interest rate response from the monetary authority; this response adversely affects the transition probabilities for positive bubbles. At point B, the economy takes a turn for the worse; recessionary pressures build as a sequence of negative output shocks begins. The negative output shocks lead to a reduction in interest rates in order to cushion the economy. This causes a short-lived pick-up in the expected duration before the equity price bubble collapses at point C. Initially, the collapse pushes down the likelihood of a positive housing bubble surviving, but the continued weak economy causes the hypothetical monetary authority to ease further in order to counter the recession. As a result, the expected duration of the positive housing bubble picks up considerably. Finally, as the recessionary headwinds abate, the expected durations fall with the increase of the interest rates to the steady state level.

Graph 8: Conditional expected duration of the housing bubble, calibrated to US data from 1995-2006*



* This is the conditional expected duration of the housing bubble given the following paths of shocks:: 1) equity price bubble begins at period 1; 2) at A, a housing price bubble begins; 3) at B, a negative 8-period output shock begins; 4) at C, the equity bubble collapses; 5) at D, output shocks stop; at E, equity bubble begins again. This is the weakly interacting bubble alternative specification. "Accommodative monetary policy" is defined in this simulation as the interest rate being held at its level at point D, which is roughly one percentage point below the steady state interest rate.

Of course, this is a counterfactual reading of history. In this case, the monetary authority pursued a tighter monetary policy two to three years after the start of the recession. As a benchmark, these counterfactual simulations might be used to evaluate the actual policy choices. One disclaimer is relevant at this juncture. While calibrated to the bubble history and recession in the United States, the timing roughly fits a much wider set of international experiences. In this sense, the simulation and following analysis is not meant to be a comment on US policy but rather as a more general critique on monetary policy actions during the period.

So, what would have happened if the monetary authority had not tightened monetary policy so aggressively after point D? One consequence is that the expected duration of the housing bubble would have increased significantly. And, as the simulations in the previous section showed, the joint expansion of the equity and housing bubbles would have been mutually reinforcing if the strongly interacting forces were operating. While this analysis is far from definitive, it may help to shed light on why the current housing boom in advanced industrial countries has had so much momentum while equity prices were relatively low; and why it looks as if equity prices are beginning to be perceived as being richly priced in many countries.

Finally, this analysis exposes some of the drawbacks of the "benign neglect" approach to asset price bubbles. One version of this approach is that central banks would refrain from "leaning against" asset price bubbles as they expand, in large part because it is hard to know with much confidence that a bubble has truly evolved. But, in the aftermath of a collapse, a central bank would want to ease aggressively to cushion the consequences for the economy. The empirical analysis above indicates two problems with this approach. First, the absence of tightening during the expansion phase of the multi-bubble would lead to a rapid increase in the expected durations and, by extension, much more persistent bubbles during the formative stages. This would translate, on average, to greater longevity of bubbles and greater size. So, bubbles are likely to be bigger and their collapses more costly. Given the possible nonlinearities, the larger the collapse, the exponentially greater the possibility of highly destabilising dynamics. Second, in the case where only one of the bubbles does burst - as was arguably the case in the early part of this decade - the resulting easing of monetary policy might set in motion conditions that would raise the probability of another round of boom-bust behaviour. Whether or not this has been the case over the past few years goes well beyond this paper, and the analysis should not necessarily be taken to suggest that a collapse of equity or housing prices is imminent or inevitable.

Uncertainty about bubbles and robust policy strategies

The discussion of the results above assumes that bubbles exist and are a clear and present danger for central banks considering the monetary policy environment. This possibility alone suggests that some consideration is warranted. Of course, this is far from a universally held view. In fact, there is considerable scepticism about the relevance of asset price bubbles, especially of the multivariate type. The key question, then, is about how much weight such possibilities should have in the conduct of monetary policy.

One approach is to assume bubbles, and in particular multivariate bubbles, exist and monetary authorities act accordingly. Another approach is to deny their relevance, and even their existence. A third approach is to explicitly consider the uncertainty with which policymakers assess the relevance of bubbles for their deliberations. This can be done using Bayesian decision-theoretic methods. [11]

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[11] The methods and nature of the empirical exercise are described in Filardo (2001).

This section considers the uncertainty associated with the existence of a double-bubble and draws conclusions about the attractiveness of the benign neglect approach. The benign neglect approach appears to be a more attractive option in a single bubble world than a double-bubble world. The policy question boils down to: how certain does the monetary authority need to be about a one-bubble world in order to adopt the benign neglect approach, assuming that it is the correct approach for a one-bubble world but not so in a double-bubble world? The monetary authority is not quite sure which view is correct, but has prior beliefs about both. In reality, such beliefs might have been formed by past experience, data and introspection but in our exercise the prior beliefs are assumed to be known.

To make this operational, the various states of the world, vis-à-vis the model, need to be enumerated. A simplified version of this problem is to consider whether β^h in equation 1 is zero or not. In the zero case, the macroeconomic importance of the housing price bubble goes away.

Associated with these possibilities is a payoff matrix for each state of the world in terms of the monetary authority's loss function. Table 3 provides such estimates. The upper left corner, for example, corresponds to the loss associated with situation in which housing and equity asset price bubbles matter, and the monetary authority assumes this to be the case. This is a situation where β^h is non-zero and the monetary authority uses an optimal monetary policy reaction function under this assumption. The upper right panel represents an economy in which the housing price bubble does not matter but the monetary authority thinks that it does. This is where the monetary authority uses the optimal monetary policy reaction function assuming that housing price bubbles matter in a situation when the housing price bubble does not matter. This non-optimal response explains why the loss is higher than in the upper left quadrant. Using the same logic, the lower right panel shows the loss associated with the monetary authority correctly thinking that housing price bubbles do not matter. Finally, the lower left panel is the loss associated with the monetary authority erroneously thinking that housing bubbles do not matter.

Given this payoff matrix, the monetary authority can calculate the threshold prior probability which determines whether it chooses to act as if the benign neglect approach is the best approach. If the prior probability is less than the threshold, the monetary authority will not choose it; if the prior probability is greater than the threshold, the monetary authority will choose the approach. In other words, the threshold is calculated as the probability that the expected loss of responding to housing bubble dynamics is just equal to the expected loss of not responding. Given the probabilities of these possible situations, the expected loss of responding to asset prices as if housing prices matter can be calculated as

$$(24) \qquad E(L_{respond}) = P_{matter} L_{matter,\, matter} + P_{not\ matter} L_{matter,\, not\ matter} .$$

Correspondingly, the expected loss of not responding is

(25) $$E(L_{not\ respond}) = P_{matter}L_{not\ matter,matter} + P_{not\ matter}L_{not\ matter,not\ matter}$$

Table 4 shows that the estimated threshold probability is roughly 10 percent. In other words, if the monetary authority is more than 10 percent certain that housing price bubbles matter, it should respond as if it does and be worried about adopting a benign neglect approach to asset price bubbles. Otherwise, if its prior probability is less than 10 percent, it would be best for the monetary authority to act as if housing price bubbles do not matter; in this case, the benign neglect view is more attractive. Practical policy implications of these results are described in the following section.

Table 3: Hypothetical structure of payoffs and prior beliefs

		PAYOFF MATRIX	
		True macroeconomic structure	
		H price bubbles matter	*H price bubbles do not matter*
Monetary authority's view	*H price bubbles matter*	$L_{matter,\ matter}$=8.2	$L_{matter,\ not\ matter}$=8.3
	H price bubbles do not matter	$L_{not\ matter,\ matter}$=9.3	$L_{not\ matter,\ not\ matter}$=8.2
		PROBABILITY STRUCTURE	
		H price bubbles matter	*H price bubbles do not matter*
Monetary authority's view	*H price bubbles matter*	P_{matter}	$P_{not\ matter}$
	H bubbles do not matter	P_{matter}	$P_{not\ matter}$

Note: The upper left and lower right panels in the payoff matrix were normalized to be the same.

This thought experiment emphasizes that without perfect information about the existence of housing bubbles, the monetary authority should still take into account the possibility that bubbles matter. Of course, the effectiveness of this approach depends on the accuracy of the underlying model in assessing the loss in each state of the world and the monetary authority's ability to elicit its prior beliefs.

Table 4: Optimal monetary policy with paradigm uncertainty

Prior beliefs of the monetary authority that H bubbles matter	Expected loss of respond less expected loss of not responding
0	0.1
.1	0.0
.2	-0.1
.3	-0.3
.4	-0.4
.5	-0.5
.6	-0.6
.7	-0.7
.8	-0.9
.9	-1.0
1.0	-1.1

IV Conclusions and policy implications

The analysis in this paper shows that the benign neglect approach to asset price bubbles is not as attractive when one considers the possibility that more than one asset price bubble may be dominating the monetary policy environment. In a more practical sense, this suggests that the benign neglect view might have been an attractive approach in the earlier part of the decade when the empirical evidence indicated that only an equity bubble was underway. But now, the policy environment is arguably more complicated, from the perspective of bubbles. In recent years, many have noted the apparent disconnect between housing prices and housing fundamentals. While not unambiguous proof, the telltale signs of a housing bubble have been becoming more evident. At the same time, equity prices have been reaching levels not seen since the last putative bubble. Taken together, these facts support the case for a double-bubble perspective. It also means that the policy lessons learned from experiences earlier in this decade may be less applicable now. In particular, it might be important to question with more scrutiny the case for benign neglect.

Of course, this is a rather speculative and intentionally provocative conclusion. It is based on the model in the paper which, along many dimensions, is a simple model that is only loosely calibrated to economic behaviour observed in advanced industrial economies. More research is called for. Future efforts might yield deeper insights into this policy issue, especially if there was greater confidence about the calibration of the bubbles. Key issues such as the drivers of the size, longevity and interactions could prove useful. In addition, the links between bubbles and the macroeconomy could be strengthened. In this model, the effects on the bubbles on output and inflation are fairly stylised. Further efforts to distinguish the effects of bubbles on consumption and investment might yield critical insights. For example, do housing boom-bust cycles have a much bigger impact than equity ones? Is there a sense in which housing investment booms crowd out business fixed investment booms and hence have important implications for medium-term growth prospects? Do housing and business investment overhangs unwind in different ways?

In addition, various policy concerns naturally arise in this context. As in Filardo (2003d), the prospect of a collapse of an asset price bubble in the context of a low inflation environment raises the likelihood of reaching the zero lower bound for the nominal interest rate. In the univariate bubble case, the proximity to the lower bound suggests that monetary authorities might need to be more aggressive toward bubbles in the formative stage. This result would generally be strengthened in the multivariate bubble case because of the possibility of a double-bubble collapse. These considerations point to the potential optimality of nonlinear and contingent policy responses; to some extent, these considerations suggest that, at a minimum, central banks need to build in sufficient flexibility in their policy frameworks. This includes not only building in sufficiently long policy horizons into existing frameworks but also having the flexibility to tighten monetary policy even if inflation over the short horizon is consistent with price stability. Moreover, the monetary policy actions cannot be analysed in isolation; other policy makers matter too. This would be particularly true if other policy makers who have the ability to regulate the frothiness of asset prices appear to fail to act or act in a counterproductive way. As can be shown in the model of this paper, if the duration dependence of bubbles were to increase due to forbearance on the part of regulators, a welfare maximising central bank might feel compelled to take a more aggressive stand toward bubbles. A more detailed exploration of these monetary and financial stability issues are left for future research.

Technical Appendix

Solving for the optimal monetary policy reaction function

The model is estimated with a simulation-based solution method. Simulations are used to solve for the coefficients of the monetary policy rule that minimizes the monetary authority's objective function, $L*$, where

$$L* = \underset{\{a_y, a_\pi, a_F, a_B\}}{\arg\min} \; L$$

$$L = \text{var}(y) + \mu_\pi \text{ var}(\pi) + \mu_r \text{ var}(r - r_{-1}) \text{ and } r_t = a_y y_t + a_\pi \pi_t + \mathbf{a}_F \boldsymbol{\pi}_{F,t} + \mathbf{a}_B \boldsymbol{\pi}_{B,t}.$$

There are three key steps to the simulation method:

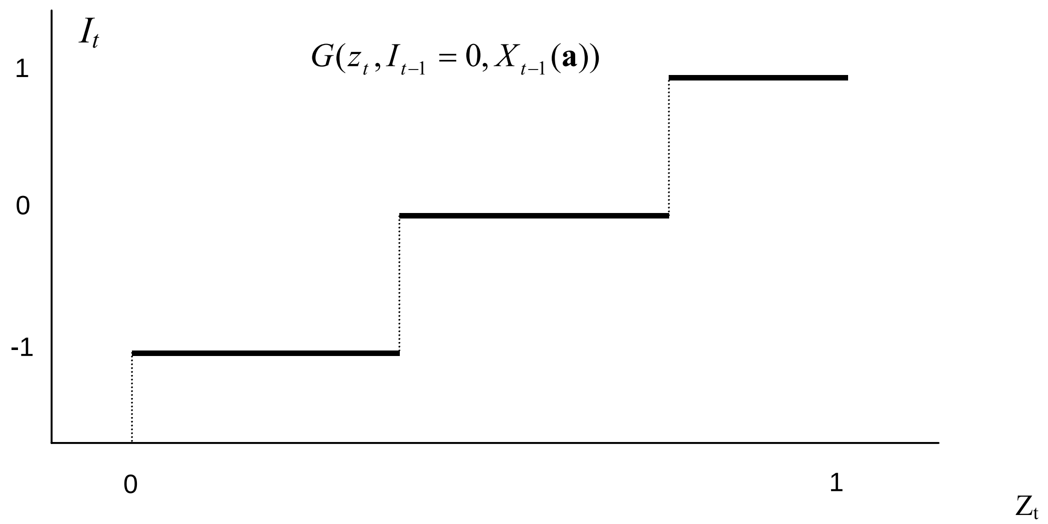
1. For each draw of $\tilde{\boldsymbol{\varepsilon}} = \{\varepsilon_t, \eta_t, \boldsymbol{\upsilon}_t\}\, and\, \mathbf{z}_t$ (where $\mathbf{z}_t$ helps determine $\boldsymbol{\zeta}_t(\mathbf{z}_t, P(\mathbf{I}_{t-1}, X_{t-1}))$), calculate a* = $\{a_y^*, a_\pi^*, \mathbf{a}_F^*, \mathbf{a}_B^*\}$ that minimizes the loss function, L. Note that $\mathbf{z}_t$ is a random variable with a uniform distribution on the interval [0, 1]; hence, $\boldsymbol{\zeta}(\mathbf{z}_t, P(\mathbf{I}_{t-1}, X_{t-1}))$ is a nonlinear function of the underlying draw from $z_t^j \sim U[0,1], for\ j = e, h$ and the time-

varying transition probability. The ζ_t function is evaluated recursively.

2. Integrate out the dependence of any particular path of $\tilde{\varepsilon}$ by simulation methods. For example, the estimate the distribution function, $f(\hat{a}_y)$, is $f(\hat{a}_y) = \int_{\tilde{\varepsilon}} f(\hat{a}_y \mid \tilde{\boldsymbol{\varepsilon}}) dF(\tilde{\boldsymbol{\varepsilon}})$
3. Estimate the reaction function parameters, $\{a_y, a_\pi, \mathbf{a}_F, \mathbf{a}_B\}$, and a dispersion measure (such as the mean and standard deviation).

The estimates in the paper are based on 10 simulations of a 1,000,000-period economy.

This method is quite computationally burdensome because of its recursive nature. The computational burden is created by the nonlinear relationship between the choice of the optimal monetary policy reaction function parameters, **a**, and the error term $\zeta_t = \zeta(\mathbf{z}_t, P(\mathbf{I}_{t-1}, X_{t-1}(\mathbf{a})))$. The burden is compounded by the need to recursively draw ζ_t. Even though ζ_t cannot be simulated independently of **a**, the underlying stochastic term $\mathbf{z}_t$, where $\mathbf{z}_t \sim U[0,1]$, can be used to generate $G(\mathbf{z}_t, \mathbf{I}_{t-1,} X_{t-1}(\mathbf{a}))$, the inverse CDF of $P(\mathbf{I}_t \mid \bullet)$. (In the fixed transition probability case, the ***A*** matrix is the only term affected by the choice of **a**, and, as a result, simulation of ζ_t can be done independently of the maximization routine.) The figure below illustrates the relationship between *z* and the value of I_t in the case where $\boldsymbol{I}_{t-1}$=0. Changes in **a** affect output, inflation and the non-fundamental component of asset prices, which in turn affects that transition probabilities and thus the sequence of ***I***.



Calculating the expected duration of the equity and housing bubbles

Calculating the conditional expected duration of each of the bubbles is done by exploiting the Markovian structure of the bubble processes. As described in the text, the generic way to calculate the expected conditional duration of each type of bubble is $E(D^i) = \int D^i \, F(D^i)$, where D^i is defined as the set of durations $D^i = \{D^i_j \mid D_j = j, j = 1,2,3,...,\infty)$ and F(D^i) is the probability distribution over these events, where the probability distribution is a function of *t* and all future transition probabilities, $P(I_{t+j} \mid I_{t-1+j}, X_{t-1+j}), j \geq 0$. Following Filardo (2003d), the conditional expected duration is approximated by noting the recursive nature of the macroeconomy and recognizing that forecasted transition probabilities, $p^*_{jj,t+i}$ converge to a constant as *i* gets large. The convergence arises generally from the fact that the state variable $y \, and \, \pi$ converge to their steady state values and the duration dependence is non-positive. In these cases, $p^*_{jj,t+i} \rightarrow \overline{p}_{jj}$

$$E_t(D^i \mid I_t = j) \approx 1 + \sum_{t=1}^{J} \prod_{k=1}^{t} p^*_{jj,k} + A\left(\frac{\overline{p}_{jj}}{1 - \overline{p}_{jj}}\right), where\, A = \prod_{k=1}^{J} p^*_{jj}$$

If there is negative duration dependence in the transition probabilities, that is, bubble length enters the transition probabilities with a negative coefficient, the transition probabilities decline to 0 for long duration bubbles, hence leaving the infinite sum bounded. Finally, the approximation error using this truncation method can be made arbitrarily small by picking *J* large enough.

To estimate the conditional probability of a bubble $P(I_{t+j} \mid I_{t-1+j}, X_{t-1+j}), j \geq 0$, future values of X_{t+j} need to be generated. This is done using the model in (2) to simulate future values of X_{t+j} given the random state variable of the system, $\tilde{X}_{t+j-1}$. Of particular importance, this random variable depends on the sequence of draws from the Markovian process and their influence on the state of the system. Thus, in contrast to Filardo and Gordon (1998) where the information variables were assumed to evolve independently of the state, the X_{t+j} will be influenced by the particular evolution of the state. As a consequence, the expected durations will be state and shock specific. This dependence is "integrated out" in the sense that the conditional expected durations are simulated for a given shock sequence and then the average response is estimated as the average over the simulations.

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