The role of asset prices in transmitting monetary and other shocks

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Abstract

In this paper we construct a framework within which we can assess the ability of asset prices to convey information about the underlying shocks hitting the economy. We first use an identified VAR to establish a set of 'stylised facts' as to how asset prices respond to exogenous monetary policy movements. We then develop a theoretical model of the economy and analyse how asset prices within it respond to different shocks. Consumers in the model consume both market-produced and home-produced goods. There are two types of firms: those producing traded goods – sold on competitive world markets – and those producing non-traded goods. Non-traded goods' producers face costs of adjusting their capital stocks and can only reset their prices once a year in a staggered fashion. We show that the model is able to replicate the 'stylised facts' found in the empirical exercise. We then show how asset prices respond to shocks to productivity in the traded, non-traded and household production sectors and a shock to the world price of traded goods. With these results we are able to assess what information asset prices may give us about the shocks affecting the economy at any particular time.

Summary

This paper aims to improve our understanding of both the information contained in asset prices, and their response to monetary policy. In particular, we concentrate on the fundamental determinants of asset price movements, and rule out asset price bubbles or speculation. To be more specific, we are interested in the following questions about asset prices:

a) What is the response of asset prices to monetary policy?

b) What information do asset prices contain about fundamental shocks affecting the economy?

Although (a) and (b) are essentially different issues, our approach is to build a common framework in which to answer them. We first estimate an empirical model to characterise the data. Then, we construct a dynamic stochastic general equilibrium (DSGE) model that enables us to address our questions at a fundamental level. Using this dual approach, we are able to uncover interactions between asset prices and monetary policy that are theoretically and empirically congruent. The DSGE model is then used to uncover the interactions between key economic variables and assets in the face of fundamental economic shocks that are difficult to identify empirically. This allows us to draw robust conclusions about the role of and informational content of fundamental asset prices and their role in the transmission mechanism.

The empirical model is a fairly standard vector autoregression (VAR) that identifies a monetary policy shock. The empirical model serves two purposes: by plotting the response of asset prices to monetary policy shocks it gives an entirely empirical answer to question (a), and it provides a benchmark with which to evaluate a theoretical model. We find that output falls after a contractionary monetary shock and exhibits a ‘hump-shaped’ response. Base money and the price level also fall. But, as is often found in this type of analysis, the effect on the price level is small. There is a short-lived rise in the exchange rate, which then follows a UIP path and gradually depreciates back to base. Short-run nominal interest rates rise after the shock. However, we find a small but significant fall in the long rate. This implies a clockwise rotation in the yield curve. House prices fall, but more quickly and by a larger amount than the general price level. There is also a short-lived fall in equity prices.

The baseline for the theoretical model is an open-economy ‘Consumption CAPM’ model, based on a representative rational agent who can hold a portfolio of various assets: domestic real and nominal bonds, foreign nominal bonds and shares in domestic firms. Agents select their portfolios to maximise the present value of their lifetime utility. The model is fairly standard with consumers exhibiting habit persistence over their consumption of traded and non-traded goods and housing services. In order to obtain housing services, they combine time spent in household production with the existing housing stock. Their derived demand for housing together with exogenous housing supply generates interesting dynamics for house prices. Our interest in house prices is motivated, in part, by empirical studies that have shown house prices to be a useful indicator for inflation. Firms combine labour and capital services to produce both traded and non-traded goods. We assume that investment decisions in the non-traded sector are subject to convex ‘costs of adjustment’. The model is calibrated for the United Kingdom. By shocking variables in the model, and plotting the response of asset prices to shocks, we can answer our two questions at a fundamental level.

We first examine the responses of variables to an exogenous monetary policy shock in the theoretical model. We find that the theoretical model is able to produce responses qualitatively similar to those uncovered from the data, although we also find some differences. We take the general congruence between model and data to be an encouraging sign.

We then use our model to show how a given fundamental shock may imply a unique pattern of asset price movements in the periods immediately after the shock. Therefore, observing patterns of asset prices and comparing them with the movements implied by our model might reveal the nature of shocks currently hitting the economy. There are, however, several important reasons why this information should only be used tentatively and to corroborate other evidence. First, the results presented in the paper are dependent on the monetary policy response to shocks. That is, they depend crucially on the monetary policy rule that we assume being a reasonable characterisation of the monetary reaction function, and that this is fully known by market participants. Second, asset prices often move for reasons not obviously related to economic fundamentals; we should be careful not to assume that any movement in asset prices is driven by fundamentals.

1 Introduction and overview

This paper aims to improve our understanding of both the information contained in asset prices, and their response to monetary policy. It is not about bubbles or speculation, but about the fundamental determinants of asset price movements. To be more specific, we are interested in the following questions about asset prices:

(a) What is the response of asset prices to monetary policy?

(b) What information do asset prices contain about fundamental shocks affecting the economy?

A number of recent papers and speeches by central bankers and academics motivate this work.(1) Broadly, this literature identifies three main reasons why policy-setters should be interested in asset prices.(2) First, asset prices will affect medium-term inflation prospects, so a good understanding of the role they play in the transmission mechanism will improve medium-term forecasts. Second, understanding how asset prices react to monetary policy could help guide the appropriate policy reaction in the face of large and potentially destabilising asset price movements. Third, asset prices provide useful information on market sentiment, changes in economic fundamentals, attitudes to risk and as a check on policy credibility.

Focusing first on the role of asset prices in the transmission mechanism, it is relatively straightforward to identify three main channels through which asset prices influence inflation. The exchange rate has a direct influence on the price level by changing the price of imported goods. This channel is particularly important for small open economies such as the United Kingdom. Also, asset prices affect household wealth and income. Wealth affects consumption and therefore aggregate demand which, in turn, impacts on inflation. Finally, asset prices affect the cost of capital faced by firms. So they may influence firms' investment decisions, and therefore aggregate demand and inflation.

The empirical evidence as to whether asset prices contain information for future output and inflation is mixed. In a study of 7 OECD countries and up to 38 different assets, Stock and Watson (2001) find that the incremental out-of-sample forecasting power of asset prices is unstable across time, assets and country. They conclude that 'some assets predict either inflation or output growth in some countries in some periods', but *ex ante* there is no way of knowing which asset is currently the most accurate predictor.

In contrast, studies that examine the in-sample properties of asset prices typically show that asset prices do contain some incremental information about future inflation and output. Goodhart and Hofmann (2000a and b) find that for real stock prices in many countries, the term spread and especially real house prices possess in-sample forecasting power. Consequently, they recommend that monetary authorities should pay close attention to

(1) For example, see Vickers (1999), Bäckström (1999), Goodhart (1999), Bergström (2000), and Cecchetti *et al* (2000).

(2) Some authors, notably Alchian and Klein (1973), have argued that since asset prices represent claims on future consumption, an accurate measure of inflation should include asset prices. In this paper, we make no attempt to address the issue of whether asset prices should enter the monetary authorities' reaction function and/or the extent to which they should be targeted.

property prices when assessing the state of the economy. This result is also found in Mayes and Virén (2001), who show that house prices are potentially useful leading indicators.

To the extent that there is information about future output and inflation contained in current asset prices, a question arises as to whether monetary authorities should seek to prevent asset prices moving substantially away from their fundamental or ‘warranted’ values. This view is argued in Cecchetti *et al* (2000) which suggests that using monetary policy to bring asset prices into line with their fundamental values can reduce their destabilising influence. On the other hand, discussions in Gertler *et al* (1998) suggest that the monetary authority should not respond directly to asset price movements, but instead should monitor them for their informational properties. This is because it is extremely difficult *ex ante* to identify asset price bubbles. Put another way, there is no reason to suppose monetary authorities possess more information about fundamental asset prices than the market. This point is made forcefully by Goodfriend, in Gertler *et al* (1998), who argues that ‘central bankers have no particular expertise … in pricing equities, which is a full-time job for armies of stock analysts and investors.’ This point is especially pertinent since responding to asset price fluctuations is only likely to increase significantly macroeconomic stability if bubbles are pricked in their infancy, which is by definition the time when they are most difficult to identify. But even if one could successfully identify bubbles there are other reasons why a monetary authority might not react directly to asset prices. Many financial prices are noisy and volatile making signal extraction difficult. Further, current asset prices reflect expectations about future monetary policy. But if policy is explicitly guided by asset prices there is a risk of a potentially destabilising circularity.

A further question is whether there are welfare gains from explicitly including asset prices in the monetary authority’s reaction function. This topic has received considerable attention for open economies in recent years, particularly regarding the usefulness of monetary conditions indices (MCIs). Ball (1999) proposes that for open economies, the optimal policy instrument is a weighted average of the interest rate and the exchange rate. Using the model of Batini and Nelson (2000), Cecchetti *et al* (2000) find that systematic reaction to the exchange rate is potentially welfare improving in the face of some, but not all, shocks. This highlights the potential flaw in using MCIs – they do not take account of the source of the shock to the exchange rate. However, by comparing a battery of different rules inside a general equilibrium model, Batini, Harrison and Millard (BHM) (2001) find that a rule that responds to changes in the real exchange rate as well as deviations of inflation and output slightly outperforms one that does not.

To examine the effects of targeting other asset prices Bernanke and Gertler (1999) formulate a closed-economy dynamic model. Their model allows for exogenous bubbles in a generic asset price. These bubbles have real effects since firms are permitted to raise finance based on inflated asset values. They find an aggressive inflation targeting strategy considerably smoothes the response of output, inflation and the interest rate to a sharp fall in asset prices. Adding a direct role for asset price changes into the policy rule is often found to be actively destabilising.

In this paper, we do not address the question of whether monetary authorities should systematically respond to asset prices. Instead we content ourselves with answering the two questions (a) and (b) above in a world where asset prices reflect only their fundamental values, that is we rule out ‘bubbles’. Although this approach assumes away a property that is intrinsically associated with many asset prices, it is potentially useful for several reasons. First, for a given characterisation of monetary policy, it potentially allows the monetary authority to observe patterns of asset price movements and use these in conjunction with other macroeconomic evidence to infer the current shocks that are hitting the economy. Second, it permits a tentative first step toward being able to identify movements in asset prices away from fundamental values. That is, in order to judge whether a given asset price is inflated, one must first have some prior about how their fundamental prices would be affected by a given set of economic conditions. For example, taken on its own the run-up in US equity prices in the 1990s could have signalled higher future inflation. But, in conjunction with a strong appreciation of the real exchange rate and other macroeconomic data, the equity price rise could reflect higher productivity growth, meaning the asset price rises need not be signalling higher inflation. Of course, under which circumstances it may be beneficial for the monetary authority to respond systematically to asset price movements is an interesting and important issue that we intend to address in future work.

Although (a) and (b) are essentially different issues, our approach is to build a common framework in which to answer them. We first estimate an empirical model to characterise the data. Then, we construct a dynamic stochastic general equilibrium (DSGE) model that enables us to address our questions at a fundamental level. Using this dual approach, we aim to uncover interactions between asset prices and monetary policy that are theoretically and empirically congruent. The DSGE model is then used to uncover the interactions between key economic variables and assets in the face of fundamental economic shocks that are difficult to identify empirically. This will allow us to draw robust conclusions about the role of and informational content of fundamental asset prices and their role in the transmission mechanism.

The empirical model is a fairly standard vector autoregression (VAR) that identifies a monetary policy shock. In recent years, this type of model has produced a broad consensus on the response of the US economy to a monetary policy shock. The empirical model serves two purposes: by plotting the response of asset prices to monetary policy shocks it gives an entirely empirical answer to question (a), and it provides a benchmark with which to evaluate a theoretical model. If our model mimics the response of the actual economy in the face of a monetary policy shock, as uncovered by the data, we are more inclined to believe the model when studying the effects of other fundamental shocks that are difficult to identify empirically.

The baseline for the theoretical model is an open-economy 'Consumption CAPM' model, based on a representative rational agent who can hold a portfolio of various assets. The agent selects his portfolio to maximise the present value of his lifetime utility. The model is calibrated for the United Kingdom and used to uncover fundamental interactions between key economic variables and assets. We also introduce house prices through the addition of a household sector. Our interest in house prices is motivated, in part, by the empirical studies cited above which show that house prices are useful indicators for inflation. By shocking variables in the model, and plotting the response of asset prices to shocks, we can answer our two questions at a fundamental level.

The structure of the paper is as follows. In Section 2, we use our empirical model to examine the response of asset prices to monetary policy; as stated above, this is useful both in answering the first of the two questions posed above as well as in giving us a basic set of predictions that we would like our theoretical model to match. In Sections 3 to 5, we develop a simple, general equilibrium model of asset prices. Section 3 describes the model and analyses how domestic asset prices are related to consumption, production and foreign variables. Section 4 concentrates on the calibration of the model and the response of asset prices and other key economic variables to monetary policy actions. Section 5, examines the effects of other shocks and draws some conclusions from the theoretical model. Section 6 concludes with some ideas for further work.

2 The effect of monetary policy on asset prices

Before attempting to build a forward-looking model of the UK economy with asset prices, we consider it useful to examine the effects of monetary policy movements within the UK data. We do this both to provide a benchmark (or 'reality' check) for the DSGE model and directly address question (a) above. Our method is to draw on the vast US literature that uses VARs to trace out the effects of monetary policy shocks. Since interest rates are largely responding endogenously to developments in both asset prices and other variables, we isolate an exogenous component of interest rate movements. This exogenous 'monetary policy shock' is identified using a minimal amount of theory, so the resulting model is based primarily on past correlations in the data.

In their review of this literature, Christiano, Eichenbaum and Evans (CEE) (1999) show that although researchers in this field have not yet converged on a particular set of identification assumptions, there has been considerable agreement on the qualitative effects of a monetary policy shock to the US economy. They uncover a set of stylised facts which can be summarised as follows: 'after a contractionary monetary policy shock, short-term interest rates rise, aggregate output, employment, profits and various monetary aggregates fall, the aggregate price level responds very slowly, and various measures of wages fall, albeit by small amounts.'

In practice, identifying the exogenous component of monetary policy is relatively straightforward. Following the method of CEE (1999), we can model the response of asset prices to the identified shock by adding them to a VAR containing a set of core macroeconomic variables and a policy instrument. Economic theory is only required to choose the appropriate policy instrument and partition the remaining variables into two blocks: a policy block and a non-policy block. The policy block contains all variables that contemporaneously affect the policy decision, but do not respond to policy changes within the period: they are *sluggish*. This implies that the system has a recursive structure that is sufficient to identify the exogenous component of monetary policy if it is assumed to be uncorrelated with the other (unidentified) shocks. Importantly, as shown by CEE (1999), this method has the desirable property that the response of each variable to the monetary policy shock is invariant to the ordering inside each block.

This method may not be readily applicable to the United Kingdom as this type of model often produces 'puzzles', especially when applied to small open economies. The most common of these are the price and exchange rate 'puzzles': prices rising and the exchange rate depreciating following a monetary contraction. These puzzles have also been found in the US literature. A common explanation (see, for example, Sims (1992)) is that if the VAR inflation forecast is a poor one, the monetary authority observes a greater information set and so the identified shock includes some endogenous policy response not captured by the model. The problem can often be overcome by adding asset or commodity prices as additional sources of information for forecasting inflation. We find this approach less successful for the United Kingdom.[3] A possible cause is that the number of regime changes experienced in the

[3] Mitchell (2000) reports some success in resolving these puzzles for the United Kingdom through the imposition of long-run economic theory.

United Kingdom makes the assumption of a constant monetary reaction function and policy instrument inappropriate. To overcome this problem, we estimate the VAR using monthly data from 1992:10-2001:9. Through this period, an inflation-targeting monetary strategy has been followed in the United Kingdom, with base rates as the policy instrument.[(4)]

We estimate a benchmark VAR using a set of core macroeconomic variables that will play a key role in our model. Specifically, these are output (y) (proxied by industrial production), the price level (P), base rates (i_s) the money supply (M) and the effective exchange rate index (e). We then add other asset prices of interest (z) to the benchmark. We use base rates as the policy instrument, and partition the vector as follows:

$$x_t = \begin{bmatrix} x_{1,t} \\ i_{s,t} \\ x_{2,t} \end{bmatrix}, \; x_{1,t} = \begin{bmatrix} y_t \\ P_t \end{bmatrix} \text{ and } x_{2,t} = \begin{bmatrix} M_t \\ E_t \\ z_t \end{bmatrix} \qquad \textbf{(1)}$$

where z represents one of the following asset prices: equity prices (V), long rates (i_l) or house prices (P_h).[(5)] All variables except base rates and long rates are logged. Standard ADF unit root tests indicate that several of the variables shown in equation **(1)** are I(1) over our sample period. However, we follow CEE (1999) and estimate the VAR in (log) levels without explicitly modelling cointegrating relations between variables. This is because it is difficult to identify a set of theoretically plausible cointegrating vectors. Although it is well known that long-horizon impulse response functions calculated from VARs containing unit roots may be inconsistent, we choose not to difference since this may entail an information loss. Instead we note this as a possible caveat to our results.

To identify the exogenous component of monetary policy, we assume that monetary policy is set according to a reaction function of the form:

$$\hat{i}_{s,t} = \alpha.\hat{P}_t + \beta.\hat{y}_t + lags \qquad \textbf{(2)}$$

where ^'s denote the deviations of variables from their trend or neutral levels. We further assume that exogenous shocks to monetary policy are orthogonal to other (unidentified) shocks.

With these assumptions, we estimate the following first-order VAR:[(6)]

$$x_t = A_1 x_{t-1} + Be_t \qquad \textbf{(3)}$$

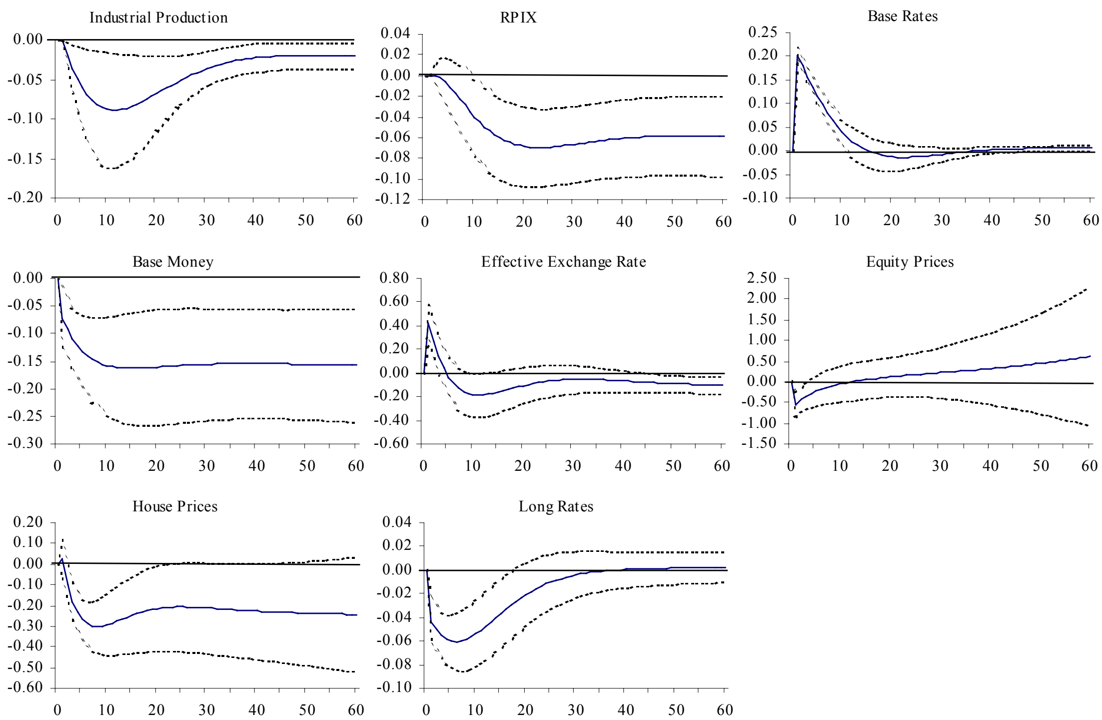
where B is a lower triangular matrix identified using a standard Choleski decomposition of the reduced-form residual variance matrix. A positive (negative) value of the 3rd element of

(4) The name and form of the policy rate has changed over this period. However, the base rate is the best proxy to use for the policy rate over the entire period as it has always moved in line with the policy rate.
(5) A complete description of the variables used can be found in the appendix.
(6) Lag length was selected using standard Hannan-Quinn and Schwarz-Bayes information criteria.

Be can be interpreted as a ‘surprise’ tightening (loosening) by the monetary authority, ie a rise (fall) larger than that implied by the rule, equation **(2)**.

Chart 1 plots the impulse responses to a one standard deviation monetary policy shock. The charts show the deviation from trend in percentage points. Output falls after the shock and exhibits a ‘hump-shaped’ response, consistent with the stylised facts listed above. Base money and the price level also fall, so we do not observe a price puzzle. But, as is often found in this type of analysis, the effect on the price level is small. There is a short-lived rise in the exchange rate so we have not encountered the familiar exchange rate puzzle either. The exchange rate then follows a UIP path and gradually depreciates back to base.

Chart 1: Responses to a one standard deviation exogenous monetary policy shock (percentage/percentage point deviation from trend, ± 1 standard error)



As we would expect, nominal interest rates rise after the shock. However, we find a small but significant fall in the long rate. This implies a clockwise rotation in the yield curve.[7] The response of the long rate is consistent with a long-run Fisher effect: the contractionary shock signals lower inflation in future, so for a given long-run real interest rate, the nominal interest rate must fall. House prices fall, but more quickly and by a larger amount than the general price level. There is also a short-lived fall in equity prices.

This simple empirical model has characterised the response of key macro-variables and asset prices to a ‘typical’ exogenous monetary policy shock, based on recent UK data. The responses also provide a useful benchmark with which to evaluate the general equilibrium model described in the following sections.

[7] This was also found in Evans and Marshall (1998).

3 The model

3.1 Consumers

The representative consumer either consumes or invests in financial assets and housing in order to maximise his utility subject to an asset accumulation constraint. Consumption consists both of goods that are bought in the marketplace and goods that are produced at home. To produce 'home' goods, the consumer combines his stock of housing with hours spent in home production. The consumer obtains utility from consumption of both goods and leisure. As we live in an open economy, we make the assumption that our consumer can borrow and lend as much as he wants on the world capital markets subject to a 'No Ponzi Game' condition.

There are two types of market-produced goods: non-traded goods and traded goods which are imported from abroad. If we denote consumption of market goods by c_n and imports by Z we can define aggregate consumption of market goods, c_m, as:

$$c_{m,t} = Z_t^{\gamma} c_{n,t}^{1-\gamma} \qquad \textbf{(4)}$$

We define the aggregate (consumption-based) price level, P, as the minimum cost of financing a unit of consumption, c_m. This implies:

$$P_t = \frac{P_{Z,t}^{\gamma} P_{n,t}^{1-\gamma}}{\gamma^{\gamma}(1-\gamma)^{1-\gamma}} \qquad \textbf{(5)}$$

where P_Z is the import price deflator and P_n is the price of non-traded goods. Given these aggregators, we can note that the shares of nominal market consumption spent on imports and non-traded goods will be constant:

$$\frac{\gamma}{1-\gamma} = \frac{P_{Z,t} Z_t}{P_{n,t} c_{n,t}} \qquad \textbf{(6)}$$

We introduce money into the model through the imposition of a cash-in-advance constraint. The consumer comes into period t with nominal wealth, A_{t-1}; this wealth is split between holdings of money, M_{t-1}, equities – V_j is the value of a share in firm j and x_j is the proportion of firm j held by the consumer at the end of the period – domestic nominal bonds of different maturities (indexed by j) bought in different periods (indexed by τ), $B_{j,\tau,t-1}$, foreign one-period nominal bonds, $B_{f,t-1}$, and one-period real bonds, b_{t-1}. He first receives a transfer, T, from the government and then acts in financial markets. This determines how his wealth is split at the end of period t. He then takes his remaining holdings of money into the goods market.

Thus, the cash-in-advance constraint can be written as:

$$P_t c_{m,t} + P_{I,t} I_{h,t} = M_{t-1} + T_t - \sum_j V_{j,t} x_{j,t} - \sum_{j=1}^{J} \sum_{\tau=t+1-j}^{t} B_{j,\tau,t} - \frac{B_{f,t}}{e_t} - P_t b_t + \sum_j \left(V_{j,t} + D_{j,t}\right) x_{j,t-1}$$
$$+ \sum_{j=2}^{J} \sum_{\tau=t+1-j}^{t-1} B_{j,\tau,t-1} + \sum_{j=1}^{J} B_{j,t-j,t-1} \left(1 + i_{j,t-j}\right)^j \quad \textbf{(7)}$$
$$+ \frac{B_{f,t-1}}{e_t}(1 + i_f) + P_t b_t (1 + r_{t-1})$$

where D_j is dividends per share of firm j held, I_h is investment in the housing stock, P_I is the price of investment goods, e is the nominal exchange rate (units of foreign currency per unit of domestic currency), i_j is the per-period rate of interest paid on a j-period nominal bond, i_f is the foreign nominal rate of interest (assumed constant for simplicity) and r is the real rate of interest.

The consumer's problem is then:

$$\text{Maximise } E_0 \sum_{t=0}^{\infty} \beta^t \left(\ln(c_t - \zeta c_{t-1}) + \psi \ln(1 - n_{m,t} - n_{h,t}) \right) \quad \textbf{(8)}$$

Subject to:

$$M_t + V_t x_t + \sum_{j=1}^{J} \sum_{\tau=t+1-j}^{t} B_{j,\tau,t} + \frac{B_{f,t}}{e_t} + P_t b_t = M_{t-1} + T_t + \left(V_t + D_t\right) x_{t-1} + \sum_{j=2}^{J} \sum_{\tau=t+1-j}^{t-1} B_{j,\tau,t-1}$$
$$+ \sum_{j=1}^{J} B_{j,t-j,t-1} \left(1 + i_{j,t-j}\right)^j + \frac{B_{f,t-1}}{e_t}(1 + i_f) \quad \textbf{(9)}$$
$$+ P_t b_t (1 + r_{t-1}) + P_t w_t n_{m,t} - P_t c_{m,t} - P_{I,t} I_{h,t}$$

$$c_t = \left(a c_{m,t}^{\xi} + (1-a) c_{h,t}^{\xi} \right)^{\frac{1}{\xi}} \quad \textbf{(10)}$$

$$c_{h,t} = e^{(1-\eta)gt + \theta_{h,t}} h_{t-1}^{\eta} n_{h,t}^{1-\eta} \quad \textbf{(11)}$$

$$P_{h,t} h_t = P_{h,t} h_{t-1} + P_{I,t} I_{h,t} \quad \textbf{(12)}$$

and the cash-in-advance constraint, equation **(7)**. Here, c is aggregate consumption, c_h is consumption of household-produced goods, h is the end-of-period housing stock, n_h is total hours worked in the household sector, w is the real wage, n_m is total hours worked in the market sector and g is the average growth rate of the economy. Notice that the consumer's utility function embodies 'habit persistence'. This means that past consumption will affect current consumption. Notice also the equation for the accumulation of housing wealth. The assumption here is that consumers purchase bricks and mortar at the same price as any other investment goods, P_I. However, once these have been converted into houses, they will then have the same price as existing houses. We have introduced a 'productivity' shock in the household sector, θ_h. This is to capture a shift in the utility that people attach to housing services. As mentioned earlier, we assume that the consumer has access to the world capital markets and so, subject to a 'No Ponzi Game' condition, is free to borrow and lend abroad at the going world nominal interest rate. This means that the consumer takes i_f as given in the above problem. We assume that he also takes dividends, real labour income, the monetary transfer and all prices and nominal interest rates as given.

Now, if we concentrate on those first-order conditions that determine the consumer's holdings of the various assets we obtain the following equations:

$$1 = E_t\left(\prod_{j=1}^{J}\frac{1}{\left(1+r_{t+j-1}\right)}\frac{\left(1+i_{J,t}\right)^J P_t}{P_{t+J}}\right) \quad \textbf{(13)}$$

$$1 = E_t\left(\frac{1+i_f}{1+i_{1,t}}\frac{e_t}{e_{t+1}}\right) \quad \textbf{(14)}$$

$$1 = E_t\left(\frac{1}{1+i_{1,t}}\frac{V_{j,t+1}+D_{j,t+1}}{V_{j,t}}\right) \quad \textbf{(15)}$$

$$1 = E_t\left(\frac{1}{1+i_{1,t}}\frac{P_{h,t+1}+R_{h,t+1}}{P_{h,t}}\right) \quad \textbf{(16)}$$

$$R_{h,t} = \frac{P_t c_{m,t}(1-a)\eta}{h_{t-1}a}\left(\frac{c_{h,t}}{c_{m,t}}\right)^{\xi} \quad \textbf{(17)}$$

Equation **(13)** is a set of 'Fisher' equations that can be used to determine both the real and nominal term structures (conditional on the term structure for implied inflation expectations that comes out of the model). Equation **(14)** is the uncovered interest parity condition. No arbitrage in the world capital markets ensures that interest rate differentials can only exist if the nominal exchange rate is expected to move.

Equation **(15)** defines equity prices given the equilibrium processes for dividends and domestic nominal interest rates. Notice that we can solve equation **(15)** to obtain the following expression for the value of firm j:

$$V_{j,t} = E_t\left(\sum_{k=1}^{\infty}\frac{1}{\prod_{i=0}^{k-1}1+i_{1,t+i}}D_{j,t+k}\right) + \lim_{k\to\infty}E_t\left(\frac{1}{\prod_{i=0}^{k-1}1+i_{1,t+i}}V_{j,t+k}\right) \quad \textbf{(18)}$$

The first term in this equation is the present discounted value of future dividends and the second term in this expression is a 'bubble'; for the rest of this paper we assume this term to be equal to zero though the possibility of bubbles is something we aim to consider in future work.

Equations **(16)** and **(17)** define a housing demand function that will determine house prices given the equilibrium processes for the housing stock and domestic nominal interest rates. The equation says that the nominal return on owning a house will be the same as the return on any other nominal asset: the nominal interest rate. The return to owning a house is composed of two parts: the expected capital gain and the rental value of the house (equivalently, the value of the services it provides to the representative consumer), R_h. Notice that we can, again, solve equation **(16)** to obtain the following expression for the value of a house:

$$P_{h,t} = E_t\left(\sum_{j=1}^{\infty}\frac{1}{\prod_{i=0}^{j-1}1+i_{1,t+i}}R_{t+j}\right) + \lim_{j\to\infty}E_t\left(\frac{1}{\prod_{i=0}^{j-1}1+i_{1,t+i}}P_{h,t+j}\right) \quad \textbf{(19)}$$

The first term in this equation is the present discounted value of future rent received on the property and the second term in this expression is a 'bubble'; as with equity prices we assume, for the rest of this paper, that this term is zero though the possibility of bubbles is something we aim to consider in future work.

3.2 Producers of traded goods

We assume that the representative producer of traded goods operates in a perfectly competitive world market.[8] It produces investment goods and goods for export; domestic consumers only consume foreign-produced traded goods. If we denote the world price of traded goods in foreign currency as P_f, then the traded-goods producer will have to sell its output in domestic markets at the price P_T (equal to P_I) given by:

$$P_T = P_I = \frac{P_f}{e} \quad \textbf{(20)}$$

Clearly, this will also be equal to the domestic price of imported goods, P_Z.

As the representative consumer owns the representative traded-goods producer, the producer's problem will be to maximise the present discounted utility value of its current and expected future dividends. It does this by choosing optimal paths for its inputs of capital and labour. If we let λ denote the marginal utility of a pound's worth of consumption, then its problem will be:

$$\text{Maximise} \quad E_0\sum_{t=0}^{\infty}\beta^t\lambda_t D_{T,t} \quad \textbf{(21)}$$

$$\text{Subject to} \quad D_{T,t} = P_{T,t}(y_{T,t} - I_{T,t}) - w_t P_t n_{T,t} \quad \textbf{(22)}$$

$$y_{T,t} = \theta_{T,t}k_{T,t-1}^{\alpha}n_{T,t}^{1-\alpha} \quad \textbf{(23)}$$

$$k_{T,t} = I_{T,t} + (1-\delta)k_{T,t-1} \quad \textbf{(24)}$$

where n_T is total hours worked in the traded-goods sector, I_T is investment in the traded-goods sector and k_T is the end-of-period capital stock in the traded sector.

(8) In future work, we aim to look at the impact of introducing monopolistic competition into the traded sector and allowing for pricing to market in traded goods.

The first-order condition for the firm's choice of investment will be:

$$\frac{\lambda_t P_{T,t}}{P_t} = \beta E_t \left(\frac{\lambda_{t+1} P_{T,t+1}}{P_{t+1}} \left(\alpha \frac{y_{T,t+1}}{k_{T,t}} + 1 - \delta \right) \right) \quad \textbf{(25)}$$

Multiplying this equation through by $k_{T,t}$ and combining with the consumer's first-order condition for equity holdings – equation **(15)** – implies:

$$V_{T,t} = P_{T,t} k_{T,t} \quad \textbf{(26)}$$

Thus, in this simple model, the value of the traded-goods producer is simply equal to the nominal value of its end-of-period capital stock. We can also note that our 'no bubbles' assumption amounts to ruling out explosive paths for either the price level or capital stock.

3.3 Producers of non-traded goods

We assume that producers of non-traded goods operate in a monopolistically competitive domestic market. We consider a unit continuum of such producers indexed by *j*. In addition, we consider a representative, perfectly competitive, final goods retailer who combines all the individual non-traded goods into a final non-traded good using a production function given by:

$$y_{N,t} = \left(\int_0^1 y(j)_t^{\frac{1}{1+\sigma}} dj \right)^{1+\sigma} \quad \textbf{(27)}$$

where y_N is total output of the final non-traded good and $y(j)$ is output of non-traded goods producer *j*. This good is produced solely for domestic consumption. Profit maximisation by the final goods retailer implies the following demand curve for the individual non-traded goods:

$$y_{N,t}(j) = \left(\frac{P_{n,t}(j)}{P_{n,t}} \right)^{-\frac{1+\sigma}{\sigma}} y_{N,t} \quad \textbf{(28)}$$

where P_N is the price of the final non-traded good and $P(j)$ is the price of non-traded good *j*. Perfect competition implies the following for the price of the final non-traded good:

$$P_{N,t} = \left(\int_0^1 P(j)_t^{-\frac{1}{\sigma}} dj \right)^{-\sigma} \quad \textbf{(29)}$$

Each intermediate non-traded goods producer purchases capital goods from the traded-goods sector and faces costs (paid in terms of traded goods) of adjusting this capital stock. We also follow Calvo (1983) and assume that with probability 1-ϕ the firm receives a signal allowing it to change its price that period. If it does not receive this signal, then it must charge the same price as in the previous period. This is a simple, and now standard, way of introducing price stickiness into these sorts of models.

As the representative consumer owns the representative non-traded-goods producer its problem will be to maximise the present discounted utility value of its current and expected future dividends. We solve this problem in two parts. We first choose optimal paths for the firm's inputs of capital and labour conditional on its price. We then develop a pricing rule. If we let λ denote the marginal utility of a pound's worth of consumption, then its problem will be:

$$\text{Maximise} \quad E_0 \sum_{t=0}^{\infty} \beta^t \lambda_t D(j)_t \tag{30}$$

$$\text{Subject to} \quad D(j)_t = P(j)_t y(j)_t - P_{T,t}\left(I(j)_t + \frac{\chi}{2}\frac{I(j)_t^2}{k(j)_{t-1}} \right) - w_t P_t n(j)_t \tag{31}$$

$$y(j)_t = \theta_{n,t} k(j)_{t-1}^{\alpha} n(j)_t^{1-\alpha} - ve^{gt} \tag{32}$$

$$k(j)_t = I(j)_t + (1-\delta)k(j)_{t-1} \tag{33}$$

and its demand curve (equation **(28)**). Here $n(j)$ is total hours worked in firm j, $I(j)$ is investment in firm j, $k(j)$ is the end-of-period capital stock in firm j and ve^g is a fixed cost the firm must pay every period.

The first-order condition for the firm's choice of labour input will be:

$$w_t P_t = (1-\alpha)\theta_{n,t} k(j)_{t-1}^{\alpha} n(j)_t^{-\alpha} MC_t \tag{34}$$

where MC is the Lagrange multiplier on equation **(32)** and will equal the firm's nominal cost of producing one extra unit of output at time t.

The first-order conditions for the firm's choice of investment will be:

$$I_{n,t} = \frac{q_t - 1}{\chi} k_{n,t-1} \tag{35}$$

$$\frac{\lambda_t P_{T,t}}{P_t} q_t = \beta E_t \left(\frac{\lambda_{t+1} P_{T,t+1}}{P_{t+1}} \left(\frac{\chi}{2} \left(\frac{I(j)_{t+1}}{k(j)_t} \right)^2 + \frac{MC_{t+1} \alpha \theta_{n,t+1} k(j)_t^{\alpha-1} n(j)_{t+1}^{1-\alpha}}{P_{T,t+1}} + q_{t+1}(1-\delta) \right) \right) \tag{36}$$

Here q is the Lagrange multiplier on equation **(33)**. This represents the value of capital installed in the non-traded sector relative to its value as a generic investment good; this is commonly known as Tobin's q.

We next consider the firm's pricing problem. Suppose that it receives a signal enabling it to change its price. Its first-order condition, derived from equations **(28)** and **(30)** through **(33)** above, will then be:

$$P(j)_t = P^*_t = \frac{(1+\sigma)\sum_{i=0}^{\infty} \frac{(\beta\phi)^{t+i}\lambda_{t+i}}{P_{t+i}} y(j)_{t+i} MC_{t+i}}{\sum_{i=0}^{\infty} \frac{(\beta\phi)^{t+i}\lambda_{t+i}}{P_{t+i}} y(j)_{t+i}} \qquad \textbf{(37)}$$

Noting that, since the signal is random, in any period 1-ϕ firms will change their price and set the price equal to *P** whereas ϕ firms will be unable to change their price, we derive the following equation for the aggregate price level in the non-traded sector as:

$$P_{N,t}^{\frac{-1}{\sigma}} = \phi P_{N,t-1}^{\frac{-1}{\sigma}} + (1-\phi) P^{*\frac{-1}{\sigma}}_t \qquad \textbf{(38)}$$

3.4 Government and monetary policy

The government in this model simply injects as much new money as is demanded into the economy through open market operations each period. The seignorage revenue is simply transferred back to the consumer lump sum. Hence:

$$M_t - M_{t-1} = T_t \qquad \textbf{(39)}$$

We assume the monetary authority operates a simple Taylor rule of the form:

$$(i_t - i) = \phi_\pi(\pi_t - \pi) + \phi_y \hat{y}_t \qquad \textbf{(40)}$$

where non-time-subscripted variables refer to their steady-state levels, π is the inflation rate and $\hat{y}$ is the percentage deviation of output from trend.

3.5 Exogenous variables

We assume that the exogenous variables in the model follow the following processes:

$$\Delta \ln(P_{f,t}) = \pi + \varepsilon_{P_f,t} \qquad \textbf{(41)}$$

$$\theta_{h,t} = 0.95\theta_{h,t-1} + \varepsilon_{\theta_h,t} \qquad \textbf{(42)}$$

$$\ln\left(\frac{h_t}{h}\right) = \rho_h \ln\left(\frac{h_{t-1}}{h}\right) + \varepsilon_{h,t} \qquad \textbf{(43)}$$

$$\Delta \ln(\theta_{T,t}) = g(1-\alpha) + \varepsilon_{\theta_T,t} \qquad \textbf{(44)}$$

$$\Delta \ln(\theta_{n,t}) = g(1-\alpha) + \varepsilon_{\theta_n,t} \qquad \textbf{(45)}$$

where *h* signifies the trend level of the housing stock and *g* is the trend growth rate in the economy. Notice that we have assumed a steady-state inflation rate in the rest of the world that is the same as in the domestic economy. This is to ensure that the nominal exchange rate is constant in the steady state. We have also assumed a simple process for housing supply; we thought that this particular approach was a useful way of modelling housing supply, as we did not want to get involved in specifying a production function for the construction sector.

4 Calibration and validation

In this section, we examine the effects of a monetary shock in our model and compare these to the results we reported in Section 2, above, obtained using UK data. The purpose of doing this is to convince ourselves that the model is a good enough approximation of reality, at least in the sense of capturing the way monetary policy works, to be useful for analysing how asset prices respond to other shocks. Before going on to do this, however, we first need to calibrate the model in order to ensure that it matches salient features of UK data. The values we used for our parameters are summarised in Table A, below. We constructed our own 'output' series as the sum of 'Consumers' expenditure' (ONS series: *ABJR+HAYO*), 'Business investment' (*NPEL*) and 'Housing investment' (*DFEA*). For the capital stock we used the annual series on 'Business sector net capital stock in current prices' (*CIXI* + *CIXH* + *CIXJ*) and divided this by an annual version of our output series at current prices to get an average value for the capital to output ratio. For imports we used the ONS series *IKBL* and for gross housing wealth we used the ONS series *SGRI*. For steady-state hours in the market and housing sectors we went with the estimates of Greenwood, Rogerson and Wright (1995) who suggested that values of 0.25 for hours spent in the household sector and 0.33 for hours spent in the market sector matched available empirical evidence.[(9)] Table A details how we used this, and other data, to calibrate the parameters of our model.[(10)]

We also needed to estimate the parameters of the exogenous processes in our model. For our monetary policy rule, we simply went with Taylor's original (1993) coefficients:

$$i_t - i = 1.5(\pi_t - \pi) + 0.5\hat{y}_t + \varepsilon_{i,t} \qquad \textbf{(46)}$$

where i is the steady-state level of nominal interest rates, 6%, π is the inflation target, 2.5%, and $\hat{y}$ is the percentage deviation of output from trend.[(11)]

(9) Specifically, the Michigan Time Use Survey found that a typical married couple allocates about 25% of its discretionary time to work in household production activities (cooking, cleaning, child care, etc) and about 33% of its discretionary time in paid employment.

(10) In all cases except for output growth the data period used was 1992 Q4 to 2001 Q2. This enabled us to match the period over which the VAR model of Section 2 was estimated. For output growth, however, we used data from 1965 Q1 to 2001 Q2. This was to avoid the problem of 'overly-high' output growth resulting from the fact that the period of our VAR runs from 'near' a trough to 'near' a peak.

(11) Nelson (2000) found the strikingly similar coefficients of 1.47 and 0.30 using UK data for the period October 1992 to April 1997. Also over the period from 1992 Q4 to 2001 Q2, quarterly inflation averaged 0.65% only slightly higher than the 0.625% we set as the inflation target (hence, steady-state rate of inflation) in our model.

Table A: Calibrating parameters

Description	*Parameter*	*Assumed value*	*Comment*
Discount factor	β	0.999	To match average real interest rate (10-year spot rate derived from IGs)
Average inflation rate	π	0.00625	Meets inflation target of 2.5%
Trend productivity growth	g	0.007	Average growth rate of 'output' (1965 Q1 to 2001 Q2)
Degree of habit persistence	ζ	0.8	Neiss and Nelson (2000)
Weight on leisure in utility function	ψ	0.435	To match steady-state hours in market sector
Weight on market vs household C	a	0.721	To match steady-state hours in household sector
Willingness to substitute between home and market	ξ	0.4	McGrattan, Rogerson and Wright (1997)
Elasticity of home production with respect to housing	η	0.111	To match gross housing wealth:output ratio
Capital's share	α	0.142	To match capital:output ratio
Depreciation rate	δ	0.02	To match investment:output ratio
Probability of having to hold price constant	ϕ	0.75	Implies an average duration of one year for individual prices
Elasticity of substitution	σ	0.172	Small (1997)
Weight on import prices in RPI	γ	0.432	To match imports:output ratio
Capital adjustment costs	χ	22	To match current value of Tobin's q

Using data on HP-filtered gross housing stock (constructed as gross nominal housing wealth divided by house prices) for the period 1992 Q4 to 2001 Q2, we obtained the following process for the housing stock:

$$\ln\left(\frac{h_t}{h}\right) = 0.675\ln\left(\frac{h_{t-1}}{h}\right) + \varepsilon_{h,t} \qquad \textbf{(47)}$$

Having calibrated the model, we are now in a position to see how well the model can capture the monetary transmission mechanism in the United Kingdom as embodied in the responses of variables to an exogenous monetary policy movement. Chart 2 plots the response of the money stock, the price level and the nominal exchange rate to a contractionary monetary policy shock. Following our empirical results in Section 2, we let the shock be such as to raise the short-term nominal interest rate by 20 basis points on impact. As we would expect, the money stock and price level fall and the exchange rate rises relative to trend. Indeed the initial falls in the money stock and price level are quantitatively similar to those found in the UK data described in Section 2: the money stock falling by 0.15% relative to trend and the price level by 0.03%. But, in the model, the price level and money supply then rise back to their trend levels. This implies that the monetary authority puts up with higher inflation in periods after the shock in order to reduce the negative output effects of the policy shock. In the data this was not the case as the price level and money stock stayed permanently lower. As the short-run interest rate is brought back to its steady-state level, the exchange rate falls back along its 'uncovered interest parity' path. This qualitatively matches what we saw in the UK data described in Section 2. However, relative to the model, the exchange rate 'overshoots' in the data, rising by 0.4% relative to trend as opposed to the 0.07% suggested by the model.

Chart 2: Effect of a monetary policy shock

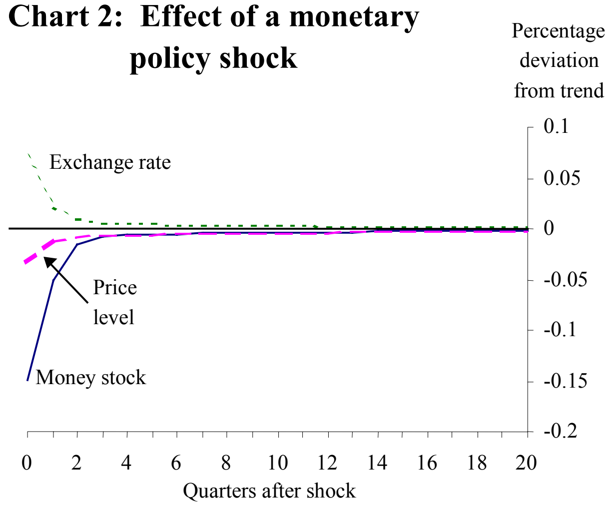


Chart 3 shows the effect of the contractionary policy shock on equity and house prices. Equity prices and house prices follow the price level in falling before returning to trend. However, we can notice that both equity and house prices fall by more than the price level. This implies that the real capital stock, which underlies firm value, is also reduced as a result of the shock. Similarly, real house prices have fallen. This qualitatively matches the empirical results presented in Section 2, though the fall in house prices happens more slowly in the data. In quantitative terms, the fall in equity prices of 0.07% relative to trend matches that seen in the data whereas the fall in house prices of 0.07% is much smaller than the 0.3% fall seen in the data.

Chart 3: Effect of a monetary policy shock

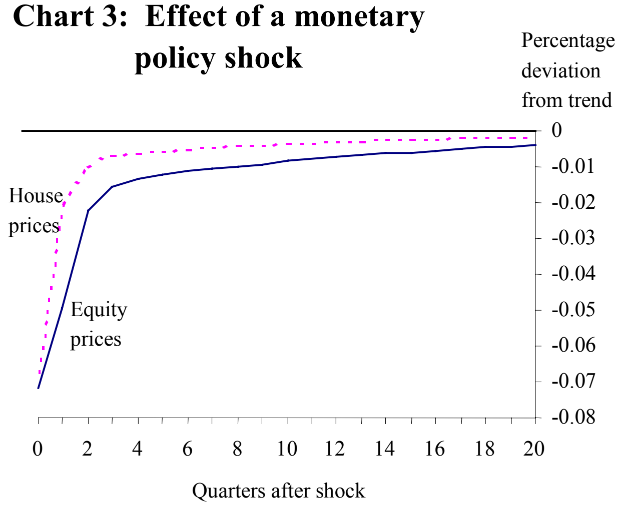
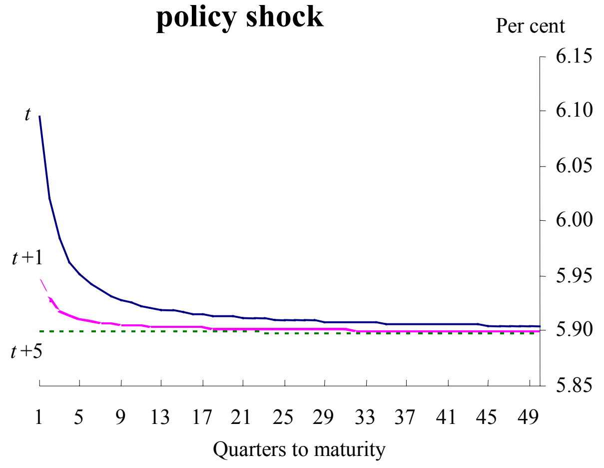


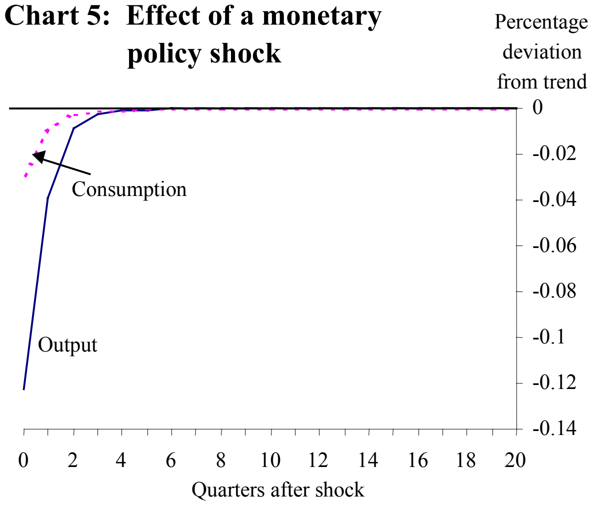
Chart 4 shows the effect of the contractionary policy shock on the term structure. As found in the UK data, the policy shock leads to a clockwise rotation of the yield curve. As the monetary authority brings the short-run interest rate back to base, the curve flattens at the longer end. Notice that even after one year the curve is flat as all the inflation stickiness has washed out. In other words, the effects of the shock are not particularly persistent in this model.

Chart 4: Effect of a monetary policy shock



Finally, Chart 5 shows that a contractionary monetary policy shock results in lower output and market consumption. The fall in output of 0.12% relative to trend is similar to the fall in the data seen in Section 2. However, in the data the response of output is 'sluggish' and has 'hump-shaped' dynamics. In the model, output falls immediately and then returns back to trend. This is a familiar feature of these models, which do not seem capable of generating the persistent real effects of a policy shock seen in the data.

Chart 5: Effect of a monetary policy shock



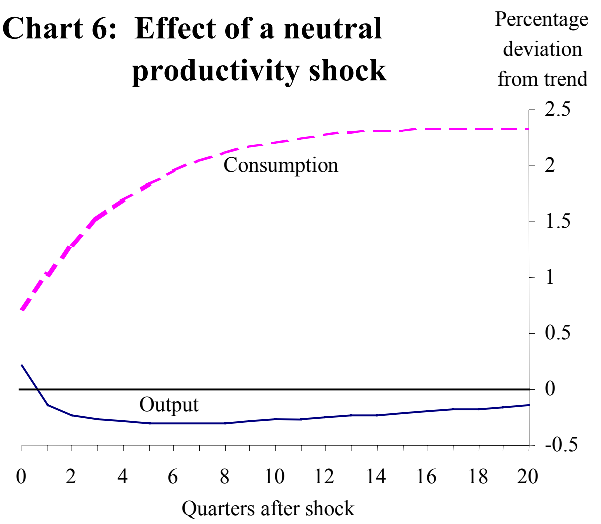
5 Effects of other shocks

A major motivation behind this work is to be able to understand what information asset prices can give us about other shocks affecting the economy. In this section, we consider the effects of different shocks within our model on asset prices. Of course, assumptions about how monetary policy responds to different shocks will make a difference to the response of asset prices. Our maintained assumption throughout what follows is that the monetary authority follows the simple Taylor rule given by equation **(45)** which enables it to meet its inflation target in the long run (ie when the effects of the shocks have died out).

5.1 Productivity shocks

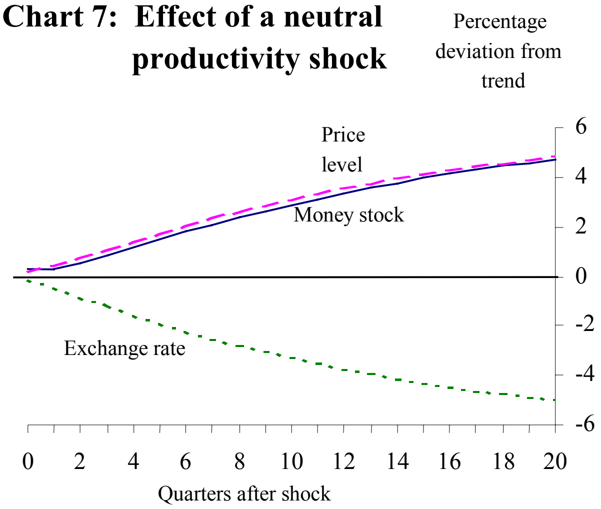
We consider a neutral shock to productivity; that is, we examine a shock that raises the level of productivity in both sectors by 1%. As we have assumed that productivity in each sector follows a random walk, any shock will have a permanent effect on the level of productivity. This might be expected to lead to a permanent increase in output. However, given the monetary policy rule being followed, the monetary authority in our model will keep output on its original trend. This means that consumers enjoy the productivity increase through increased consumption, leisure and home production since they have to work less hard to produce the same output. Chart 6 shows this by examining the response of market consumption and output to a 1% increase in productivity in both the non-traded and traded sectors. Output rises initially in response to the shock but then falls as monetary policy is tightened. Eventually, it returns to base. Had the monetary authority followed a Taylor rule that was specified in terms of an 'output gap', then this would not have happened. In that case, the monetary authority would recognise the productivity improvement and adjust policy so as to allow output to rise to its new, higher, balanced growth path. What we have illustrated in our paper is what would happen if the monetary authority failed to recognise a positive productivity shock. Orphanides (2000) suggests that, in reality, measuring the output gap is extremely difficult and that this has led to policy responses to productivity shocks, in the United States at least, such as implied in our paper.

Chart 6: Effect of a neutral productivity shock



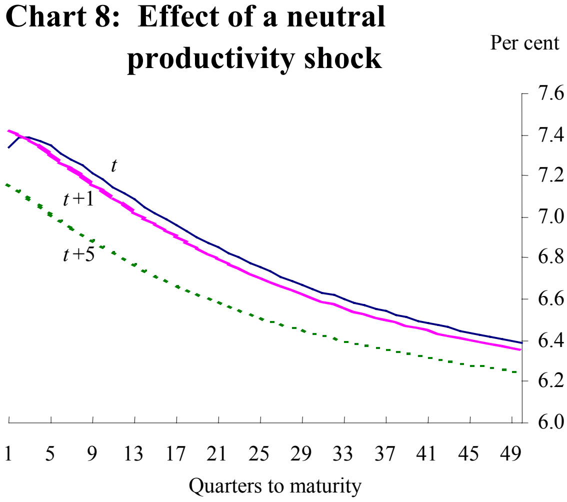
The productivity shock leads to a gradual depreciation of the nominal exchange rate. This leads to 'imported inflation' and the monetary authority reacts to this, and higher initial output, by raising interest rates. Since the exchange rate depreciation is larger than the rise in the price level, the real exchange rate depreciates in response to the shock. This is in accordance with standard wisdom; the intuition is that a productivity shock in one country results in more output in that country relative to the rest of the world and, so, its relative price must fall.

Chart 7: Effect of a neutral productivity shock



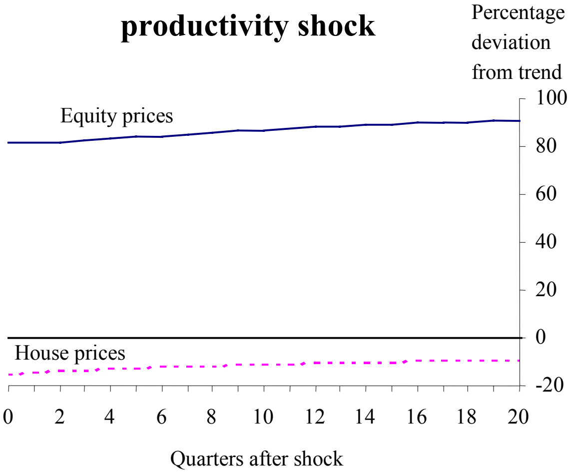
The nominal term structure reflects the response of monetary policy to the shock. The increase in output leads to a monetary tightening. After two quarters, rates begin to fall back down to their steady-state level. The yield curve reflects this, having a hump shape in response to the initial shock.

Chart 8: Effect of a neutral productivity shock



The productivity shock leads to a huge increase in equity prices; this follows from the large increase in the future expected return on capital. Since the productivity increase in the market sector is not reflected in the home sector, the demand for housing will fall leading to a sharp fall in house prices.

Chart 9: Effect of a neutral productivity shock



We also examined the effects of a shock to productivity in the traded sector. The key difference in the response of variables to this shock is that the real exchange rate appreciates. This results from the familiar Balassa-Samuelson effect. Also, the rise in equity prices is much smaller in the case of a traded-sector productivity shock since the relative price of capital goods (which are traded) falls, *ceteris paribus* lowering the value of firms' equity.

5.2 Housing market shocks

We next examine shocks to the demand for and supply of housing. Examining the responses of different variables to these shocks should enable us better to understand data from the housing market in general, and house prices in particular. Recall that housing demand is driven, in the model, by shocks to productivity in the household sector. Such shocks, unlike the market productivity shocks we have already considered, will only have temporary effects. Shocks to the supply of housing are also temporary.

We consider, first, the effect of a temporary increase in productivity in the household sector (rise in demand for housing) of 1%. As may be expected, Chart 10 shows that house prices increase taking the general price level with it. Real house prices also increase since general prices rise by less than house prices.

Chart 10: Effect of a housing demand shock

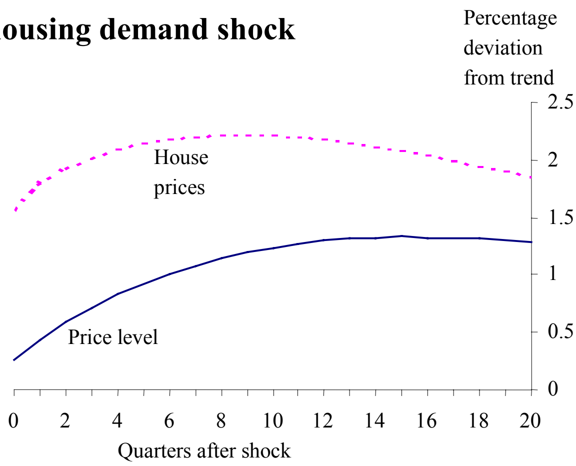


Chart 11 shows that market consumption falls as consumers switch from market-produced goods to household-produced goods. This, in turn, leads to a fall in market-produced output. Finally, Chart 12 shows that monetary policy makers respond to the increase in inflation by raising interest rates. Rates then fall back to their steady-state level. This response of policy is, again, reflected in the nominal term structure for the first few quarters after the shock.

Chart 11: Effect of a housing demand shock

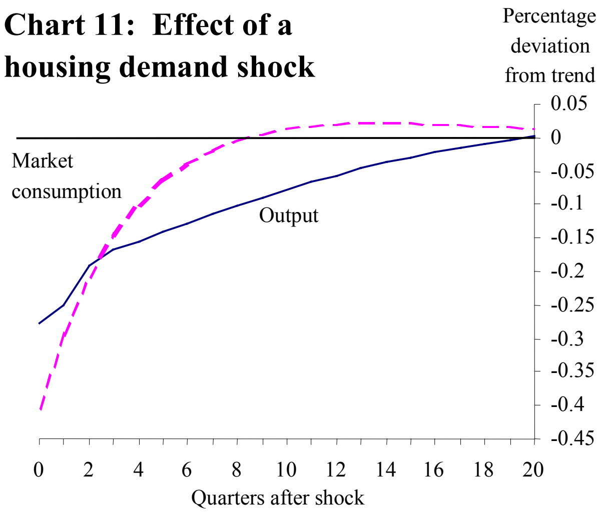
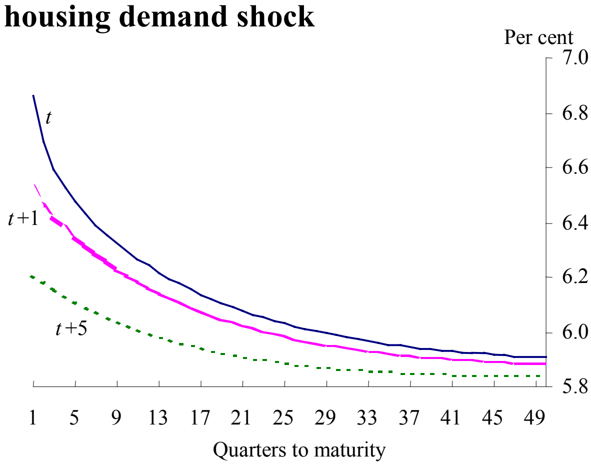


Chart 12: Effect of a housing demand shock

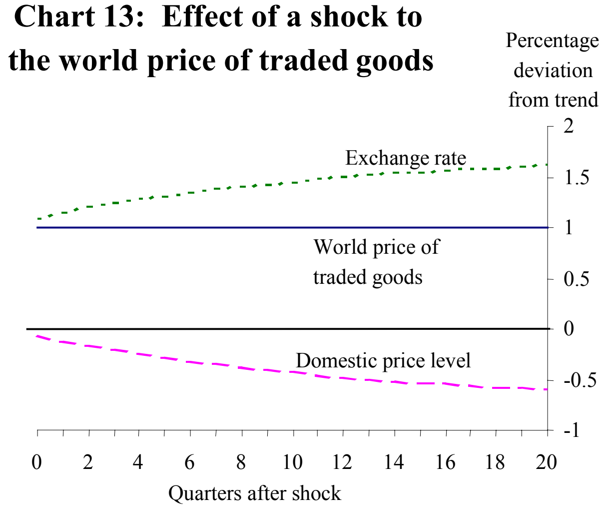


A temporary increase of 1% in the supply of housing leads to an immediate and temporary fall in house prices. The effects on all other variables are insignificant as a result of the speed at which the housing stock returns to its steady-state level; recall the autocorrelation coefficient on this shock was 0.675.

5.3 A shock to the world price of traded goods

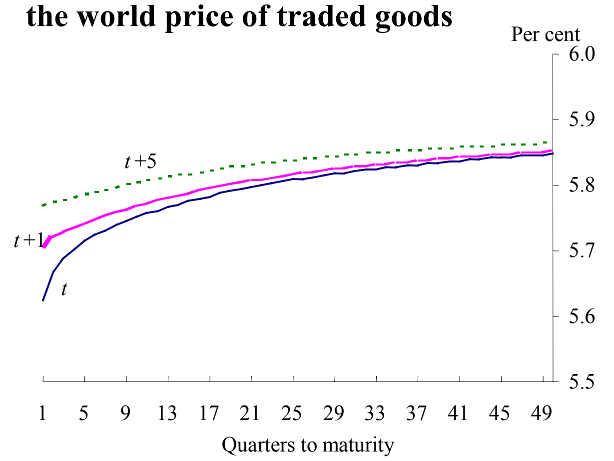
We close by examining the effects of a rise in the world price of traded goods. We can think of this being brought about either by an increase in the world demand for traded goods or a reduction in their supply. In either case, the increase in traded goods prices leads to an immediate appreciation of the exchange rate which is large enough to offset the effect of the world price increase on the domestic price level. In the periods after the shock, the exchange rate continues to rise and the domestic price level continues to fall. This is illustrated in Chart 13.

Chart 13: Effect of a shock to the world price of traded goods



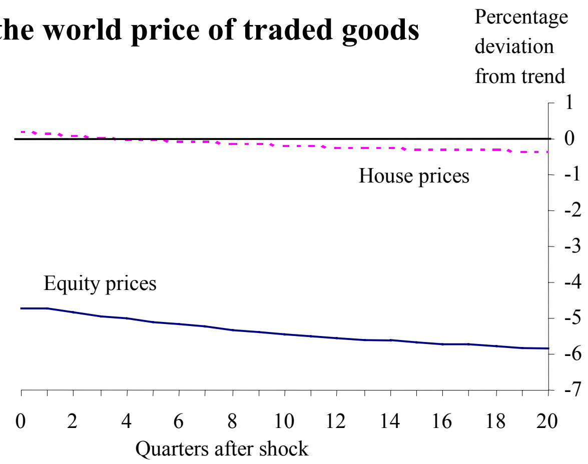
Since inflation falls on impact, the monetary authority responds by lowering interest rates. This implies an expectation of exchange rate appreciation through uncovered interest parity, consistent with the path shown in Chart 13. As is shown in Chart 14, this monetary policy response is reflected in the nominal yield curve, which is upward-sloping every period after the shock having fallen in the period of the shock.

Chart 14: Effect of a shock to the world price of traded goods



Equity prices essentially follow the response of the aggregate price level. However, since capital is a traded good, real equity prices will permanently fall as a result of such a shock. House prices initially jump up, as consumers switch from market-produced goods to home-produced goods. But after this initial rise, house prices start to fall in line with the general price level. However, the switch away from market consumption to consumption of home-produced goods is enough to leave real house prices permanently higher.

Chart 15: Effect of a shock to the world price of traded goods



5.4 Summary

There are a number of general results that fall out of the impulse responses presented in this and the previous section that are worth commenting on. One crucial point is the extent to which these responses depend on the monetary policy regime in force. The monetary policy rule in our model clearly responds in an inappropriate way to the productivity shocks. A positive productivity response would normally be associated with a rise in output that the policy rule simply does not allow. It could be supposed that this would result in a large welfare loss as it ensures lower output for the rest of time. Having said that, consumers within the economy still enjoy higher consumption so the welfare results are not clear. Another issue is that of price stickiness in the non-traded sector. A particular shock may lead, in a fully flexible price model, to a particular response of traded goods prices relative to non-traded goods prices. If traded goods prices have to bear the brunt of this movement in relative price, then the model could suggest that there may be real effects caused by the traded sector having to make excessive cost adjustments to stay competitive.

Another interesting result that can be seen from the figures above is that house prices tend to move by much more than the general price level. Perhaps unsurprisingly, this is most clear when looking at the response of house prices and the general price level to a shock to the demand for housing: the impact effect of a 1% shock to 'productivity in the household sector' was to move house prices by about 1.6% relative to trend but general prices by only 0.3%. In the case of a monetary policy shock we found that house prices fell by slightly more than twice the fall in the general price level. This effect was smaller than we found in the data: the response of house prices to a monetary policy shock in our VAR was about four times as great as the response of the aggregate price level.

Finally, in terms of the usefulness of observing asset prices in order to infer shocks, Table B summarises the results obtained for our different shocks. In particular, for each shock in Table B we tabulate the direction of the 'impact' effect on our asset price variables in the model. This table suggests that we can use the response of asset prices in order to understand what shocks may be hitting the economy. For instance, if we saw a fall in house prices with no discernible impact on equity prices, we could conclude that there had been a positive shock to housing supply: perhaps, a technological improvement in the construction sector or simply good weather enabling builders to work more rapidly. Alternatively, if nominal and real interest rates and equity prices all shifted up unexpectedly while the exchange rate and house prices shifted down unexpectedly, we might suggest that there had been either a positive shock to non-traded sector productivity or a negative shock to world export prices. Other information, say from talking to exporters, would enable us to differentiate between the two hypotheses.

However, we need to take care in making such inferences as they depend on the monetary policy rule in force, in addition to other fundamental variables. This is a particular worry if the monetary authority were to start using these results to guide monetary policy since the requisite response to each shock is that implied by the response of nominal interest rates that was being used to infer the shock. The results summarised in Table B only tell us what shocks the market may have thought have affected the economy if they have correctly guessed the monetary policy response to them. Indeed there is a wider problem here. The fact that there is any monetary policy reaction embedded in the response of variables to shocks means that it is extremely difficult for us to use the response of variables to shocks to infer what the shocks are. In order to be sure that movements in asset prices are giving us useful information about shocks hitting the economy, we need to define some characteristics of the response of asset prices to shocks that are independent of the central bank's reaction. This idea forms the basis of future research that we plan to do in this area.

Table B: Asset price responses to different shocks

Shock	Equity prices	Nominal interest rate	Real interest rate	House prices	Exchange rate
Monetary policy	Down	Up	Up	Down	Up
Non-traded sector productivity	Up	Up	Up	Down	Down
Traded-sector productivity	Up	Down	Down	Down	Up
Housing demand	Up	Up	Up	Up	Down
Housing supply	No effect	Up	No effect	Down	Down
World export prices	Down	Down	Down	Up	Up

6 Conclusions

In this paper we have developed a framework which analyses the response of asset prices to different shocks at a fundamental level. We first estimated an empirical model that characterised how asset prices have typically responded to movements in monetary policy in the past. We then developed a dynamic stochastic general equilibrium model capable of plotting the response of fundamental asset prices and key macro variables to several fundamental shocks. In the case of an exogenous monetary policy shock, the theoretical model was able to produce responses qualitatively similar to those uncovered from the data, although we also found some differences. We take the general congruence between model and data to be an encouraging sign.

We have used our model to show how a given fundamental shock may imply a unique pattern of asset price movements in the periods immediately after the shock. Therefore, observing patterns of asset price movements and comparing them with the movements implied by our model might reveal the nature of shocks currently hitting the economy. There are, however, several important reasons why this information should only be used tentatively and to corroborate other evidence. First, the results presented in this paper are dependent on the monetary policy response to shocks. That is, they depend crucially on our assumed Taylor rule being a reasonable characterisation of the monetary reaction function, and that this is fully known by market participants. As mentioned above, our current rule clearly reacts inappropriately to some shocks. Second, as discussed in Section 1, asset prices are hard to use for policy purposes since they are 'noisy': they often move for reasons not obviously related to economic fundamentals. Despite these strong caveats, we believe we have succeeded in building a framework in which we can think about asset price movements in terms of economic fundamentals.

Further work to be done in this area includes developing the model with a view to extracting implications for monetary policy. Given that our results depend crucially on the monetary policy reaction function, it would be interesting to develop the model by experimenting with different policy rules. Another improvement that could be made to the model would be to introduce some price stickiness into the traded-goods sector. This would make it possible to study in more detail the response of domestic asset prices to foreign shocks. With these changes in place, our model could potentially be used for two practical purposes. First, if we suspected the UK economy had been hit by a particular shock (or combination of shocks) that exists in our model, we could compare recent movements in asset prices with predictions from our model. This may offer corroborative evidence supporting our hypothesis. Second, we could examine the implications for asset prices of more general macroeconomic risks. For example, if we believed that the economy had recently experienced a domestic productivity shock, but were uncertain about its magnitude, we could use our model to map our uncertainty around this shock into uncertainty about future asset prices.

Appendix

The data used in the empirical is summarised in the table below.

Variable	*Source*	*Code*
Output, *y, industrial production*	ONS	CKYW.M
Price level, *P, RPIX price index*	ONS	CHMK.M
Effective exchange rate, *e*	Sterling ERI (ONS)	AJHX.M
Base (short-term) interest rates, i_s	BoE	
Long-term interest rates, i_l, *Redemption yield on 20-year gilt*	BoE / ONS	AJLX.M
Money holdings, *M, break-adjusted M0*	BoE	
House prices, P_h	DETR	
Equity prices, *V, FTSE All-Share*	ONS	AJMA.M

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