# Equity Prices and Monetary Policy: An Overview with an Exploratory Model*

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**Abstract**

This paper begins by surveying the potential links between financial markets and the real economy and its implications for the design of monetary policy. Within the framework of a linear rational expectations model, we then show that the benefits from reacting to misalignments in equity prices may disappear when there is noise in the variables to which the monetary policy instrument responds and this noise is positively correlated across variables. Our conclusion is that uncertainty may reduce the case for reacting to asset prices and that knowledge about the persistence and relative importance of the different types of shocks is a crucial aspect of the problem.

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# 1 Introduction

With inflation stabilised in almost all industrialised countries[1] central banks have shifted their attention to financial markets and its institutions. In Mark Gertler's (1998) words, "the issue of financial stability has become one of the most discussed issues among monetary authorities."

Several factors help explain why financial markets have become so important for monetary policymakers. First, the extraordinary development of financial markets since the beginning of the 1980s, accompanied by an increasing importance of the share of stock-market investment in households' wealth in developed countries. The deregulation and privatisation trends noticeable since the beginning of the 1980s have contributed importantly to this development — see, for example, Shiller (2000). Second, the stronger international economic interdependence, due to the globalisation of financial markets, contributed to increase uncertainty and volatility in asset markets — see, for example, Krugman (2000), and on the latter aspect Borio, Kennedy, and Prowse (1994).[2] Finally, in last decades there has been a renewed interest in an approach to economic analysis that goes back to the 1930s, to Irving Fisher's ideas on the Great Depression. This approach places financial markets at the centre of the explanation of business cycles and highlights their relevance in the transmission mechanism of monetary policy. The Japanese recession in the 1990s, the 1991 crisis in the USA, the East Asia crisis of 1998 and the discussion about the potential damaging effects of a bubble in the American stock markets during the 1990s have certainly contributed decisively to focus attention on the association between movements in real economic activity and in financial markets.

Closely related to these developments are the recent concerns of central bankers about what to do in the presence of asset-price volatility and, in the more extreme cases, how to deal with a bubble economy and with the aftermath of the bubble burst. These circumstances have motivated several comments, among which is the widely cited Alan Greenspan's December 1996 speech (Greenspan (1996)). There, the Chairman of the Federal Reserve mentioned the importance of asset-price stability to the stability of the

[1]Cecchetti and Krause (2001) provide some evidence of an improvement in macroeconomic performance in 23 countries, over the last two decades, measured as an index of output and inflation volatility.

[2]Goodhart (2000a), however, associates the higher volatility of financial markets with the deregulation and liberalisation of financial markets.

overall economy and, after mentioning the case of the Japanese economy, asked when should central bankers be concerned about irrational exuberance in asset prices. These remarks synthesise two problems of developed economies, often present in monetary policy discussions. First, should the central bank intervene when there is "irrational exuberance" in the stock market? The answer to this question depends partly on the answer to a second question: What are the effects of developments in the stock market on the real economy?

The answer to the second question is discussed in section 2. There we briefly survey the potential links between financial markets, with a special emphasis on equity prices, and the real economy. We also analyse its implications to the monetary policy's transmission mechanism.

The answer to the first question is more complex in the sense that it depends not only on the implications of asset price movements for economic outcomes, but also on the ability to estimate those effects and react appropriately. It has been argued that reacting to asset prices requires estimating misalignments in those prices. Since this is far from trivial, so the argument continues, reacting to estimated misalignments is a dangerous thing to do and it could actually be destabilizing. The counter-argument says that if it is the case that asset prices do affect the economy's path, then estimation of the other typical elements in a policy rule (usually, the output gap and inflation expectations) will have to rely on some estimate of the evolution of asset prices. Therefore, estimates of misalignments are already being used, although implicitly, in monetary policy decisions. The counter-argument then concludes that the difficulties in estimating misalignments should not deter policymakers from introducing them in the policy rule.

Our contention is that this counter-argument is not necessarily valid. The counter-argument implies that there should be a positive correlation between the errors in the estimation of the different elements of a typical policy rule, since we would expect — see the discussion in section 2 — the output gap and inflation to be higher (lower) than expected when asset prices are also higher (lower) than expected. In section 3 we show that if this is the case, then the benefits from reacting with a positive coefficient to asset prices may vanish, thus weakening the case for reacting to asset prices. We do this in the context of a linear rational expectations model. The basis of the model (of the New Keynesian variety) is nowadays common in the literature. We therefore motivate the model only briefly and provide the reader with alternative references.

In section 2 the potential links between financial markets, with a special emphasis on equity prices, and the real economy are surveyed. We also analyse its implications for the transmission mechanism of monetary policy. This section furnishes the rationale for the inclusion of a wealth effect in the standard model.

# 2 Asset Prices and the Economy

## 2.1 The channels by which asset prices impinge on the real economy

Traditionally, theories of the monetary transmission mechanism have stressed the direct effects of interest rates and exchange rates on output, and then, indirectly, on inflation. However, an old tradition in macroeconomics that focused on the importance of financial markets in the transmission of monetary policy has recently been recovered. This renewed interest results basically from the belief of policymakers and theorists in the existence of causal links between movements in financial markets and output fluctuations. From this emerges their relevance for the making of monetary policy. Furthermore, recall that monetary policy is implemented through financial markets.[3] We begin our exposition of these issues by describing the links between financial markets and the real economy and their implications for the monetary transmission mechanism.[4] We then examine the relevance of equities for real macroeconomic outcomes in contemporary developed economies.

### 2.1.1 Financial markets, the real economy and the transmission mechanism

To find a reference to the links between financial markets and the behaviour of economic activity we can go as far back as the 1930s, during the Great Depression. At that time several economists, notably Irving Fisher, considered over-indebtedness and the resulting crisis in the financial system as the main

[3]As Blinder (1998) remarks "Monetary policy works through financial markets, so perceptions of likely market reactions must be relevant to policy formulation and actual market reactions must be relevant to the timing and magnitude of monetary policy effects."

[4]Gertler (1988) gives a nice description of the role financial markets have had in the explanation of output fluctuations.

cause of the contraction in output.[5] Although Keynes stressed the importance of financial markets for real activity, namely in the determination of investment, his followers centred their attention on the role of interest rates in the transmission of monetary policy to the real economy. Thereafter, with a few marginal exceptions, notably Gurley and Shaw (1955), the role of financial markets was for long forgotten in mainstream macroeconomics, either in its neoclassical or in its Keynesian form. As Bernanke (1993) put it, "in the standard model, factors such as the financial conditions of banks and firms play no role in affecting investment or other types of spending."

Behind that view was the paradigm of perfect information and complete markets. In such a world the role of the financial system is almost irrelevant, as one of the most influential results in this literature, the Modigliani-Miller irrelevance theorem, illustrates.

However, developments in the economics of imperfect information in the 1970s, notably with Akerlof (1970), challenged the results of the complete markets literature and allowed a new understanding of the functioning of credit markets, namely of the crucial role of banks and other financial intermediaries. The imperfect and asymmetric information that characterise financial markets will determine the borrower-lender relationship and the financial structure of firms. For example, Jensen and Meckling (1976) concluded that with imperfect information and incentive problems external finance is more expensive than internal finance. Thus firms that base their investment projects on external finance will be willing to invest less than firms that do not.

The key role of imperfect information in the relationship between borrowers and lenders is that it makes it costly for banks to obtain information on firms' projects. These capital market imperfections result in an inefficient allocation of funds in credit markets and in a sub-optimal investment level in the economy. That is, if due, for example, to agency costs external finance is more costly than internal finance — that is, we have an external finance premium — then investment demand must depend on the firm's balance sheet position and the Modigliani-Miller theorem does not hold any-

[5] His debt-deflation theory of great depressions, presented in Fisher (1933), works as follows: over-indebtedness of firms, created by "new opportunities to invest at a big prospective profit" and "easy money," leading to liquidation, results in a contraction of firms' activity and deflation; the decrease in the price level increases the real debt burden of firms and precipitates bankruptcies with the consequent decrease of output and in the price level, trapping the economy in a recession.

more. The higher the agency costs the less efficient will be the allocation of funds in credit markets and the lower will be the investment in the economy. Therefore, Bernanke and Gertler (1989) argue that the level of investment depends positively on the firms' balance sheet position: a higher net worth or cash flow has a positive effect on investment directly, because it increases the sources of internal finance, and indirectly because it reduces the external costs of financing, by offering more collateral — see also Kiyotaki and Moore (1997). Because agency costs vary counter-cyclically — increasing during recessions and decreasing during expansions — they will have an amplification effect during the cycle. Bernanke, Gertler, and Gilchrist (1996) call this amplification effect of the cycle the *financial accelerator mechanism*.

All these developments have contributed to put the emphasis on the role of credit market imperfections and financial markets in general when explaining economic fluctuations. Some authors — like Mishkin (1978) and Bernanke (1983) — focused on the importance of financial factors in the Great Depression and both concluded on the significant role of the collapse of the financial system in causing and reinforcing the deep economic crisis of the 1930s. Bernanke's paper recovered Irving Fisher's idea that the Great Depression was mainly a financial crisis and provided some evidence of the role of non-monetary factors, in contrast with the, until then prevalent, analysis of Friedman and Schwartz (1963).[6] Bernanke and Gertler (1999) argue that this framework has also been very useful in understanding several other historical and contemporaneous episodes, most notably the behaviour of the Japanese economy in the 1990s.

Another very important influence of the developments described above was on the way economists and policymakers see the effects of monetary policy and the role of financial markets in the transmission of monetary policy to the real economy. According to this view, imperfections in capital markets result in a "new" channel for monetary policy. This "new" channel for monetary policy is usually known as the *credit channel*. According to Bernanke and Gertler (1995) the "credit channel" should be seen as a set of factors that "amplify and propagate conventional interest rate effects," and can be decomposed into a balance sheet and a bank-lending channel.

The balance sheet channel captures the potential impact of monetary

[6]The strong correlation between money and output, specifically between 1929 and 1933, found in Friedman and Schwartz's work highlighted the importance of money in the explanation of cycles and dwarfed the role of other financial factors.

policy decisions on firms' balance sheets and therefore on its investment ability (Bernanke and Gertler 1995). For example, a rise in interest rates that lowers asset prices reduces the market value of borrowers' collateral. This reduction in value may force some firms to reduce investment spending as their ability to borrow declines. From this results an additional impact of monetary policy on the real economy: because agency costs vary counter-cyclically, an increase in interest rates with the resulting contraction in economic activity helps to deteriorate balance sheets, raising agency costs and therefore constraining firms' investment capacity. This endogenous change in borrowers' balance sheets and its effect on economic activity constitutes the financial accelerator mechanism mentioned above. Bernanke et al. (1996) provide empirical evidence supporting the relevance of the balance sheet channel.

The second, the bank lending channel, captures the effect of monetary policy on banks' ability to lend and thus on the funds available for firms' investment. Kashyap and Stein (1994) provide empirical evidence on the importance of the bank-lending channel.

Because nowadays equity has an increasing weight on the balance sheet position of firms and because of high asset price volatility, we will now concentrate on the importance of stock markets to the real economy.

### 2.1.2 How equity prices impinge on the real economy

Highlighting the relation between equity prices and the real economy, Bernanke and Gertler (1999) mention that the bust part of the asset price cycle was in many cases associated with contractions in the real economy. Although it is very difficult to obtain accurate estimates of the effects of changes in asset prices on the real economy, there is some historical evidence that large asset prices movements can have important effects on the economy. As argued by Bernanke and Gertler (2001), "asset booms and busts have been important factors in macroeconomic fluctuations in both industrial and developing countries." The same assertion can be found in Cecchetti, Genberg, Lipsky, and Wadhwani (2000), who stress as examples of this relation the cases of the Great Depression and Japan in the 1990s.[7]

We now briefly describe the channels through which equity price move-

[7] As Christina Romer (1993) wrote, "The most likely source of the precipitous drop in American consumption following the stock market crash in 1929 is the crash itself."

ments impinge on the real economy. The three most likely channels are the households' wealth effect, Tobin's $q$ effects and the firms' balance sheet channel.

The relevance of the wealth channel has been increasingly referred to as one of the main vehicles transmitting changes in asset markets to real economic activity. The wealth effect describes the influence of asset prices (mainly stock prices) on households' wealth and then on aggregate consumption. The increasing number of families that own shares in developed countries — more than 50% of the families in the United States own stocks, a percentage that is even greater in Australia; and even in a country like Germany, where unions are still very important, more than 20% of the families own stocks — have made the role of this channel increasingly important through its impact on the households' wealth — see, for example, Shiller (2000). Despite the conclusions concerning the effects of the stock market crash on consumption during the Great Depression (more evidence on the same effect is provided by Temin (1976)), recent empirical studies have not found a strong or reliable relation between stock market and consumption — see, for example, Ludvigson and Steindel (1999) and Campbell (1999).

An additional demand-diminishing effect of a stock market crash is the one described by Christina Romer (1993). According to this author, the extraordinary drop in consumption during the Great Depression is partly explained by the uncertainty about future incomes due to the stock market crash. In Romer (1990), the same author used regression analysis to provide evidence of the role of the stock market crash in explaining the decrease in consumer purchases of durable goods.

Another channel linking equity prices and real economic activity works through the value of firms' capital relative to its replacement cost, that is, Tobin's $q$. An increase (decrease) in equity prices increases (decreases) the value of capital relative to its replacement cost and thus stimulates (inhibits) investment demand by firms. A related issue is the effect of overvaluation of stocks on investment decisions by firms. This issue is analysed empirically in Blanchard, Rhee, and Summers (1993). In their regression analysis using time series for the period 1900-1990, these authors concluded that, although market valuations appear to have a role in the determination of investment decisions, it is a limited one. However, when commenting on the potential effects of the increase in stock prices during the last decade, Blanchard (2000) says that empirical evidence suggests that firms with overvalued stocks may increase investment beyond what is justified by fundamentals, the result being an excess of capital accumulation. This same link between equity prices and the real economy is stressed by Poole (2001). Poole offers the example of the *dotcom* industry (and the extraordinary increase in its stock prices — between December 1990 and March 2000, the Nasdaq Telecommunications Index increased approximately 1300 percent) where "the distorted price signals from the stock market permitted the industry to raise capital easily and cheaply, which certainly contributed to the overexpansion."

Besides these direct effects of equity price oscillations on goods and services demand, they can also have important effects on economic activity through their indirect effects on the financial structure of firms and on the stability of the financial system. Here is a more promising link between asset prices and the real economy working through the above described balance sheet channel (Bernanke et al. (1999)). As we saw above, capital markets work imperfectly due to information, incentive and enforcement problems. In such a world the cost of borrowing depends on the financial position of agents and, therefore, a decrease in asset prices reduces the market value of borrowers' collateral and their ability to borrow and then to invest. These effects can be highly damaging for the economy in the special case when a bubble in asset prices bursts, as the experiences of the Great Depression and in Japan in the 1990s seem to suggest. In this context, Kent and Lowe (1997) stress that movements in asset prices, by disturbing the process of financial intermediation, may result in an asymmetric effect: declines in asset prices may have stronger effects on output and inflation. That is, the effects of asset price movements tend to be more conspicuous when asset prices fall than when they increase.[8]

## 2.2 Monetary policy and asset prices

The already mentioned 1996 speech of the Chairman of the Federal Reserve, Alan Greenspan, where he alluded to the irrational exuberance in the American stock market, is the most cited remark on policymakers' concerns with movements in the stock market. However, movements in the stock markets have influenced monetary policy at least since the 1920s.[9] Actually, one

[8]However, an asymmetric wealth effect of stock prices on consumption has been somewhat elusive in the data — for a recent study using non-parametric methods see Alessandri (2003).

[9]This exceptional period of the American economy still motivates a great deal of research. Among the reasons for that interest is certainly the remarkable movements in the

of the most famous examples of those actions was the monetary tightening by the Federal Reserve, in 1928, aiming to prevent the development of a bubble in the American stock market. According to Romer (1993): "The U.S. slipped into recession in mid-1929 because of tight domestic monetary policy aimed at stemming speculation on the U.S. stock market."[10]

However, for the reasons mentioned above, the potential effects of stock markets on the real economy are nowadays certainly more acute: increasing integration of national financial markets and a strengthening of links with real economic activity have reinforced the concerns of monetary policymakers with movements in equity prices. Thus, several studies have discussed whether asset prices should be taken into account in the formulation of monetary policy. There is wide agreement, among both economists and central bankers, that that should be case — see, for example, Greenspan (1996), Gertler, Goodfriend, Issing, and Spaventa (1998), Bernanke and Gertler (1999), Cecchetti et al. (2000), Goodhart and Hofmann (2000), among others.[11] However, there is disagreement on the exact role asset prices should play in the design of monetary policy and how they should be used in practice. Some authors defend that policymakers should target a broader price index that includes asset prices (for a discussion of this view see Goodhart (2000b)); others argue that they should only be used in inflation forecasts (Bernanke and Gertler (1999)); and others believe that asset prices should be taken into account in everyday monetary decisions, with policymakers aiming at stabilising their value around fundamentals (Cecchetti et al. (2000)). We briefly discuss next the arguments of the first two approaches. Then we concentrate our attention on the last issue of whether or not central banks should react to equity prices.

Alchian and Klein (1973) suggested that the traditional Consumer Price Index (CPI), aimed at measuring household's purchasing power and the target of monetary policy, should include asset prices. Their argument was based on the idea that the purchasing power of households depends not only

stock market: the 1920s were a period of euphoria in capital markets only surpassed by the exuberance of the 1990s. For a very interesting description of the similarities between these two "eras" see Shiller (2000).

[10]Hamilton (1987), an important paper on monetary policy in this period, concludes that "the major factor influencing monetary policy during 1928-29 was surely the stock market."

[11]According to a survey study by the Centre for Central Banking Studies of the Bank of England, mentioned in Cecchetti et al. (2000), asset prices influence monetary policy in most of the countries questioned.

on current prices of consumption but also on future prices. Since asset prices can be seen as a measure of future prices they should therefore be included in the construction of price indexes.[12] Charles Goodhart has been one of the supporters of the replacement of traditional price indexes targets, like the Consumer Price Index, with a broader measure of the price level that includes housing and stock prices with an appropriate weight.

The same author also argues for the inclusion of asset prices in the price index to be targeted by the monetary authority based on the idea that asset prices contribute to improve inflation forecasts. Thus, an increase in asset prices could imply an increase in interest rates even when conventionally measured inflation remains unchanged. This practice could then result in a better macroeconomic performance, so the argument goes. However, as we discuss below, the predictive power of asset prices is subject to discussion. Additionally, changes in asset prices can give wrong indications about future inflation given its high volatility and the variety of its possible origins (Filardo (2000)). Cecchetti et al. (2000) argue that the problems associated with its implementation make the construction of such an index unpractical. Vickers (2000) shares the same view.

This interest in the role of asset prices to build inflation forecasts was also strengthened by the fact that a great number of developed and developing countries are now inflation targeters that have made inflation forecasts a crucial instrument in policymakers' actions. An example of information conveyed by asset prices is the information on inflation expectations.

Goodhart and Hofmann (2000) analysed the explanatory power of asset prices through the estimation of equations for CPI inflation for seventeen countries and concluded that equity prices are a "relatively limited predictor of future inflation." However, they concluded that house prices could help forecast inflation. Filardo (2000) also concludes on the benefits of considering housing price inflation in the prediction of future consumer price inflation, although "the marginal improvement in forecasting accuracy is fairly small." Cecchetti et al. (2000) stress the fact that the role of asset prices in inflation forecasts depends crucially on the importance of the different channels by which asset prices impinge on the real economy. For instance, the exchange rate will certainly have a more important role as an input of inflation forecasts in small-open economies — as is the case at the

[12] Shibuya (1992) shows that their proposed measure of inflation can be written as a weighted sum of a traditional measure of inflation and asset price inflation.

Bank of England — than in a large closed-economy like the United States (Cecchetti et al. (2000)). Poole (2001) argues that, in the special case of stock markets, its information is more useful as a supplement of information from other sources.

In the next section we use a simple macro-model to assess the benefits of reacting to asset prices. We perform a sensitivity analysis with respect to the coefficients and to the presence of estimation errors.

# 3 Asset Prices and Uncertainty in a Macromodel

## 3.1 A Stylized Model

Our stylized system of macroeconomic equations is the following:

$$y_t = E_t y_{t+1} - \alpha_1.(i_t - E_t\pi_{t+1}) + \alpha_2.A_t + \varepsilon_t^d \quad (1)$$

$$\pi_t = \beta_1.\pi_{t-1} + (1-\beta_1).\beta.E_t\pi_{t+1} + \beta_2.y_{t-1} - \varepsilon_t^s \quad (2)$$

$$A_t = \gamma_1.(y_t + \varepsilon_t^s) + \gamma_2.E_t A_{t+1} - (i_t - E_t\pi_{t+1}) + \varepsilon_t^e \quad (3)$$

$$F_t = \gamma_1.(y_t + \varepsilon_t^s) + \gamma_2.E_t F_{t+1} - (i_t - E_t\pi_{t+1}) \quad (4)$$

$$\varepsilon_t^j = \rho_j.\varepsilon_{t-1}^j + e_t^j,\ j = d, s, e \quad (5)$$

The variables represent percent deviations around the economy's steady state. Equation (1) is the aggregate demand equation. An IS equation equal to the one above, except for the asset-price term, was derived by McCallum and Nelson (1999) from a dynamic general equilibrium model with optimising agents. It includes a leading term for output ($E_t y_{t+1}$),[13] which captures the effects of expected income on today's spending. Output also depends negatively on the real interest rate ($r_t = i_t - E_t\pi_{t+1}$). We set the coefficient $\alpha_1$ equal to 0.6 as in Estrella and Fuhrer (2002). We add an *ad hoc* term ($\alpha_2 A_t$) to incorporate the wealth effect, through consumption, of asset-price movements on aggregate demand, as discussed in section 2. We set the coefficient $\alpha_2$ equal to 0.04 following Bernanke and Gertler (1999). Given that the estimations presented in Ludvigson and Steindel (1999) yield somewhat higher values, we also use $\alpha_2 = 0.15$.

Equation (2) is a "hybrid" Phillips curve including both expected and lagged inflation on the right-hand side. An equation like this one has been

[13] The notation "$E_t x_{t+i}$" stands for the rational expectation of the value at time $t+i$ of variable $x$, using the information available at the end of period $t$.

derived from micro-foundations by, e.g., Galí and Gertler (1999). The backward-looking term ($\pi_{t-1}$) reflects the existence of a fraction of firms that employ a "rule of thumb" procedure to set their prices.[14] If all firms are forward looking, then $\beta_1 = 0$ and equation (2) becomes a standard *New Keynesian Phillips Curve*. Empirical estimates of inflation "persistence" ($\beta_1$) vary widely. Rudebusch (2002) concludes, from a survey of several studies, that a plausible range for $\beta_1$ would be $[0.4, 1]$. Therefore, we employ two levels of persistence in our analysis: a low level of persistence ($\beta_1 = 0.4$) and a high level of persistence ($\beta_1 = 0.9$).[15] In Galí and Gertler's derivation, the coefficient $\beta$ represents the discount factor in the agent's utility function, which they set equal to 0.99; we follow this practice here. The difference between equation (2) and Galí and Gertler's hybrid Phillips curve is that we have substituted lagged output for marginal cost. The empirical evidence Galí and Gertler present shows that output leads inflation, while their measure of the marginal cost moves contemporaneously with inflation. Thus, we use lagged output to proxy their marginal cost — see the discussion in Galí and Gertler (1999). Following Rudebusch (2002), we set $\beta_2 = 0.13$. We have also added an exogenous shock ($\varepsilon_t^s$) to Galí and Gertler's derivation. The inclusion of a shock in this equation has been justified (e.g., by Galí (2002)) as the result of wage staggering in the economy. $\varepsilon_t^s$ may be seen as either an approximation to this effect or as a generic supply/productivity shock — on this issue see also Erceg, Henderson, and Levin (2000) and Clarida, Galí, and Gertler (1999).

Equation (3) is derived from a standard dividend model of asset pricing: it gives equity prices as a function of next-period dividends (assumed to depend on current output and the productivity shock), expected future dividends (incorporated into the expected equity price, $E_t A_{t+1}$), and the real interest rate. Following Bernanke et al. (1999), we set $\gamma_1 = 0.05$. The coefficient on $E_t A_{t+1}$ is the inverse of the gross risk-adjusted rate of interest. The net risk-adjusted rate of interest is assumed to be approximately 3%, still following Bernanke et al. (1999), which gives $\gamma_2 = 0.97$. We add a disturbance ($\varepsilon_t^e$) which represents an equity premium shock of the type

[14] It could also be justified by the existence of "near-rational" agents (Ball 2000). Kozicki and Tinsley (2002) survey the possible sources of a lagged term in the Phillips curve.

[15] We set $\beta_1 = 0.9$ instead of $\beta_1 = 1$ because the latter would completely eliminate the forward-looking component in the determination of inflation. This would run contrary to the current standard models of the Phillips curve — see, e.g., Galí and Gertler (1999) or Bernanke, Gertler, and Gilchrist (1999).

discussed in Cecchetti et al. (2000).

An equity premium shock could be justified by a change in the risk of equity holdings or in shareholders' preferences. In our model these changes do not occur and thus equity shocks will be seen as the source of misalignments. That is, $\varepsilon_t^e$ is a non-fundamental shock. Equation (4) gives the fundamental value of equities. It is the same as equation (3), except for the omission of the non-fundamental equity premium shock.[16]

Equation (5) defines the shocks in the system as first-order autoregressive processes. We allow for two degrees of persistence, low ($\rho_j = 0.1$) and high ($\rho_j = 0.9$). Given the lack of estimates in the literature (a hard task in view of the non-observability of the equity-premium shocks), the variance-covariance matrix of the innovations ($e_t^j$) is assumed to be the identity matrix.[17]

To this system of equations we add another equation describing the behaviour of the central bank. We assume (we would say, realistically) that the central bank does not observe the shocks that buffet the economy, only the macroeconomic variables.[18] Further, we assume that the central bank sets the nominal interest rate at the beginning of time $t$ using the information available at the end of time $t-1$. Again, this seems a reasonable assumption to make, in view of the delays in obtaining (accurate) data on the state of the economy — see McCallum (1999) — especially in the case of output.

[16]Notice that, although there are misalignments, there are not "bubbles" (in the usual mathematical sense) in our model. Thus, the model will not address the issue of whether central banks should react to asset prices in order to prevent the development of bubbles. A model that pretends to study that issue must treat bubbles as endogenous in some way, so that central bank's actions may influence their evolution. However, this is not possible in the framework of linear rational expectations models that we use here. The purpose of this paper is to argue that estimation errors may be an important element in the debate on asset prices and monetary policy. Research on the effect of estimation errors when there is an asset price bubble may be interesting, but would not make our analysis redundant. After all, bubbles are not the norm.

[17]This implies that when we change the persistence we also change the variance of the shocks. Again because of the lack of estimates to guide our choice of calibration, we chose to let the two effects to mix. Note that we will keep the persistence of "demand" shocks equal to that of "supply" shocks, i.e., we are only interested in looking at the effect of changing the importance of non-fundamental shocks *relative to that of the two "standard" shocks.*

[18]This is not strictly true since the misalignment in asset prices ($A_t - F_t$) is a function of the non-fundamental shock. However, when we introduce noise in the estimation of the misalignment below, that will indeed be the case.

We will employ two types of simple policy rules:[19]

$$i_t = \lambda_1.y_{t-1} + \lambda_2.\pi_{t-1} + \lambda_3.(A_{t-1} - F_{t-1}) \quad (6)$$

$$i_t = \delta_1.E_{t-1}.\pi_{t+1} + \delta_2.(A_{t-1} - F_{t-1}) \quad (7)$$

Equation (6) is a monetary policy rule that expresses the nominal interest rate as a function of lagged output and inflation deviations from the steady state ("Taylor Rule" after Taylor (1993), a nowadays common benchmark in the analysis of monetary policy), to which we add a reaction to the misalignment in asset prices $(A_t - F_t)$.[20] Equation (7) is an *inflation-forecast targeting rule* — see Svensson (1997) — where the interest rate responds to movements in the expected inflation and also to misalignments in asset prices. According to Bernanke and Gertler (1999), an inflation-forecast targeting rule that does not react to asset prices is the most adequate monetary strategy to deal with non-fundamental movements in asset prices.[21]

[19]For justifications of the use of simple policy rules, see, e.g., Taylor (1999) and Williams (2003). Note that since these are simple rules, any addition to the policy rule of a variable that is not irrelevant in the model, or perfectly correlated with those variables already included in the rule, would improve the performance of the policy rule. In this paper we only discuss the possibility of adding asset prices to the policy rule, since this is the case that has been addressed in the strand of literature to which this paper wishes to contribute.

[20]In Alexandre and Bação (2002) it is argued that it is preferable to react to misalignments in asset prices than to asset prices themselves. The reason is that the misalignment — as mentioned in footnote 18 — is a function of the equity premium shock. Therefore, the misalignment provides the policy maker with additional information on the type of shock that is affecting the economy. In our model, movements in asset prices act like demand shocks. The difference is that there is an indicator available to the policy maker, the misalignment, for this particular type of "demand shock." Our model may be said to focus on demand side (consumption) effects, while neglecting supply-side (investment) effects. We switch the focus in another paper under preparation, in which the analysis is based on the model developed by Casares and McCallum (2000).

[21]Comparisons of the performance of different policy rules in the context of an otherwise unchanged model always bring to mind the "Lucas critique." The parameters in our model — equations (1)−(5) — do not explicitly depend, as a result of how the model was derived, on the policy rule parameters. However, it may be argued that the Lucas critique could be relevant in two equations of this model. First, since the volatility of asset prices will vary with the choice of policy, the equilibrium equity premium should also vary with the choice of policy. Taking this into account would make the computations even harder and would require additional calibration assumptions, namely regarding $\gamma_2$. Second, one argument for reacting to asset prices is that doing so would reduce the likelihood of misalignments. In the context of our model, this could be interpreted as meaning that the distribution of $\varepsilon_t^e$ would also depend on the choice of policy. Again, taking this into account would

The values of the parameters in the policy rule will be chosen so as to minimise the following loss function:[22]

$$Loss\ Function = V(\pi_t) + V(y_t) + 0.5V(i_t - i_{t-1})$$

where $V(x)$ represents the unconditional variance of variable $x$.

The inclusion of output and inflation volatility in the loss function reflects the wide agreement that they constitute the most important concerns of policymakers. Several authors argue — see, for example, Rudebusch and Svensson (1999), Batini and Haldane (1999) and the insider's view in Blinder (1998) — that the inclusion of both output and inflation volatility in the loss function is common practice among central bankers, including "inflation targeters." Even inflation targeters as the Bank of England claim that they are not "inflation nutters," in Mervyn King's (1997) words. The inclusion of an interest rate smoothing term in the loss function reduces the volatility of the policy instrument and is justified, among other reasons (see, e.g., Woodford (1999)), because policymakers are concerned about financial stability (see also Mishkin (1999)). A loss function of this type can be derived from a micro-founded dynamic general equilibrium model, as shown in Rotemberg and Woodford (1999), as a second-order approximation to the utility function of a representative agent. As Rotemberg and Woodford argue, this formulation also allows the analysis to bypass the problem of time inconsistency and focus on the issue at hand.

As we explained before, although it is theoretically conceivable that there may be benefits from reacting to asset prices, in practice central banks face several difficulties when attempting to do so. Among them are the problems posed by the estimation of misalignments. In this paper we look at the implications of uncertainty in the estimation of misalignments. We introduce uncertainty in the model in the following way. We assume that the policymaker observes a noisy measurement of the variables that are included in the policy rule, i.e., the actual policy rules will be

$$i_t = \lambda_1.\left(y_{t-1} + n_t^y\right) + \lambda_2.\left(\pi_{t-1} + n_t^\pi\right) + \lambda_3.\left(A_{t-1} - F_{t-1} + n_t^A\right) \quad (8)$$

$$i_t = \delta_1.\left(E_{t-1}.\pi_{t+1} + n_t^\pi\right) + \delta_2.\left(A_{t-1} - F_{t-1} + n_t^A\right) \quad (9)$$

make the computations even harder and would require additional calibration assumptions. Besides, the purpose here is just to illustrate the consequences of adding noise to the policy variables, an important — though previously unmodelled — element in the debate.

[22] Also used by, e.g., Rudebusch and Svensson (1999) and Rudebusch (2002).

| Case | $\beta_1$ | $\rho_e$ | $\rho_d, \rho_s$ |
|---|---|---|---|
| $(a)$ | 0.4 | 0.1 | 0.9 |
| $(b)$ | 0.9 | 0.1 | 0.9 |
| $(c)$ | 0.4 | 0.1 | 0.1 |
| $(d)$ | 0.9 | 0.1 | 0.1 |
| $(e)$ | 0.4 | 0.9 | 0.9 |
| $(f)$ | 0.9 | 0.9 | 0.9 |
| $(g)$ | 0.4 | 0.9 | 0.1 |
| $(h)$ | 0.9 | 0.9 | 0.1 |

Table 1: The different parameterizations employed

where $n_t^y$, $n_t^\pi$, and $n_t^A$, are serially uncorrelated noise processes. We will allow for different degrees of contemporaneous correlation between these noise processes, following the argument of Cecchetti et al. (2000) that errors in the estimation of inflation, the output gap and asset price misalignments are likely to be correlated. The variances of the noise processes are assumed to be a fraction of the variance of the variables to which they relate, i.e., $V\left(n_t^y\right) = n.V\left(y_t\right)$, $V\left(n_t^\pi\right) = n.V\left(\pi_t\right)$, and $V\left(n_t^A\right) = n.V\left(A_t - F_t\right)$. The coefficient $n$, assumed, for simplicity and to keep the computational effort manageable, to be common to the three processes, is the "noise-to-signal ratio". Below we examine the effect of the size of the noise-to-signal ratio on the desirability of reacting to asset prices, for different levels of correlation between the noise processes.[23]

### 3.2 Results

We first optimised the coefficients of the Taylor and IFT rules, under the different parameterizations employed (presented in Table 1). The optimisation was carried out via grid search,[24] with a step length equal to 0.01.

[23]To solve this linear rational expectations model, we employed the Schur decomposition as described in Soderlind (1999), after writing the model in the Blanchard-Kahn form (see Blanchard and Kahn (1980)). We ran all the programs in Gauss and used the implementation of the Schur decomposition made available by Paul Soderlind at http://www.hhs.se/personal/psoderlind.

[24]Grid search was preferred to numerical optimization because the latter did not lend itself to automatic processing of the results, for convergence would depend on the point chosen to initialise the procedure and the shape of the objective function. Given the number of alternative cases analysed, the ability to process the results automatically

Experimentation indicated that reducing the step length would affect the results only slightly, leaving the conclusions unchanged.

Tables 2 to 6 report the optimised coefficients, the corresponding value of the loss function, the variances of key variables and the percentage gain achieved by reacting to asset prices. Table 8 compares the performance of the two rules under each parameterization, with and without reaction to asset prices. A number of results can be gathered from these tables. Generally, the higher inflation "persistence" ($\beta_1$) is, the lower the coefficient on the asset-price misalignment tends to be. Also, the higher inflation "persistence" is, the lower the coefficient on expected inflation tends to be (in the IFT rule), but the higher the coefficient on inflation tends to be (in the Taylor rule). In most cases considered, reacting to misalignments in asset prices has little impact on the loss. Understandably, the exceptions arise when equity shocks ($\varepsilon^e$) are more persistent than demand ($\varepsilon^d$) and supply shocks ( $varepsilon^s$), i.e., in cases ($g$) and ($h$). In the other cases, the impact of reacting to asset prices on the loss function is less than that associated with the choice between the Taylor and the IFT rules. Table 8 shows that the Taylor rule is better, in our model, than the IFT rule except when there is both low inflation "persistence" and low persistence (and lower variance) of the demand and supply shocks — cases ($c$) and ($g$). The persistence of equity shocks also influences the optimised coefficient corresponding to the misalignment in the policy rule: the lower the persistence, the lower the reaction coefficient tends to be. In cases ($a$) and ($b$), the optimised reaction coefficient in the Taylor rule even became negative. Naturally, the variance of equity prices, in these cases, is higher when the policy rule reacts to equity prices than when it does not.

Next we assessed the "robustness" of the optimised policy rules just presented. Table 9 reports the noise-to-signal ratio beyond which the optimised rule that does not react to misalignments in asset prices yields a lower loss than the corresponding optimised rule that does react to misalignments. These values were computed assuming that the estimation errors are uncorrelated. One noticeable feature of the results is that the Taylor rule with reaction to asset prices appears to be much more robust than the IFT rule in the sense that for most of the cases considered, the reacting rule always dominates the no-reaction rule. However, in case ($c$), in which it does not, the critical noise-to-signal ratio is very low. In the case of the IFT rule, the

became a very important issue.

| Case | no reaction $E_{t-1}\pi_{t+1}$ | loss | reaction $E_{t-1}\pi_{t+1}$ | mis | loss | gain from reacting |
|---|---|---|---|---|---|---|
| $(a)$ | 2.19 | 262.9521 | 2.19 | 0.02 | 262.9513 | 0.00% |
| $(b)$ | 1.55 | 321.7150 | 1.55 | 0.02 | 321.7147 | 0.00% |
| $(c)$ | 3.51 | 5.9735 | 3.50 | 0.02 | 5.9732 | 0.01% |
| $(d)$ | 1.29 | 12.2901 | 1.29 | 0.02 | 12.2896 | 0.00% |
| $(e)$ | 2.26 | 263.7329 | 2.19 | 0.05 | 263.0520 | 0.26% |
| $(f)$ | 1.59 | 323.3620 | 1.55 | 0.04 | 321.8184 | 0.48% |
| $(g)$ | 4.07 | 6.2687 | 3.52 | 0.06 | 6.0738 | 3.11% |
| $(h)$ | 1.65 | 14.3729 | 1.29 | 0.04 | 12.3945 | 13.77% |

Table 2: Optimised coefficients for the IFT rule with $\alpha_2 = 0.04$ and no noise

| Case | no reaction $E_{t-1}\pi_{t+1}$ | loss | reaction $E_{t-1}\pi_{t+1}$ | mis | loss | gain from reacting |
|---|---|---|---|---|---|---|
| $(a)$ | 1.69 | 264.9645 | 1.69 | 0.10 | 264.9440 | 0.01% |
| $(b)$ | 1.33 | 331.4911 | 1.33 | 0.07 | 331.4825 | 0.00% |
| $(c)$ | 3.49 | 5.6978 | 3.48 | 0.09 | 5.6903 | 0.13% |
| $(d)$ | 1.17 | 12.2137 | 1.17 | 0.07 | 12.2024 | 0.09% |
| $(e)$ | 2.20 | 269.9036 | 1.69 | 0.09 | 265.3561 | 1.68% |
| $(f)$ | 1.72 | 340.7439 | 1.33 | 0.08 | 331.8824 | 2.60% |
| $(g)$ | 5.47 | 6.7110 | 3.47 | 0.11 | 6.0737 | 9.50% |
| $(h)$ | 2.28 | 18.2721 | 1.17 | 0.08 | 12.6204 | 30.93% |

Table 3: Optimised coefficients for the IFT rule with $\alpha_2 = 0.15$ and no noise

| | IFT rule with $\alpha_2 = 0.04$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | no reaction | | | | reaction | | | |
| Case | $A$ | $i$ | $\pi$ | $y$ | $A$ | $i$ | $\pi$ | $y$ |
| $(a)$ | 673.63 | 25.05 | 10.97 | 248.67 | 673.59 | 25.05 | 10.97 | 248.67 |
| $(b)$ | 673.60 | 33.79 | 16.85 | 302.94 | 673.56 | 33.80 | 16.85 | 302.94 |
| $(c)$ | 3.42 | 1.49 | 3.17 | 1.85 | 3.38 | 1.49 | 3.17 | 1.85 |
| $(d)$ | 9.82 | 4.44 | 5.16 | 6.34 | 9.77 | 4.44 | 5.16 | 6.34 |
| $(e)$ | 825.72 | 25.58 | 10.62 | 249.73 | 813.9 | 25.42 | 10.99 | 248.70 |
| $(f)$ | 844.53 | 33.95 | 16.18 | 305.20 | 814.04 | 34.36 | 16.85 | 302.98 |
| $(g)$ | 148.38 | 2.51 | 3.09 | 2.02 | 143.31 | 1.88 | 3.18 | 1.88 |
| $(h)$ | 175.64 | 5.65 | 4.40 | 8.94 | 150.39 | 5.01 | 5.16 | 6.38 |

| | IFT rule with $\alpha_2 = 0.15$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | no reaction | | | | reaction | | | |
| Case | $A$ | $i$ | $\pi$ | $y$ | $A$ | $i$ | $\pi$ | $y$ |
| $(a)$ | 179.93 | 9.28 | 7.58 | 256.14 | 179.65 | 9.29 | 7.58 | 256.11 |
| $(b)$ | 184.98 | 13.00 | 9.70 | 320.88 | 184.81 | 13.01 | 9.70 | 320.87 |
| $(c)$ | 2.73 | 1.13 | 2.97 | 1.98 | 2.58 | 1.13 | 2.97 | 1.96 |
| $(d)$ | 4.49 | 3.37 | 4.94 | 6.64 | 4.30 | 3.38 | 4.94 | 6.63 |
| $(e)$ | 233.32 | 12.01 | 6.22 | 262.09 | 217.71 | 10.51 | 7.68 | 256.25 |
| $(f)$ | 267.83 | 13.75 | 6.81 | 332.77 | 221.89 | 14.88 | 9.72 | 321.03 |
| $(g)$ | 43.78 | 4.36 | 2.75 | 2.61 | 40.25 | 2.60 | 3.03 | 2.08 |
| $(h)$ | 62.54 | 7.11 | 3.43 | 13.56 | 40.99 | 5.11 | 4.97 | 6.79 |

Table 4: Variances under the IFT rule with no noise

| | no reaction | | | reaction | | | | gain from |
|---|---|---|---|---|---|---|---|---|
| Case | $y$ | $\pi$ | loss | $y$ | $\pi$ | mis | loss | reacting |
| $(a)$ | 0.54 | 2.53 | 258.1874 | 0.54 | 2.53 | -0.01 | 258.1873 | 0.00% |
| $(b)$ | 1.05 | 4.04 | 290.8912 | 1.05 | 4.04 | -0.02 | 290.8907 | 0.00% |
| $(c)$ | 0.37 | 0.99 | 6.1043 | 0.37 | 0.99 | 0.01 | 6.1043 | 0.00% |
| $(d)$ | 0.34 | 1.25 | 12.1357 | 0.34 | 1.25 | 0.01 | 12.1355 | 0.00% |
| $(e)$ | 0.56 | 2.58 | 258.5369 | 0.54 | 2.53 | 0.04 | 258.3169 | 0.09% |
| $(f)$ | 1.07 | 4.11 | 291.1116 | 1.03 | 3.99 | 0.03 | 291.0380 | 0.03% |
| $(g)$ | 0.67 | 1.44 | 8.4968 | 0.36 | 0.99 | 0.04 | 6.2172 | 26.83% |
| $(h)$ | 0.79 | 1.80 | 13.4104 | 0.33 | 1.24 | 0.04 | 12.2472 | 8.67% |

Table 5: Optimised coefficients for the Taylor rule with $\alpha_2 = 0.04$ and no noise

| | no reaction | | | reaction | | | | gain from |
|---|---|---|---|---|---|---|---|---|
| Case | $y$ | $\pi$ | loss | $y$ | $\pi$ | mis | loss | reacting |
| $(a)$ | 0.40 | 1.95 | 254.3633 | 0.40 | 1.95 | 0.00 | 254.3633 | 0.00% |
| $(b)$ | 0.78 | 3.14 | 289.8027 | 0.78 | 3.14 | -0.03 | 289.8012 | 0.00% |
| $(c)$ | 0.48 | 0.98 | 5.9185 | 0.48 | 0.98 | 0.01 | 5.9184 | 0.00% |
| $(d)$ | 0.39 | 1.22 | 11.9925 | 0.39 | 1.22 | 0.03 | 11.9904 | 0.02% |
| $(e)$ | 0.57 | 2.42 | 256.2887 | 0.39 | 1.93 | 0.09 | 254.8089 | 0.58% |
| $(f)$ | 1.06 | 3.98 | 290.9147 | 0.72 | 2.96 | 0.08 | 290.3199 | 0.20% |
| $(g)$ | 0.86 | 1.83 | 10.8384 | 0.48 | 0.98 | 0.08 | 6.3628 | 41.29% |
| $(h)$ | 1.10 | 2.25 | 15.3492 | 0.37 | 1.20 | 0.08 | 12.4417 | 18.94% |

Table 6: Optimised coefficients for the Taylor rule with $\alpha_2 = 0.15$ and no noise

| Taylor rule with $\alpha_2 = 0.04$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | no reaction | | | | reaction | | | |
| Case | $A$ | $i$ | $\pi$ | $y$ | $A$ | $i$ | $\pi$ | $y$ |
| $(a)$ | 649.81 | 46.66 | 31.70 | 220.04 | 649.83 | 46.66 | 31.70 | 220.04 |
| $(b)$ | 662.27 | 37.28 | 30.79 | 258.71 | 662.29 | 37.28 | 30.79 | 258.71 |
| $(c)$ | 4.66 | 1.84 | 2.69 | 2.12 | 4.64 | 1.84 | 2.69 | 2.12 |
| $(d)$ | 9.81 | 4.49 | 5.17 | 6.12 | 9.78 | 4.49 | 5.17 | 6.12 |
| $(e)$ | 796.07 | 47.75 | 31.89 | 220.01 | 790.27 | 47.25 | 31.70 | 220.07 |
| $(f)$ | 808.59 | 37.83 | 30.62 | 259.01 | 803.28 | 37.83 | 30.66 | 258.89 |
| $(g)$ | 157.74 | 4.91 | 3.18 | 2.70 | 145.34 | 2.36 | 2.68 | 2.17 |
| $(h)$ | 165.98 | 6.33 | 5.13 | 6.63 | 150.06 | 5.04 | 5.16 | 6.17 |

| Taylor rule with $\alpha_2 = 0.15$ | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | no reaction | | | | reaction | | | |
| Case | $A$ | $i$ | $\pi$ | $y$ | $A$ | $i$ | $\pi$ | $y$ |
| $(a)$ | 169.14 | 28.46 | 31.74 | 218.81 | 169.14 | 28.46 | 31.74 | 218.81 |
| $(b)$ | 161.04 | 22.31 | 29.54 | 259.60 | 161.07 | 22.30 | 29.54 | 259.60 |
| $(c)$ | 3.38 | 1.53 | 2.64 | 2.07 | 3.37 | 1.53 | 2.64 | 2.07 |
| $(d)$ | 4.37 | 3.56 | 4.99 | 6.22 | 4.31 | 3.57 | 4.99 | 6.22 |
| $(e)$ | 214.26 | 32.29 | 31.59 | 219.96 | 205.72 | 29.99 | 31.47 | 219.23 |
| $(f)$ | 206.56 | 24.86 | 29.46 | 260.37 | 197.06 | 24.63 | 29.63 | 259.64 |
| $(g)$ | 49.02 | 8.63 | 3.32 | 3.72 | 40.11 | 3.07 | 2.70 | 2.15 |
| $(h)$ | 52.37 | 8.54 | 4.79 | 7.97 | 40.77 | 5.38 | 4.99 | 6.39 |

Table 7: Variances under the Taylor rule with no noise

|  | no reaction |  | reaction |  |
|---|---|---|---|---|
| Case | 0.04 | 0.15 | 0.04 | 0.15 |
| $(a)$ | 1.81% | 4.00% | 1.81% | 3.99% |
| $(b)$ | 9.58% | 12.58% | 9.58% | 12.57% |
| $(c)$ | -2.19% | -3.87% | -2.19% | -4.01% |
| $(d)$ | 1.26% | 1.81% | 1.25% | 1.74% |
| $(e)$ | 1.97% | 5.04% | 1.80% | 3.97% |
| $(f)$ | 9.97% | 14.62% | 9.56% | 12.52% |
| $(g)$ | -35.54% | -61.50% | -2.36% | -4.76% |
| $(h)$ | 6.70% | 16.00% | 1.19% | 1.42% |

Table 8: Gain (loss) from using the Taylor rule, relative to the IFT rule

critical noise-to-signal ratios are usually high. Another result is that the size of the wealth effect does not affect robustness in a unique way, i.e., a stronger wealth effect will not make reacting to misalignments always more robust when the level of noise is unknown. Table 10 shows the results of the same exercise carried out assuming that the correlation coefficient between the estimation errors equals 0.5. The noteworthy aspect is that the critical noise-to-signal ratio is now very much reduced. Even some of the cases for which reacting was always preferred when the correlation coefficient was zero now report a low critical noise-to-signal ratio (cases $(c)$ and $(d)$ under the Taylor rule). However, under the Taylor rule, it is always best to react to misalignments when the non-fundamental shock is highly persistent (cases $(e) - (h)$), regardless of the correlation coefficient.

Finally, we computed (approximate) "critical" noise-to-signal ratios, i.e., the noise-to-signal ratio at which the coefficient corresponding to the reaction to asset prices becomes non-positive. We did not compute the actual critical noise-to-signal ratio. Rather we optimised the coefficients of the policy rules for each level of correlation (0.0, 0.1, ..., 0.9) and for noise-to-signal ratios equal to 0.1, 0.2, ..., 1.0. For each level of correlation, the first noise-to-signal ratio for which the reaction coefficient is non-positive is reported as being the critical noise-to-signal ratio. Tables 11 to 14 present the results. It must be noticed that at zero correlation, the optimised reaction coefficient was always found to be positive, even in cases $(a)$ and $(b)$, for which the optimised reaction coefficient in the Taylor rule was negative in the no-noise context. However, even in the zero correlation case, it is still the case that

| | IFT rule | | Taylor rule | |
|---|---|---|---|---|
| Case | $\alpha_2 = 0.04$ | $\alpha_2 = 0.15$ | $\alpha_2 = 0.04$ | $\alpha_2 = 0.15$ |
| $(a)$ | 1.67 | 0.97 | - | - |
| $(b)$ | 0.71 | 1.10 | - | - |
| $(c)$ | 0.29 | 0.84 | 0.02 | * |
| $(d)$ | 1.02 | 1.33 | * | * |
| $(e)$ | 0.58 | 0.75 | * | * |
| $(f)$ | 1.29 | 1.35 | * | * |
| $(g)$ | 0.39 | 0.27 | * | * |
| $(h)$ | 3.25 | 2.17 | * | * |

*: the rule with reaction to misalignments always performed better.

Table 9: Critical noise-to-signal ratio with zero correlation using the coefficients optimised without noise

| | IFT rule | | Taylor rule | |
|---|---|---|---|---|
| Case | $\alpha_2 = 0.04$ | $\alpha_2 = 0.15$ | $\alpha_2 = 0.04$ | $\alpha_2 = 0.15$ |
| $(a)$ | 0.01 | 0.04 | - | - |
| $(b)$ | 0.00 | 0.02 | - | - |
| $(c)$ | 0.02 | 0.08 | 0.00 | 0.01 |
| $(d)$ | 0.01 | 0.04 | 0.00 | 0.01 |
| $(e)$ | 0.11 | 0.31 | * | * |
| $(f)$ | 0.23 | 0.59 | * | * |
| $(g)$ | 0.12 | 0.14 | * | * |
| $(h)$ | 0.75 | 0.74 | * | * |

*: the rule with reaction to misalignments always performed better.

Table 10: Critical noise-to-signal ratio with correlation equal to 0.5 using the coefficients optimised without noise

| | coefficient of correlation between estimation errors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| $(a)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(b)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(c)$ | NF | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(d)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(e)$ | NF | NF | NF | 0.7 | 0.5 | 0.4 | 0.3 | 0.3 | 0.2 | 0.2 |
| $(f)$ | NF | NF | NF | 1 | 0.7 | 0.6 | 0.5 | 0.4 | 0.4 | 0.3 |
| $(g)$ | NF | NF | NF | NF | NF | NF | 0.8 | 0.6 | 0.5 | 0.4 |
| $(h)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |

*NF*: the reaction to asset-price misalignments was always positive.

Table 11: Critical noise-to-signal ratio using the IFT rule and $\alpha_2 = 0.04$

increasing the noise-to-signal ratio reduces the reaction coefficient.[25] It appears then that when the correlation between the estimation errors is zero, there is a non-monotonic relation between the reaction coefficient and the noise-to-signal ratio at very low levels of noise.

For higher levels of correlation, the critical noise-to-signal ratio is usually low in cases $(a) - (d)$ and somewhat higher, or even not found in the range $[0.1, 1.0]$, in cases $(e) - (h)$.

# 4 Conclusion

The main conclusion we wish to offer is that the desirability of reacting to asset prices as a means to stabilize the economy depends crucially on the persistence and relative importance of the different shocks that hit the economy. Introducing correlated noise in the estimation of the variables that enter the policy rule reduces the optimised value of the coefficient corresponding to the misalignment in asset prices. Depending on the value of the parameters in the model, this reaction coefficient may quickly become negative, thus contradicting the "lean against the wind" prescription. Empirical research

[25] To save space, the optimised coefficients for all the different correlation/noise-to-signal ratio combinations are not reported. We may add that the coefficient on $E_{t-1}\pi_{t+1}$ increased with the level of correlation. In the Taylor rule, the coefficient on $y$ tends to decrease, while that on $\pi$ appears to change non-monotonically with the noise level, first decreasing and then increasing.

| | coefficient of correlation between estimation errors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| $(a)$ | NF | 0.4 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(b)$ | NF | 0.3 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(c)$ | NF | 0.7 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 |
| $(d)$ | NF | 0.5 | 0.3 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(e)$ | NF | NF | NF | NF | NF | NF | NF | NF | 1 | 0.8 |
| $(f)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |
| $(g)$ | NF | NF | NF | NF | NF | NF | 0.9 | 0.8 | 0.6 | 0.5 |
| $(h)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |

*NF*: the reaction to asset-price misalignments was always positive.

Table 12: Critical noise-to-signal ratio using the IFT rule and $\alpha_2 = 0.15$

| | coefficient of correlation between estimation errors | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| $(a)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(b)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(c)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(d)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(e)$ | NF | NF | NF | NF | NF | 0.4 | 0.3 | 0.2 | 0.2 | 0.1 |
| $(f)$ | NF | NF | NF | NF | NF | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 |
| $(g)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |
| $(h)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |

*NF*: the reaction to asset-price misalignments was always positive.

Table 13: Critical noise-to-signal ratio using the Taylor rule and $\alpha_2 = 0.04$

| coefficient of correlation between estimation errors | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Case | 0 | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 | 0.6 | 0.7 | 0.8 | 0.9 |
| $(a)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(b)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(c)$ | NF | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(d)$ | NF | 0.3 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| $(e)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |
| $(f)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |
| $(g)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |
| $(h)$ | NF | NF | NF | NF | NF | NF | NF | NF | NF | NF |

*NF*: the reaction to asset-price misalignments was always positive.

Table 14: Critical noise-to-signal ratio using the Taylor rule and $\alpha_2 = 0.15$

on the degree of persistence and relative importance of different shocks is required to help discern which are the more plausible calibrations and, consequently, whether reacting to asset prices (with a positive coefficient) is desirable or not.

It must be stressed, though, that our model does not take into account the possibility that reacting to asset prices may by itself reduce the likelihood of significant misalignments (or bubbles) occurring. If reacting (with a positive coefficient) to misalignments has that effect, then this benefit will have to be weighed against the consequences arising from the existence of (correlated) estimation errors, which could make such reaction undesirable.

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