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# Asymmetric monetary policy towards the stock market: A DSGE approach

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## ABSTRACT

In the aftermath of the financial crisis, it has been argued that a guideline for the design of the future policy framework should be to take the 'a' out of 'asymmetry' in the way monetary policy deals with asset price movements. Recent empirical evidence has suggested that the Federal Reserve may have followed an asymmetric policy towards the stock market in the pre-crisis period. According to these findings, monetary policy in the US before the crisis involved a reaction to stock price drops, but no reaction to increasing stock prices. The present paper studies the effects of such a policy in a DSGE model. The asymmetric policy rule introduces an important non-linearity into the model: Booms in output and inflation tend to be amplified, while recessions are dampened. Moreover, such a policy gives rise to expectations-driven booms in asset prices. We further investigate to what extent an asymmetric stock price reaction could be motivated by the desire of policymakers to correct for inherent asymmetries in the way stock price movements affect the macroeconomy.

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## 1. Introduction

While the recent financial and economic crisis does not invalidate everything we have learned about macroeconomics since 1936, as [Barro \(2009\)](#) eloquently puts it, it has led economists to reconsider some ideas that once were considered common sense. As one example, the crisis has led to a revival of the debate about the role of asset prices in monetary policy; see [Kuttner \(2011\)](#) for an overview. Despite some enduring disagreement, a certain degree of consensus had been reached before the crisis, according to which central banks should not lean against asset price movements. The reason for this was not only that 'bubbles' in asset prices may be extremely hard to identify in real time, but also that even in the face of 'normal' fluctuations in asset prices, the interest rate tool may be too blunt and have unpleasant side effects. Instead, monetary policymakers should stand ready to cut the interest rate in response to plummeting asset prices.<sup>1</sup> The aftermath of the crisis has witnessed an emerging appreciation and critique of an inherent asymmetry in this approach to monetary policy (e.g. [White, 2009](#); [Mishkin, 2010](#); [Issing, 2011](#)). In the words of [Stark \(2011\)](#), the consensus implied that '*monetary policy should react to asset price busts; not to asset price booms*'. [Issing \(2011\)](#) points to the risk that such a policy might lead to moral hazard problems by covering part of the downside risk faced by investors in the stock market.

Some recent studies lend empirical support to the existence of an asymmetric monetary policy towards the stock market in the US before the crisis. [Ravn \(2012\)](#) finds that during the period 1998–2008, a 5% drop in the S&P 500 index increased the

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E-mail address: [shr@nationalbanken.dk](mailto:shr@nationalbanken.dk)<sup>1</sup> This view has been coined the 'pre-crisis consensus' by [Bini Smaghi \(2009\)](#), and the 'Jackson Hole consensus' by [Issing \(2009\)](#).

probability of a subsequent 25 basis point interest rate cut by between 1/3 and 1/2, depending on the estimation method. On the other hand, he finds no significant policy reaction to stock price increases. Similarly, Hoffmann (2013) reports that for the longer period 1987–2008, the Federal Reserve lowered interest rates in response to stock market drops, but did not raise rates when stock prices boomed. For the same sample period, Hall (2011) finds that stock price deflation led to a highly significant cut in the interest rate, and that the inclusion of stock price deflation improves the fit of an estimated Taylor rule.

In this paper, we contribute to the recent debate by examining the effects of an asymmetric monetary policy in general equilibrium. We build a Dynamic Stochastic General Equilibrium (DSGE) model in which asset prices play an important role via the financial accelerator of Bernanke et al. (1999). We then allow the central bank to follow a monetary policy rule with an asymmetric reaction to stock prices. This introduces an important discontinuity into the model that cannot be 'log-linearized away'. As a result, it is not possible to solve the model using standard techniques. Instead, we apply a numerical solution method which exploits the piecewise linearity of the model. Essentially, the model consists of two linearized systems around the same steady state; one system for when stock prices are increasing (or constant), and another for when they are decreasing. We construct a 'shooting' algorithm to detect the switching points between these systems in order to solve the model. In this sense, we make a methodological contribution to the sparse literature on endogenous regime switching in monetary policy initiated by Davig and Leeper (2006). The solution method is similar to the one used by Bodenstein et al. (2009) to deal with the zero lower bound on interest rates, which in turn builds on work by Eggertson and Woodford (2003) and Christiano (2004).

The analysis uncovers some interesting implications of the asymmetric policy. By reacting only to stock price drops, the central bank induces an outcome where booms in output and inflation are amplified, while recessions are dampened. In other words, the asymmetric policy translates into an asymmetric business cycle. We briefly relate this finding to the existing literature on asymmetric business cycles. In addition, the asymmetric policy gives rise to what we call an *anticipation boom* in asset prices. In the wake of an expansionary shock, the asset price jumps up. It turns out that this jump is larger than in a model with no reaction to stock price changes, despite the fact that in both cases, the actual policy reaction to stock prices is zero during the asset price boom. The anticipation boom, which measures the *additional* rise in asset prices when the asymmetric policy is introduced, can be attributed to forward-looking agents anticipating that whenever stock prices start falling, the central bank will cut the interest rate. This implicit, partial insurance against asset price drops amplifies the rise in asset prices immediately after the shock. If the asymmetric policy reaction to stock prices is of the magnitude found in the recent empirical studies, these effects are quantitatively quite small. In the literature, an important divergence exists between the magnitude of the reaction to asset prices found in empirical studies, which is often quite small, and the values used in theoretical investigations, which are usually a lot larger. To bridge this gap, we therefore also employ a value of the reaction parameter which is more in accordance with the values in other theoretical contributions. When this is done, the above effects are sizeable. In general, we conclude that while an asymmetric policy has the theoretical potential to generate severely skewed business cycles and important additional asset price volatility, the asymmetric reactions found in recent empirical studies are too small to have had quantitatively important macroeconomic effects.

We also discuss potential motivations for an asymmetric monetary policy. One such motivation could be an asymmetric loss function of the central bank, as previously studied in the literature. Another potential explanation is that such a policy could be an attempt by the central bank to 'correct for' other asymmetries in the economy, in particular in the way stock prices influence the macroeconomy. We therefore evaluate how an asymmetric monetary policy interacts with other potential asymmetries, such as the financial accelerator of Bernanke et al. (1999) and the stock wealth effect on consumption. We demonstrate that if the financial accelerator is assumed to be stronger when net worth of firms is low, as has been suggested by several authors, the asymmetric policy is able to 'cancel out' this asymmetry in the case of supply shocks, but not after demand shocks. A similar conclusion is reached under the assumption of asymmetric wealth effects.

The debate about the role of asset prices in monetary policy goes back at least to Bernanke and Gertler (1999, 2001), who argue that monetary policy should not react to asset prices *per se*. This view has received support from Gilchrist and Leahy (2002) and Tetlow (2005), as well as in speeches by leading Federal Reserve officials (Kohn, 2006; Mishkin, 2008). In contrast, Cecchetti et al. (2000) find that the optimal monetary policy rule does include a reaction to the stock market. Bordo and Jeanne (2002) and Borio and White (2003) arrive at the same conclusion.

While most of these first contributions to this debate assumed the presence of a 'bubble' term in the asset price, more recent studies have focused on monetary policy reactions to fundamental movements in asset prices. Faia and Monacelli (2007) find that there is no additional welfare gain from reacting to asset prices on top of what may be obtained through a strong reaction to inflation. Leduc and Natal (2011) arrive at the opposite result, and explain how this difference is related to the assumption of Faia and Monacelli (2007) that policymakers are able to compensate workers in a lump-sum manner for the distortion arising from monopolistic competition, thereby making the flexible-price equilibrium efficient. Gilchrist and Saito (2008) assume that private agents and policymakers learn about the underlying trend growth in productivity over time. In their setup, the desirability of a policy reaction to asset prices depends on the information structure of the economy. In the present paper, we follow this recent tradition and abstract from asset price 'bubbles'.<sup>2</sup>

<sup>2</sup> Another common feature of these studies is the crucial role played by financial frictions, which we also include in our model as described in the next section.

The remainder of the paper is structured as follows. Section 2 describes the DSGE workhorse model. Section 3 illustrates the dynamics of the model and the implications of introducing an asymmetric reaction to stock prices. In Section 4, we discuss possible explanations for the asymmetric policy within the model framework. Section 5 concludes. Appendix A contains details about the model and the solution method.<sup>3</sup>

## 2. The model

The general equilibrium model is a version of the standard New-Keynesian sticky-price model with capital. We augment the model with the financial accelerator of Bernanke et al. (1999). This mechanism is one of the most widespread ways of incorporating financial frictions into general equilibrium models, as it captures one of the most important channels through which asset prices affect the macroeconomy on the firm side. In particular, it is a common feature in most of the studies of the role of asset prices in monetary policy cited above, and therefore makes for straightforward comparisons with the existing literature.<sup>4</sup> While it would be possible to study a monetary policy reaction to asset prices without the financial accelerator (or a similar mechanism), such a model would be tilted towards finding very small effects of such a reaction.

An additional feature is that contracts are written in terms of the nominal interest rate as in Christensen and Dib (2008), introducing the debt-deflation channel of Fisher (1933). Christiano et al. (2010) find that this channel is empirically relevant. The model is in large part similar to that of Christensen and Dib (2008) or Gilchrist and Saito (2008). This has the advantage that the dynamics of this class of models are well described in the literature, allowing us to isolate the effects of the asymmetric monetary policy rule. Moreover, this allows us to calibrate the model using the parameter values estimated by Christensen and Dib for the US economy for most of the parameters. The stochastic part of the model is quite parsimonious, as only two shocks are included: a technology shock and a monetary policy shock. These two shocks, which can loosely be interpreted as a supply and a demand shock, are sufficient to highlight the effects of the asymmetric policy.

### 2.1. Entrepreneurs

Entrepreneurs produce the intermediate goods that the final goods producers take as input. Each entrepreneur employs labor  $H_t$  and capital  $K_t$ , and produces output  $Y_t$  according to the following production technology:

$$Y_t = (A_t H_t)^{1-\alpha} K_t^\alpha. \quad (1)$$

The technology level  $A_t$  evolves according to

$$\ln(A_t) \equiv (1 - \rho_a)A + \rho_a \ln(A_{t-1}) + \varepsilon_t^a, \quad (2)$$

where  $\varepsilon_t^a$  is a normally distributed shock to technology with mean zero. In each period, entrepreneurs face a constant probability  $(1 - \nu)$  of leaving the economy. As described by Bernanke et al. (1999), this assumption is made in order to ensure that entrepreneurs do not eventually accumulate enough capital to be able to finance their own activities entirely. To ensure that new entrepreneurs start out with non-zero net worth, we follow Christensen and Dib (2008) and allow newly entering firms to inherit a portion of the net worth of those firms who exit the economy.<sup>5</sup>

Entrepreneurs choose the inputs of capital and labor to maximize their profits, subject to the production technology. The first-order conditions are shown in the online Appendix. Each entrepreneur can obtain the capital needed for production in two ways: He can issue equity shares (internal financing), or he can borrow the money from a financial intermediary (external financing). Because internal financing is cheaper, as discussed below, entrepreneurs use all of their net worth, and borrow the remainder of their funding needs from the financial intermediary. The total funding needed by an entrepreneur is  $q_t K_{t+1}$ , where  $q_t$  is the real price of capital as measured in units of consumption. In order to ensure that any financial constraint faced by the entrepreneur applies to the capital stock as such, and not just to the investment in any given period, we assume that the entrepreneur must refinance his entire capital stock each period. If  $n_t$  denotes the net worth of the entrepreneur, the amount he needs to borrow is then  $q_t K_{t+1} - n_{t+1}$ . Letting  $f_t$  denote the external financing cost of one extra unit of capital, the demand for external finance must satisfy the following condition in optimum:

$$E_t[f_{t+1}] = E_t \left[ \frac{mp_{t+1} + (1 - \delta)q_{t+1}}{q_t} \right]. \quad (3)$$

The numerator on the right-hand side is the marginal productivity of a unit of capital plus the value of this unit of capital (net of depreciation) in the next period. Note that we interpret the price of capital  $q_t$  as the stock price in the model economy.<sup>6</sup> Equity shares are ultimately claims to the assets of firms, which in this model amounts to their capital stock. Therefore, in

<sup>3</sup> In addition, we provide further details about the model, its properties, and the solution in an extended online Appendix.

<sup>4</sup> One notable exception is the study by Faia and Monacelli (2007), who instead use the agency cost framework of Carlstrom and Fuerst (1997). Importantly, however, Faia and Monacelli (2007) modify that framework so as to obtain a countercyclical external finance premium, which is a key feature of the model of Bernanke et al. (1999).

<sup>5</sup> In contrast, Bernanke et al. (1999) ensure this by assuming that entrepreneurs also work. This difference is of little importance for the results.

<sup>6</sup> In the rest of the paper, we will use the terms *price of capital*, *asset price* and *stock price* interchangeably.

a model of this type,  $q_t$  is the relevant variable to enter the central bank's reaction function in order to model a reaction to stock prices.<sup>7</sup>

As in [Bernanke et al. \(1999\)](#), the existence of an agency problem between borrower and lender renders external finance more costly than internal finance. While entrepreneurs observe the outcome of their investments costlessly, the financial intermediary must pay an auditing cost to observe this outcome. Entrepreneurs must decide – after observing the outcome – whether to report a success or a failure of the project, i.e. whether to repay or default on the loan. If they default, the financial intermediary pays the auditing cost, and then claims the returns to the investment. [Bernanke et al. \(1999\)](#) demonstrate that the optimal financial contract involves an external finance premium (the difference between the cost of external and internal finance) which depends on the entrepreneur's net worth, and show that the marginal external financing cost is equal to the external finance premium times the opportunity cost of the investment; given by the risk-free real interest rate (the reader is referred to [Bernanke et al. \(1999\)](#) for details):

$$E_t[f_{t+1}] = E_t \left[ \Psi \left( \frac{n_{t+1}}{q_t K_{t+1}} \right) \frac{R_t}{\pi_{t+1}} \right], \quad (4)$$

where the function  $\Psi(\cdot)$  describes how the external finance premium depends on the financial position of the firm.  $\frac{n_{t+1}}{q_t K_{t+1}}$  denotes the ratio of the firm's internal financing to its total financing, and is thus a measure of the leverage ratio. Eq. (4) is the key to the financial accelerator mechanism. [Bernanke et al. \(1999\)](#) demonstrate that  $\Psi'(\cdot) < 0$ , implying that if firms' net worth goes up (or, equivalently, their leverage ratio goes down), the external finance premium falls, and firms get cheaper access to credit. As the entrepreneur puts more of his own money behind the project, thus lowering the leverage ratio, the agency problem between borrower and lender is alleviated. The entrepreneur's incentive to undertake projects with a high probability of success increases, and as a result, the lender demands a lower return on the loans he makes. The drop in the external finance premium leads to an increase in the firm's demand for external finance, which in turn causes an increase in the firm's stock of capital in the next period, and thus its production level. In this way, to the extent that movements in net worth are procyclical, the financial accelerator works to amplify business cycle movements.

The net worth of entrepreneurs consists of the financial wealth they have accumulated (i.e., profits earned in previous periods) plus the bequest  $Y_t$  they receive from entrepreneurs leaving the economy:

$$n_{t+1} = v[f_t q_{t-1} K_t - E_{t-1} f_t (q_{t-1} K_t - n_t)] + (1 - v) Y_t. \quad (5)$$

## 2.2. Households

A continuum (of unit length) of households derive utility from an index of the final consumption goods produced by the retailers ( $C_t$ ) and leisure ( $1 - H_t$ ), and decide how much labor to supply to entrepreneurs producing intermediate goods. As all households are identical, they each solve the following utility maximization problem:

$$\max_{C_t, H_t, D_t} U = E_0 \sum_{t=0}^{\infty} \beta^t \left[ \frac{\gamma}{\gamma - 1} \ln \left( C_t^{\frac{\gamma-1}{\gamma}} \right) + \eta \ln(1 - H_t) \right], \quad (6)$$

subject to the relevant budget constraint:

$$C_t + \frac{D_t - R_{t-1} D_{t-1}}{P_t} \leq \frac{W_t}{P_t} H_t + \Omega_t. \quad (7)$$

$D_t$  are deposits which are stored at a financial intermediary at the risk-free rate of interest  $R_t$ .  $\Omega_t$  denotes dividend payments deriving from households' ownership of retail firms. The first-order conditions of the household are presented in the [online Appendix](#).

## 2.3. Capital producers

The role of capital producers is to construct new capital  $K_{t+1}$  from invested final goods  $I_t$  and existing capital. As in [Bernanke et al. \(1999\)](#), it is implicitly assumed that capital producers rent existing capital from entrepreneurs within each period at a rental rate of zero. They face capital adjustment costs, implying a non-constant price of capital  $q_t$ . We use the same quadratic functional form for the capital adjustment costs as [Christensen and Dib \(2008\)](#):  $\frac{\chi}{2} \left( \frac{I_t}{K_t} - \delta \right)^2 K_t$ . Profits of capital producers are then:

$$\Pi_t^c = q_t I_t - I_t - \frac{\chi}{2} \left( \frac{I_t}{K_t} - \delta \right)^2 K_t. \quad (8)$$

Choosing the level of investment that maximizes this expression results in the following equilibrium condition:

<sup>7</sup> This is standard in the literature; see for instance [Tetlow \(2005\)](#) or [Gilchrist and Saito \(2008\)](#). In [Bernanke and Gertler \(1999, 2001\)](#), the central bank reacts to the price of capital plus a bubble term.

$$q_t - \chi \left( \frac{I_t}{K_t} - \delta \right) = 1. \quad (9)$$

Note that in the absence of adjustment costs, the parameter  $\chi$  equals zero, so the optimality condition collapses to  $q_t = 1$ .<sup>8</sup> The condition is essentially a Tobin's  $q$ -relation, ensuring that the investment level is chosen so that the 'effective' price of capital (i.e., net of capital adjustment costs) is equal to 1.

#### 2.4. Retailers

Firms in the retail sector take intermediate goods as inputs, repackage these costlessly, and sell them. The retail sector is included in the model with the single purpose of creating price stickiness. Following Calvo (1983), price rigidity is introduced by assuming that in each period, only a fraction  $(1 - \xi)$  of firms in the retail sector are allowed to change their price. The price of firms who are not allowed to change their price is indexed with the steady state inflation rate  $\pi$ . In other words, this sector is completely standard. In the online Appendix, we describe the problem of each firm in the retail sector, and demonstrate how the associated first-order condition gives rise to a standard version of a log-linear New-Keynesian Phillips Curve.

#### 2.5. Monetary policy

To introduce an asymmetric policy reaction to stock prices, we assume that the central bank follows a Taylor rule augmented with a term that captures a reaction to stock price drops. This is in line with the specifications used by Hoffmann (2013) and Hall (2011). Ravn (2012) attempts to control for the movements in the interest rate that are driven by macroeconomic variables such as output and inflation. Therefore, also his result is interpretable as a reaction to stock prices on top of the reaction to those variables, in line with the implicit assumption behind an augmented Taylor rule.<sup>9</sup> We further add interest rate smoothing, as this tends to improve the empirical performance of Taylor rules (Clarida et al., 1999; Christiano et al., 2010). This gives rise to the following monetary policy rule:

$$\frac{R_t}{\bar{R}} = \left( \frac{R_{t-1}}{\bar{R}} \right)^{\rho_r} \left[ \left( \frac{\pi_t}{\bar{\pi}} \right)^{\phi_\pi} \left( \frac{Y_t}{\bar{Y}} \right)^{\phi_y} \left\{ \left( \frac{\Delta q_t}{\bar{q}} \right)^{\phi_q} \right\}^{1[\Delta q_t < 0]} \right]^{(1-\rho_r)} e^{\varepsilon_t^r}, \quad (10)$$

where  $1[X]$  is the indicator function; equal to 1 if  $X$  is true and zero otherwise. This captures that the central bank is reacting to the change in stock prices only when this change is negative.  $\varepsilon_t^r$  is a normally distributed monetary policy shock with mean zero. The stated monetary policy rule allows for interest rate smoothing, as measured by the parameter  $\rho_r$ . The parameters  $\phi_\pi$  and  $\phi_y$  measure the monetary policy reaction to deviations of inflation from its target level, and of output from its steady state level, respectively. Note that the steady state or natural level of output ( $\bar{Y}$ ) is below the efficient level of output ( $Y^*$ ) due to the presence of monopolistic competition.

While this paper is the first to study theoretically a Taylor rule with a reaction to stock price drops, Taylor rules augmented with a symmetric reaction to stock price changes have been studied by Tetlow (2005) and Gilchrist and Saito (2008) in models largely similar to the one outlined above. A similar type of 'speed limit'-rule is also studied by Leduc and Natal (2011). The rule above is essentially a speed-limit rule with no upper speed limit.

#### 2.6. Model solution

To solve the model, we log-linearize the equilibrium conditions around the non-stochastic steady state. The log-linearized model consists of 14 equilibrium conditions in 14 variables as described in the Appendix A, while the steady state is described in the online Appendix. The equilibrium of the model consists of a vector of allocations  $(\bar{C}_t, \bar{H}_t, \bar{Y}_t, \bar{K}_t, \bar{n}_t, \bar{I}_t)$  and prices  $(\bar{\pi}_t, \bar{R}_t, \bar{w}_t, \bar{m}c_t, \bar{m}p_t, \bar{q}_t, \bar{f}_t, \bar{\lambda}_t)$  such that those 14 log-linear equations are satisfied, where  $\hat{x}_t$  denotes log-deviations of a variable  $x_t$  from its steady state.

However, the non-linear monetary policy rule implies that even after log-linearization, an important non-linearity remains in the model. As a result, the model cannot be solved with standard techniques. Instead, we solve the model using a numerical solution method which exploits the piecewise linearity of the model. This method follows the approach taken by Bodenstein et al. (2009) in order to deal with problems where the zero lower bound on interest rates is binding in a number of periods. While Bodenstein et al. study a one-off switch, we generalize the solution method to handle multiple switches between policy regimes. As the only non-linearity in the present model is the monetary policy reaction to asset prices, the model in effect consists of two linear systems; one for when asset prices are decreasing, and one for when they are non-decreasing. Following Bodenstein et al. (2009), we first build a shooting algorithm in order to identify the 'turning points' in the evolution of the asset price following a shock; i.e. when the sign of  $\Delta q_t$ , and thus the monetary policy regime, switches. For any initial guess of the turning points, the model is then solved using backward induction. If the initial guess turns out

<sup>8</sup> Recall that  $q_t$  is a real price measured in units of consumption. Hence,  $q_t = 1$  will hold in the absence of adjustment costs, irrespective of the fact that the price level on consumption goods fluctuates due to the price stickiness faced by retailers.

<sup>9</sup> In fact, Ravn (2012) also estimates the reaction to stock prices in an augmented Taylor rule, and obtains similar results.

not to be consistent with the sign of  $\Delta q_t$  switching at that time, the guess is adjusted accordingly, and the process is repeated until the switching criteria are satisfied, as further outlined in the Appendix.

It should be noted that this approach to endogenous regime switching is somewhat different from that of Davig and Leeper (2006). They solve their model, in which the monetary policy reaction to inflation depends on the lagged level of inflation, numerically over a discrete partition of the state space. However, applying this method to our model, which is considerably larger than that of Davig and Leeper, involves substantial computational problems, as their approach suffers heavily from the curse of dimensionality. The ability to handle endogenous switching even in a medium-scale DSGE model is thus an advantage of the shooting method employed in the present paper.<sup>10</sup> On the other hand, the shooting method in effect combines two approximations, as the model is linearized under each regime. This is a potential drawback, albeit a small one, as the two systems are almost identical. Moreover, observe that the steady state of the model is unaffected by the non-linear policy, as the reaction to asset price changes will always be zero in steady state. As a result, we are linearizing each of the systems around the same steady state. A more substantial disadvantage of using a numerical, non-linear solution method is that it renders welfare calculations unfeasible, and thus prevents an investigation of whether the asymmetric policy is optimal in terms of welfare.

### 2.7. Equilibrium determinacy

Following Blanchard and Kahn (1980), equilibrium determinacy of rational expectations models is ensured if the number of endogenous state variables in the model is equal to the number of stable eigenvalues (i.e., eigenvalues inside the unit circle) of the matrix governing the law of motion. However, due to our use of a numerical solution method, we are unable to write the solution analytically as a law of motion on the standard form. As a result, we can only make a formal check of the Blanchard–Kahn conditions for each of the two piecewise linear systems comprising our model, but not for the model as such. To make sure that equilibrium determinacy is in fact preserved in our model, we first verify that the Blanchard–Kahn conditions are satisfied for each of the two systems. This turns out to be the case, which is not surprising. First, as described below, the interest rate reaction to inflation is larger than 1 in both regimes, as we keep  $\phi_\pi = 1.5$  constant. In other words, the Taylor principle is satisfied in both systems. Second, Pfajfar and Santoro (2011) show that adding a reaction to asset price growth does not compromise equilibrium determinacy, but rather promotes it.<sup>11</sup> Having established that each of the two systems satisfy the Blanchard–Kahn conditions, it follows that the model as such also satisfies the criteria for equilibrium determinacy. If the model economy switches between two regimes that both satisfy equilibrium determinacy, the model itself will never be exposed to problems of indeterminacy. It is straightforward to show that in a model where the economy switches between two regimes, and the monetary policy reaction to inflation is strictly larger than 1 in both regimes, the ‘long run Taylor principle’ of Davig and Leeper (2007), which is a necessary and sufficient condition for equilibrium determinacy, is always satisfied.<sup>12</sup> In particular, the regime-switching probabilities, which in our case are determined by the sign of the stock price change, have no impact on the conditions for equilibrium determinacy in this case. We conclude that the asymmetric reaction to stock prices does not in itself lead to equilibrium indeterminacy.

### 2.8. Calibration

As already mentioned, we obtain most of the parameter values from Christensen and Dib (2008), who estimate a model largely similar to the one outlined above using US data for the sample period 1979–2004. The parameters that were not estimated by Christensen and Dib are instead calibrated. With a few minor exceptions, we follow the calibration in Christensen and Dib (2008). The reader is therefore referred to Christensen and Dib for a more detailed discussion of the parameter values. All parameter values are presented in the Appendix A.

The parameter measuring the elasticity of the external finance premium with respect to changes in firms’ leverage position deserves special mention. We use the value  $\psi = 0.042$  as estimated by Christensen and Dib. This value is somewhat smaller than the value used by Bernanke et al. (1999) and Gilchrist and Saito (2008) of  $\psi = 0.05$ . This implies that the financial accelerator mechanism is less strong in the present paper.

As for monetary policy, the policy rule in our model differs substantially from that of Christensen and Dib (2008). Therefore, we do not use their parameter estimates. Instead, we set  $\phi_\pi = 1.5$  as suggested by Taylor (1993). Furthermore we set  $\phi_y = 0.2$ , whereas the interest rate smoothing parameter is set to 0.67, indicating a degree of interest rate smoothing around 2/3 as suggested by, among others, Clarida et al. (1999). Finally, a value must be assigned to the parameter  $\phi_q$ , the reaction to stock price drops. Hoffmann (2013) and Hall (2011) directly estimate this parameter from comparable Taylor rules with interest rate smoothing.<sup>13</sup> For the case of falling stock prices ( $\Delta q_t < 0$ ), Hoffmann (2013) reports an estimate of 0.331 for

<sup>10</sup> The shooting method is in fact more similar in spirit to the ‘guess-and-verify’ method used by Mäckowiak (2007) in order to study the outbreak of currency crises. However, common to all these studies is the use of numerical methods. The task of developing analytical tools to deal with endogenous regime switching is an obvious next step, but beyond the scope of this study.

<sup>11</sup> As these authors demonstrate, the reason is that a reaction to asset price growth is isomorphic to a higher degree of interest rate smoothing, which has been shown to alleviate potential indeterminacy problems.

<sup>12</sup> This is shown explicitly in the online Appendix.

<sup>13</sup> To be exact, Hoffmann (2013) finds a reaction to stock price changes relative to the change in the underlying HP-filtered trend, while Hall (2011) finds a reaction to the lagged stock price change relative to the change in the fundamental value as measured by dividend yields.

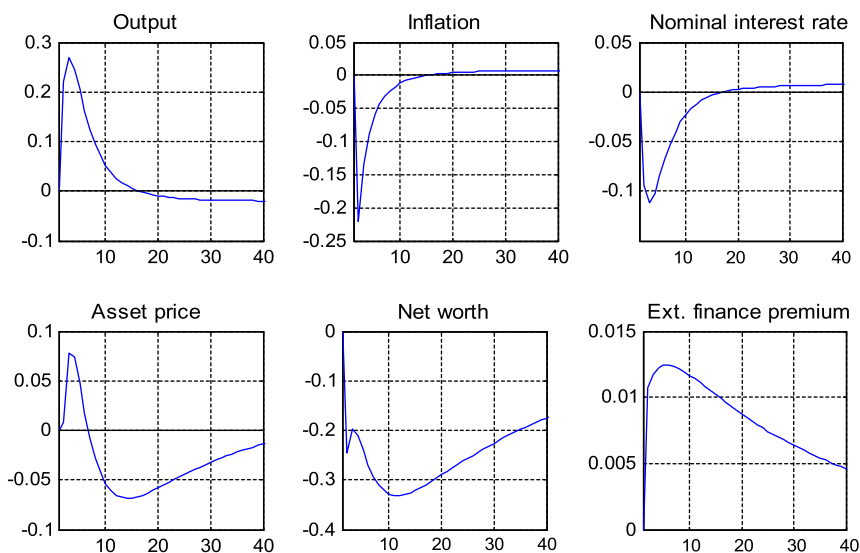


Fig. 1. Effects of a positive technology shock, no policy reaction to asset prices

the period 1987–2008, while Hall (2011) arrives at an estimate of 0.139 in her baseline specification. Ravn (2012) reports estimates from a high-frequency study using daily data. To cast his results in terms of the Taylor rule, the point estimate needs to be transformed.<sup>14</sup> Following the same line of reasoning as Ravn (2012), his estimated result implies a value of  $\phi_q = 0.0246$  whenever  $\Delta q_t < 0$ .<sup>15</sup>

These estimates are quite low. The DSGE literature offers little guidance on the magnitude of this parameter. However, some information can be obtained from the contributions of Tetlow (2005) and Gilchrist and Saito (2008), who augment the Taylor rule with a symmetric reaction to the change in stock prices. Tetlow evaluates a rule with a stock price reaction that is quite large; always bigger than 1. Gilchrist and Saito allow the parameter to take on values between 0.1 and 2.0. In other words, there seems to be a substantial divergence between estimated and calibrated values of this parameter.<sup>16</sup> To bridge this gap, we therefore perform most of the simulations below for two different values of  $\phi_q$ : the estimate of 0.0246 obtained from Ravn (2012), which represents a lower bound for the various empirical estimates, and a value of 0.5, more in line with the theoretical literature.

### 3. Dynamics of the model

In this section, we investigate the dynamics of the model when the asymmetric monetary policy rule is in place. In linear models, the impulse response to a positive shock is by construction the mirror image of the response to a negative shock of the same type and size. In this model, instead, positive and negative shocks have different dynamic effects.

Before looking into the effects of the asymmetric policy, we report the effects of each shock in the model without an asymmetric policy. Figs. 1 and 2 display the impulse responses of some key endogenous variables to an orthogonalized unit shock to technology and monetary policy when the policy reaction to stock prices is always zero;  $\phi_q = 0$ . Fig. 1 illustrates that a positive technology shock leads to a rise in output, while inflation and the nominal interest rate both fall. Lower inflation in turn implies a higher real cost of repaying outstanding debt, depressing the net worth of firms. This is the debt-deflation channel. As net worth goes down, the external finance premium increases. In turn, this dampens economic activity. Thus, the term financial accelerator is in fact misleading in the case of a technology shock when the debt-deflation channel is included, as in this case the fluctuations in output are actually attenuated. This was already noted by Iacoviello (2005). The presence of the debt-deflation channel is crucial for this result, as also demonstrated by Christiano et al. (2010).<sup>17</sup>

<sup>14</sup> The interpretation offered by Ravn (2012) relies on the fact that the Federal Open Market Committee meets once every six weeks. The model of the present paper is formulated (and calibrated) in quarterly terms. This involves an implicit assumption that monetary policy can only be changed every 12 weeks; once per quarter.

<sup>15</sup> In fact, Ravn (2012) also estimates an augmented Taylor rule, and finds a somewhat larger reaction.

<sup>16</sup> Indeed, if one were to use the result of Rigobon and Sack (2003) in the present setting, this would imply a (symmetric) value of  $\phi_q = 0.0428$ . One potential explanation of this divergence is that in theoretical investigations, the researcher is often interested only in policy reactions to stock price changes larger than some threshold value, while the empirical contributions considered here measure the (presumably smaller) reaction to stock price changes of any size.

<sup>17</sup> In a model similar to ours, they find that the debt-deflation channel and the financial accelerator mechanism reinforce each other in the wake of shocks that drive output and inflation in the same direction, whereas they counteract each other after shocks that, like the technology shock, drive output and inflation in different directions.



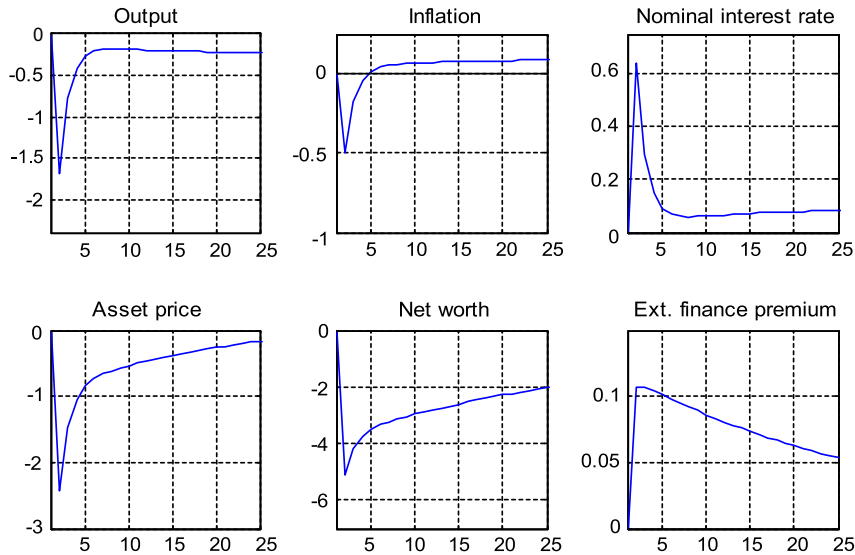


Fig. 2. Effects of a contractionary monetary policy shock, no reaction to asset prices.

The technology shock leads to a boom-bust cycle in the asset price. The initial rise in the price of capital is due to the investment boom following the technology shock. The price of capital ‘undershoots’ its steady state level for a number of periods, as the persistent drop in net worth leads to a persistent rise in the price of external funding, lowering the demand for capital (and thus, the asset price) even many periods after the shock. The reason that net worth and the price of capital move in different directions is that the initial (and numerically quite small) increase in the price of capital is the result of two opposing effects: While the positive technology shock increases investment and the price of capital; the resulting rise in the external finance premium has the exact opposite effect.

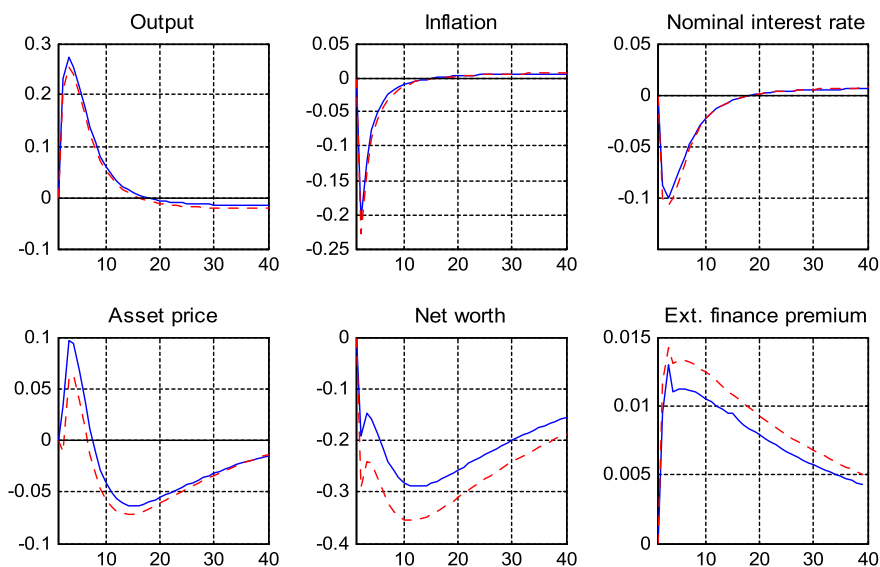
Fig. 2 illustrates the dynamics after a positive innovation to monetary policy.<sup>18</sup> In this case, the financial accelerator does work to amplify business cycle fluctuations. The rise in the interest rate depresses economic activity and in particular investment, reducing the price of capital. This leads to a drop in the net worth of firms, which is further enhanced by the drop in inflation through the debt-deflation channel. Lower net worth increases the external finance premium, which further depresses investment and output. These dynamics explain why this mechanism is referred to as the financial accelerator.

In the [online Appendix](#), we show that introducing a moderate, symmetric policy reaction to asset price changes does not lead to major changes in the dynamics described above. We also demonstrate that the same is true for a policy rule with a reaction to stock price *deviations* from their steady state level, as suggested by [Faia and Monacelli \(2007\)](#) and [Gilchrist and Saito \(2008\)](#), among others.

### 3.1. Dynamics under asymmetric policy

Having discussed the effects of each shock in the absence of asymmetric policy, we now turn to study how these effects are altered when an asymmetric monetary policy rule is introduced. When computing impulse responses, we use the value of  $\phi_q = 0.5$  in order to clearly illustrate the effects of the asymmetric policy. For each shock, we compare the effects of positive and negative shocks on the dynamics of key endogenous variables. Consider first the effects of a technology shock. Fig. 3 illustrates what happens after positive and negative technology shocks. The ‘mirror image’ of a negative shock is just the impulse responses of the negative shock multiplied by  $-1$ ; facilitating comparison. As illustrated, the asymmetric policy has a dampening effect on contractions in output relative to expansions. A positive technology shock causes output to increase by more than it decreases following a similar-sized negative shock. The explanation is that in the wake of a negative technology shock, the asset price is pushed down for a number of periods (except for the effect on impact, when the asset price actually rises). Under the asymmetric policy, this drop in asset prices is met with an interest rate cut (although this cut is dominated by the increase in the interest rate as a reaction to the jump in inflation), spurring economic activity and thus dampening the initial economic slowdown. On the other hand, as asset prices rise following a positive technology shock, this induces no increase in the interest rate *per se*. In other words, output contractions following technology shocks are mitigated by an interest rate reaction to asset prices, while output expansions are not. Also for inflation, increases will be larger than drops, as the interest rate reaction to asset prices exerts an upward pressure on inflation following a negative shock, but no

<sup>18</sup> While some of the variables appear to have stabilized at non-zero values at the end of the period displayed, we have checked that all variables eventually return to zero.



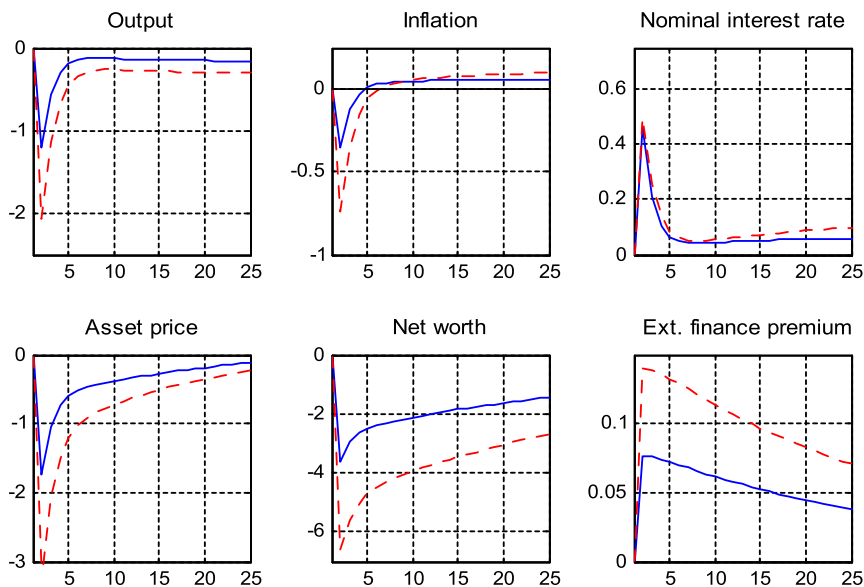
**Fig. 3.** Effects of a technology shock, asymmetric model. Solid blue line: Positive shock. Dashed red line: Mirror image of negative shock. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

corresponding downward pressure after a positive shock. While the asset price still displays a boom-bust cycle, the asymmetric policy implies that the decline following a negative shock is less severe than the boom following a positive shock. It thus seems that the policy reaction to asset price drops succeeds in mitigating these drops. The quantitative impact of the asymmetric policy on the macroeconomy is quite small, though, as indicated by the small absolute distance between the impulse responses for the positive and (mirrored) negative shocks.

It is interesting to compare the effects on the asset price to the effects of a similar-sized shock with no stock price reaction (Fig. 1). As the negative shock induces a monetary policy reaction to the drop in stock prices, it is not surprising that the effects of a negative shock (Fig. 3) are numerically smaller than the effects of a positive shock under no stock price reaction at all. However, we also observe that the increase in the asset price following a positive shock is larger under the asymmetric policy than in the absence of an asset price reaction. As the asset price increases immediately after a positive technology shock, both models imply no reaction of monetary policy to this increase. Under the asymmetric policy, however, agents realize that whenever asset prices start to fall, this drop will be alleviated by a monetary policy reaction. This expectation drives up the asset price more than in the case where the reaction to asset prices is always zero, giving rise to an ‘anticipation boom’. This anticipation boom measures the additional increase of the asset price under asymmetric policy, relative to its increase in the case of no stock price reaction following a positive shock. Quantitatively, the anticipation boom is quite substantial under the calibration with  $\phi_q = 0.5$ ; amounting to 23.9% when evaluated two periods after the shock; the last period before the asset price starts to fall and monetary policy actually starts reacting to asset price changes. On the other hand, using the smallest of the estimated values ( $\phi_q = 0.0246$ ), the number is reduced to only 1.1%. Recall that the other empirical estimates were all in the range between these two values.

Consider finally the asymmetric effects on the two financial variables, net worth and the external finance premium. Recall that because of the debt-deflation channel, net worth is depressed after a positive technology shock, as the drop in inflation increases the real burden of firms’ debt repayments. However, it is apparent that the effect on net worth is much larger following a negative shock. After a positive shock, the drop in net worth is counteracted by the rise in the asset price. In the case of a negative shock, this effect is much weaker, as the drop in asset prices is much smaller. Indeed, after a negative shock, the asset price rises in the first period, which is exactly where most of the difference arises in the effects on net worth. As net worth is highly persistent, so is this difference. In turn, also the external finance premium is affected more by a negative shock, which is unsurprising given the movements in net worth.

Fig. 4 illustrates the asymmetric effects of contractionary and expansionary monetary policy shocks. Once again, output and inflation both drop following a contractionary monetary policy shock. An expansionary shock, however, induces an even larger increase in output and inflation. As was the case for technology shocks, then, the asymmetric policy implies that when the economy is hit by monetary policy shocks, booms become larger than recessions, once again creating an asymmetric business cycle. The explanation is again linked to the movements in the asset price. Following a contractionary shock, the asset price goes down, inducing the central bank to cut the interest rate. This mitigates the initial economic downturn caused by the shock, and also pushes inflation up. On the other hand, the rise in asset prices following an expansionary shock is not met with any monetary policy reaction, so the counteracting effect is not present in that case. Furthermore, adding to the asymmetric effects on output and inflation stemming from the monetary policy reaction to asset prices, the increase in



**Fig. 4.** Effects of a monetary policy shock, asymmetric model. Solid blue line: Contractionary shock. Dashed red line: Mirror image of expansionary shock. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the external finance premium during expansions is much larger than the drop during contractions. In turn, this implies cheaper access to credit for firms, increasing the demand for capital, the investment level, and eventually output. Note that while the nominal interest rate does not display a large, numerical difference, the real interest rate, which matters for consumption and investment decisions, is affected differently during expansionary and contractionary phases, as implied by the impulse responses for inflation. As a result, the macroeconomic effects of the asymmetric policy are much larger than in the case of technology shocks.

As in the case of technology shocks, an expansionary shock to monetary policy leads to an anticipation boom in asset prices. This is evident when comparing the effects of an expansionary shock under asymmetric policy (Fig. 4) to the effects in the case of no stock price reaction (Fig. 2). In the case of monetary policy shocks, the anticipation boom is evaluated one period after the shock; the last period before the asset price starts declining. The extra rise in asset prices is substantial, 28.1%, when  $\phi_q$  is set to 0.5. Using instead the much smaller estimated value from Ravn (2012), the number drops to 1.1%.

The emergence of the anticipation boom can be related to what Davig and Leeper (2006) call the *preemption dividend*. In their model, the central bank is assumed to react stronger to inflation if the lagged inflation level is above a certain threshold (the inflation target). Rational agents will embed this non-linearity in their inflation expectations. As a consequence, monetary policy will be more effective in bringing down inflation in the wake of an inflationary shock, compared to a situation with a linear reaction to inflation. As the central bank is able to successfully manage expectations, the actual increase in the interest rate does not have to be very large. In our setup, agents embed the monetary policy reaction to stock price drops in their expectations, leading to a larger increase in asset prices immediately after a positive shock. This happens despite the fact that when asset prices are increasing, as in the first period(s) after the shock, the actual monetary policy reaction to asset prices is zero under the asymmetric policy as well as with no reaction to asset prices at all. As the preemptive dividend of Davig and Leeper (2006), the anticipation boom arises solely due to the central bank's ability to manage the expectations of private agents. In this way, the asymmetric monetary policy amplifies the boom-bust cycle in asset prices following a shock to the economy, thereby creating additional volatility in asset prices.<sup>19</sup>

The results above can be related to some of the results from the empirical literature on asymmetric business cycles. The finding that the asymmetric policy amplifies booms relative to recessions seems to contradict a number of empirical studies which tend to find that recessions are bigger than booms (Neftci, 1984; Acemoglu and Scott, 1997). This suggests that an asymmetric policy of the type investigated above has not historically been driving the business cycle. For several reasons, this is not particularly surprising. First, the recent empirical findings are obtained only for relatively short samples, especially in the case of Ravn (2012). Second, these results are of too little quantitative importance to be a dominant driver of the business cycle. On the other hand, Beaudry and Koop (1993) find that negative shocks to the economy are much less persistent than positive ones, implying that recessions should be shorter than booms. This is more in line with

<sup>19</sup> Finally, and similar to Davig and Leeper (2006), we find substantial differences between the impulse responses shown above, which take into account that agents anticipate the possibility of future regime switches, and the impulse responses (not shown, but available upon request) obtained when agents naively expect the present regime to be in place forever.

the effects of an asymmetric policy shown above, even if the quantitative differences between booms and recessions are too small to match the findings of Beaudry and Koop. Finally, the implications of an asymmetric policy are also consistent with the results of Cukierman and Muscatelli (2008) and Wolters (2012), who find that the Federal Reserve has displayed a recession avoidance preference in the recent past.<sup>20</sup> According to these studies, estimated reaction functions for the Federal Reserve indicate that US monetary policymakers tend to react more strongly to the output gap during recessions than during expansions. This creates outcomes that are in line with the impulse responses displayed above, suggesting that an asymmetric reaction to stock prices can be rationalized by recession avoidance preferences. This is further discussed in the next section.

#### 4. Potential motivations for an asymmetric policy

As demonstrated by the impulse responses in the previous section, reacting asymmetrically to asset prices can lead to a situation in which recessions are attenuated relative to expansions. This raises the question of whether one could think of the central bank as aiming to obtain exactly such an asymmetric outcome. While the central bank is usually assumed to minimize a fully symmetric loss function (e.g. Woodford, 2003), it is not given that the objective of the central bank should be perfectly symmetric. Among others, Blinder (1997), Ruge-Murcia (2004), and Surico (2003, 2007) suggest that the central bank could be seeking to minimize an asymmetric loss function. For example, Ruge-Murcia (2004) assumes that the social loss associated with high unemployment exceeds the social benefits when unemployment is low.<sup>21</sup> If the loss function of the central bank is asymmetric, this could serve as motivation for an asymmetric stock price reaction.

Moreover, even if the loss function of the central bank is of the usual, symmetric form, this does not necessarily imply that the tools of the central bank should also be symmetric. Indeed, if the central bank believes that certain asymmetries exist in the economy, for example that stock price drops and increases have asymmetric macroeconomic effects, an asymmetric policy might be seen as an attempt to correct for this inherent asymmetry, and in turn obtain symmetric outcomes. Ravn (2012) acknowledges this possibility, and points out two potential sources of asymmetric effects of stock prices. In the following, we study each of them in more detail.

##### 4.1. Asymmetric financial accelerator

One channel which may give rise to asymmetric effects of stock price movements is the financial accelerator. The possibility of a non-linear financial accelerator has received some attention in the literature (Bernanke and Gertler, 1989; Gertler and Gilchrist, 1994; Bernanke et al., 1996). During a recession, when asset prices tend to be falling, more firms are likely to be liquidity constrained and in need of external financing. Moreover, small changes in the net worth of firms are likely to be more costly when the collateral value of firms is already low, and the agency costs of borrowing are already large. Ultimately, a credit crunch might result. Gertler and Gilchrist (1994) and Peersman and Smets (2005) have provided empirical support for the hypothesis that the financial accelerator may be more relevant in bad times.

In the model of this paper, the strength of the financial accelerator is measured by the elasticity of the external finance premium with respect to the net worth of firms. To see this directly, consider the log-linearized version of Eq. (4):

$$E_t \hat{f}_{t+1} - (\hat{R}_t - E_t \hat{\pi}_{t+1}) = -\psi E_t (\hat{n}_{t+1} - \hat{q}_t - \hat{K}_{t+1}), \quad (11)$$

As seen from (11), the impact on the external finance premium of changes in the firm's leverage ratio is determined by the magnitude of the parameter  $\psi$ . The larger is  $\psi$ , the stronger is the effect on the external finance premium, and thus on the business cycle, of a given change in net worth. In other words, an asymmetric financial accelerator can be modeled by allowing  $\psi$  to take on different values. In particular, in light of the above discussion, we allow  $\psi$  to take on one value ( $\psi_L$ ) for the case when net worth is above its steady state value, i.e.,  $\hat{n}_t > 0$ , and a higher value ( $\psi_H$ ) when  $\hat{n}_t < 0$ . In this way, the financial accelerator becomes a source of asymmetric business cycle fluctuations by amplifying bad economic shocks more than good ones.

Consider first the effects of technology shocks in the presence of this asymmetry. After a positive shock, net worth drops below its steady state value, implying that the elasticity of the external finance premium becomes high. This exerts a downward pressure on output through the accelerator effect, dampening the initial boom, while the drop in inflation is amplified. In the case of a negative technology shock, net worth instead rises, so the dampening of the initial downturn in output is small. Hence, the drop in output is large, which in turn mitigates the increase in inflation. In consequence, the effects of positive and negative shocks are asymmetric.<sup>22</sup> By following an asymmetric policy and cutting the interest rate in

<sup>20</sup> On the contrary, Surico (2007) finds no evidence of a recession avoidance preference in the US.

<sup>21</sup> A recent strand of the literature has suggested that policymakers may instead have a preference for robustness towards model uncertainty. Ellison and Sargent (2012) provide an example of how such a preference may rationalize alternative policy outcomes. A preference for robustness could potentially rationalize an asymmetric policy towards stock prices, although this remains to be explored.

<sup>22</sup> Note that the debt-deflation channel is not critical for this conclusion. Without the debt-deflation channel, net worth would be procyclical after technology shocks (Gilchrist and Saito (2008)). An asymmetric financial accelerator would then amplify recessions more than booms.

**Table 1**  
Asymmetric financial accelerator, technology shocks.

Value of $\phi_q$	Value of $\psi_L$	Calibrated value of $\psi_H$	Ratio $\frac{\psi_H}{\psi_L}$
0.0246	0.042	0.043	1.02
0.50	0.042	0.059	1.40

response to the drop in stock prices after a negative shock, the central bank can drive up output and inflation, and thereby mimic (the mirror image of) a positive shock. In fact, for a given ‘degree’ of asymmetry of the financial accelerator, there exists a magnitude of the asymmetric policy reaction ( $\phi_q$ ) that exactly eliminates the initial asymmetry after supply-side shocks.

It turns out that the same is not true after shocks originating from the demand side. An expansionary shock to monetary policy pushes up net worth, so that the financial accelerator is relatively weak. The resulting amplification of the initial boom in output is limited, while the increase in inflation is relatively large. On the other hand, the financial accelerator is much stronger following a contractionary monetary policy shock due to the drop in net worth, resulting in a large drop in output and a strong dampening of the initial drop in inflation. An asymmetric policy induces an interest rate cut in response to the stock price drop after the contractionary shock. While this dampens the drop in output, again mimicking the mirror image of a positive shock, it also mitigates further the drop in inflation, which was already ‘too small’ compared to the relatively large increase in inflation after a positive shock. In other words, a trade-off arises between bringing output or inflation to their ‘symmetric’ values. While the asymmetric policy might alleviate the effects of a non-linear financial accelerator, it never obtains the fully symmetric outcome.<sup>23</sup> This will in general be the case for shocks that drive output and inflation in the same direction, as demand shocks tend to do.

To shed light on the empirical relevance of these issues, it seems natural to ask: How severe should the asymmetry of the financial accelerator be in order to ‘rationalize’ the recent empirical findings about asymmetric monetary policy, in the sense that this policy ‘cancels out’ the asymmetric financial accelerator under supply shocks, or obtains the most favorable trade-off under demand shocks? In order to quantify the necessary degree of asymmetry, we fix the elasticity of the external finance premium at the baseline value of  $\psi_L = 0.042$  when net worth is above its steady state value. We then use impulse response matching of output and inflation responses for positive and negative shocks to calibrate the ‘optimal’ value of  $\psi_H$ .<sup>24</sup> This value can then be compared to  $\psi_L$ . Table 1 shows the degree of asymmetry needed to optimally match the impulse responses of output and inflation to technology shocks for different values of  $\phi_q$ , the reaction coefficient of monetary policy to stock price changes. As the table illustrates, the degree of asymmetry in the financial accelerator needed to match impulse responses is quite sensitive to the choice of  $\phi_q$ . For the value found by Ravn (2012), the balance-sheet channel needs to be only slightly asymmetric (2% stronger when net worth is low, compared to when it is high) in order for the two asymmetries to ‘cancel each other out’ under supply shocks. If instead  $\phi_q$  is set at 0.50, this number rises to 40%.

For the same values of  $\phi_q$ , Table 2 shows the degree of asymmetry of the financial accelerator needed to obtain the most favorable trade-off between symmetry in output and in inflation after monetary policy shocks. If the policy reaction to stock price changes is set at  $\phi_q = 0.50$ , the balance-sheet effect has to be much stronger (77%) during periods of low net worth in order to minimize the distance to the symmetric outcome. For a policy reaction of the size estimated by Ravn (2012), the number reduces to 8%.

To put these numbers in perspective, we look to the empirical study of an asymmetric financial accelerator by Peersman and Smets (2005). They show that a positive innovation of 1%-point to the interest rate causes a drop in the growth rate of output of 0.22%-points during a boom, but a much larger drop of 0.66%-points during a recession. They then estimate how various measures of firms’ financial position contribute in explaining this asymmetry. They find that if firms’ leverage ratio increases by 5% of its average value, the *difference* between the effect on output growth of a monetary policy shock in booms and in recessions increases by 0.14%-points; i.e. from the original 0.44%-points to 0.58%-points. In other words, the financial position of firms is able to account for substantial asymmetries over the business cycle, indicating that the financial accelerator effect is considerably stronger in recessions than in booms. In this light, the degrees of asymmetry computed above to ‘rationalize’ the results of Ravn (2012) do not seem unrealistic. The other empirical results require a somewhat higher, but not necessarily unrealistic degree of asymmetry.

<sup>23</sup> To visualize these scenarios, observe that an asymmetric financial accelerator induces a ‘kink’ in both the aggregate demand (AD) and aggregate supply (AS) curves, as firms are on the demand side of the market for financing, but on the supply side of the goods market. Through an asymmetric policy reaction of the ‘right’ size, the central bank can eliminate the kink in the AD curve, but not in the AS curve. As a consequence, shocks to aggregate supply shifts the AS curve along the resulting, potentially linear AD curve, giving rise to symmetric outcomes of positive and negative shocks. On the other hand, the AD curve will intersect steep or flat areas of the non-linear AS curve in response to positive or negative shocks, respectively.

<sup>24</sup> More specifically; for each of the two types of shocks, we focus on the impulse responses of output and inflation. We then compute the sum of squared errors (SSE) between the impulse response to a positive shock and the mirror image of the impulse response to a negative shock. For this, we use the values in the first 16 periods after the shock. Finally, we solve for the value of  $\psi_H$  that minimizes the sum of the SSE’s.

**Table 2**  
Asymmetric financial accelerator, monetary policy shocks.

Value of $\phi_q$	Value of $\psi_L$	Calibrated value of $\psi_H$	Ratio $\frac{\psi_H}{\psi_L}$
0.0246	0.042	0.0455	1.08
0.50	0.042	0.0745	1.77

#### 4.2. Asymmetric wealth effects

Another possible source of asymmetric macroeconomic effects of stock price movements is the wealth effect on consumption. Shirvani and Wilbratte (2000) and Apergis and Miller (2006) provide empirical evidence that the wealth effect of stock prices is stronger when stock prices are declining than when they are increasing. One possible, theoretical explanation for this finding is provided by prospect theory (Kahneman and Tversky, 1979). Prospect theory introduces an inherent asymmetry in agents' preferences, as the utility loss from bad outcomes is assumed to be larger than the utility gain from good outcomes. If agents display such loss aversion on consumption, as suggested by, among others, Koszegi and Rabin (2009), this might give rise to non-linear effects on consumption from asset price movements, as the wealth effect will be stronger in the face of declining asset prices. Gaffeo et al. (2012) show that in a DSGE model with loss aversion in consumption, optimal monetary policy features an asymmetric reaction to inflation.

With the introduction of loss aversion in consumption into our model, an expansionary shock to monetary policy would still drive up inflation, output and the asset price. However, the weak wealth effect would attenuate the boom in output. At the same time, more labor would be needed to satisfy the extra demand. However, with consumption increasing, the labor supply of households would be relatively low, giving rise to a large increase in marginal costs and inflation. Instead, after a monetary contraction the wealth effect would be strong, inducing a large drop in output, but also an increase in labor supply to compensate for the loss in consumption. Hence, the drop in inflation would be relatively small. A reaction to the drop in stock prices would be able to offset the direct wealth effect, but not the effects on the labor-leisure decision.

As for supply shocks, the initial rise in asset prices following a positive innovation to technology would lead to only a small wealth effect, moderating the boom in output and amplifying the drop in inflation. A negative technology shock would instead cause a large drop in output through a strong, negative wealth effect. At the same time, the rise in inflation would be modest due to the increase in labor supply. An asymmetric reaction to the stock price drop will tend to push up inflation and output, bringing both variables closer to the mirror image of a positive shock. In sum, if the stock wealth effect is assumed to be asymmetric over the business cycle, an asymmetric policy is able to 'correct for' this asymmetry and obtain symmetric outcomes only in the case of supply-side shocks, while a trade-off arises after demand-side shocks, just as we saw in the previous subsection.<sup>25</sup>

#### 5. Concluding remarks

The present paper provides some theoretical inputs to the recent debate concerning a potentially asymmetric reaction of monetary policy to stock prices. We demonstrate that an asymmetric policy towards the stock market will translate into an asymmetric business cycle. Booms in output following expansionary shocks will tend to be amplified, while recessions will be dampened. A similar pattern emerges for inflation. This could be motivated by assuming that the desire of the policy-maker is to minimize an asymmetric loss function, or by the existence of other asymmetries in the economy. We show that if the financial accelerator or the stock wealth effect is assumed to be non-linear over the business cycle, an asymmetric monetary policy can obtain symmetric outcomes in response to supply shocks, but only partly alleviate such asymmetries after demand shocks.

The magnitude of the asymmetric policy reaction found in recent empirical studies is rather small, and our analysis shows that its quantitative impact on the macroeconomy is limited. This is especially the case when economic fluctuations are driven by technology shocks. The asymmetric policy exerts a small additional effect on movements in output and inflation. It also does not lead to problems of equilibrium indeterminacy.

Although an asymmetric policy reaction to stock prices might be useful in order to eliminate or mitigate other asymmetries, it also implies a risk of creating moral hazard problems by effectively insulating stock market investors from part of their downside risk. As a matter of fact, this has been at the heart of the critique of the pre-crisis consensus and the plea to take the 'a' out of 'asymmetry' in the policy approach to asset prices (Mishkin, 2010; Issing, 2011). The potential moral

<sup>25</sup> A related line of argument, also deriving from prospect theory, is that gains and losses in financial wealth might have direct, asymmetric effects on utility. Barberis et al. (2001) assume that agents display loss aversion with respect to fluctuations in their financial wealth. In that case, an asymmetric policy could be an attempt to cushion agents from the utility losses when asset prices decline.

hazard problems of an asymmetric monetary policy towards the stock market was already analyzed by Miller et al. (2001). In the present paper, this issue is linked to the anticipation boom in asset prices that arises following expansionary shocks as a result of the asymmetric policy. However, we have not attempted to analyze the potential moral hazard problems in detail. A comprehensive study of how an asymmetric monetary policy can cause moral hazard problems by distorting the incentives of the individual investor would require an even richer microfoundation than that of the present paper, explicitly modeling the investment decision. While this is surely an interesting idea for future research, it is beyond the scope of this paper.

The present paper follows most of the modern macroeconomic literature by log-linearizing the equilibrium conditions around a steady state. Thus, by construction, the economy eventually returns to the same steady state following a shock. This inherent limitation implies that it is not possible to study whether the asymmetric policy might push the economy to a new steady state. For example, if economic booms are consistently stronger and longer than recessions, as suggested by the impulse responses, one would eventually expect a ‘level’ effect on output. Another question is whether the asymmetric policy will sooner or later drive the interest rate to its zero lower bound. Due to the limitations of the log-linear approach, the model above does not have much to say about such issues.

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## Appendix A. Model details

Appendix A describes the calibration, the equilibrium conditions, and the solution method.

### A.1. Calibration

See Table A1.

**Table A1**  
Parameter values.

Parameter	Interpretation	Value
$\alpha$	Capital share in production	0.3384
$\beta$	Discount factor	0.984
$\gamma$	Preference for consumption	0.0598
$\delta$	Depreciation rate	0.025
$e^p$	Elasticity of substitution between final goods	6
$\eta$	Preference for leisure	1.315
$\nu$	Entrepreneurs' survival rate	0.9600
$\xi$	Probability of not adjusting price	0.7418
$\chi$	Importance of capital adjustment cost	0.5882
$\psi$	Elasticity of ext. fin. premium wrt. leverage	0.042
$\bar{\Psi}$	Steady state external finance premium	1.0250
$\pi$	Steady state inflation rate	1
$\frac{\kappa}{\pi}$	Rate of capital to net worth in steady state	1.8
$\rho_r$	Degree of interest rate smoothing	0.67
$\phi_\pi$	Monetary policy reaction to inflation	1.5
$\phi_y$	Monetary policy reaction to output	0.2
$\hat{\phi}_q$	Monetary policy reaction to stock price drops (estimated)	0.0246
$\phi_q$	Monetary policy reaction to stock price drops (calibrated)	0.5
$\rho_a$	Persistence of technology shock	0.7625

### A.2. Log-linearized equilibrium conditions

We log-linearize the conditions describing the equilibrium around the steady state of the model. For details, see the [online Appendix](#). In the following,  $\hat{x}_t$  will denote the log-deviation of variable  $x_t$  from its value in the nonstochastic steady state; denoted  $x$ .

$$\hat{\lambda}_t = -\hat{C}_t, \quad (\text{A1})$$

$$H\hat{H}_t = (1 - H)(\hat{\lambda}_t + \hat{w}_t), \quad (\text{A2})$$

$$\hat{\lambda}_t = E_t \hat{\lambda}_{t+1} - E_t \hat{\pi}_{t+1} + \hat{R}_t, \quad (\text{A3})$$

$$\hat{Y}_t = (1 - \alpha)\hat{A}_t + (1 - \alpha)\hat{H}_t + \alpha\hat{K}_t, \quad (\text{A4})$$

$$\widehat{mp}_t = \hat{Y}_t + \widehat{mc}_t - \hat{K}_t, \quad (\text{A5})$$

$$\hat{w}_t = \hat{Y}_t + \widehat{mc}_t - \hat{H}_t, \quad (\text{A6})$$

$$\hat{f}_{t+1} = \frac{mp}{f} \widehat{mp}_{t+1} + \frac{1 - \delta}{f} \hat{q}_{t+1} - \hat{q}_t, \quad (\text{A7})$$

$$E_t \hat{f}_{t+1} - (\hat{R}_t - E_t \hat{\pi}_{t+1}) = -\psi E_t (\hat{n}_{t+1} - \hat{q}_t - \hat{K}_{t+1}), \quad (\text{A8})$$

$$\hat{n}_{t+1} = \frac{K}{n} \hat{f}_t + \left(1 - \frac{K}{n}\right) (\hat{R}_{t-1} - \hat{\pi}_t) + \psi \left(1 - \frac{K}{n}\right) (\hat{q}_{t-1} + \hat{K}_t) + \left[1 + \psi \left(\frac{K}{n} - 1\right)\right] \hat{n}_t, \quad (\text{A9})$$

$$\hat{K}_{t+1} = \frac{I}{K} \hat{I}_t + (1 - \delta) \hat{K}_t, \quad (\text{A10})$$

$$\hat{q}_t = \chi (\hat{I}_t - \hat{K}_t), \quad (\text{A11})$$

$$\hat{R}_t = \rho_r \hat{R}_{t-1} + (1 - \rho_r) [\phi_\pi \hat{\pi}_t + \phi_y \hat{Y}_t + \phi_q [\Delta \hat{q}_t < 0] \Delta \hat{q}_t] + \varepsilon_t^r, \quad (\text{A12})$$

$$Y\hat{Y}_t = C\hat{C}_t + \hat{I}_t, \quad (\text{A13})$$

$$\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \frac{(1 - \xi)(1 - \beta\xi)}{\xi} \widehat{mc}_t. \quad (\text{A14})$$

These 14 equations in 14 variables characterize the log-linearized economy.

### A.3. The solution method

As the solution method we use is an extension of the work of [Bodenstein et al. \(2009\)](#), the rest of this Appendix builds on their [Appendix A](#). The log-linearized version of the model consists of Eqs. (A1)–(A14). Note that the monetary policy condition (A12) is not linear, as the value of the parameter  $\phi_q$  depends on the sign of  $\Delta \hat{q}_t$ . However, the model is piecewise linear, in the sense that given one of the two possible values of  $\phi_q$ , all equations are linear. This is the key insight underlying the solution method. We can represent each of the two linear systems in the following way, stacking the 14 equations and 14 variables. Let

$$0 = \bar{A}E_t s_{t+1} + \bar{B}s_t + \bar{C}s_{t-1} + \bar{D}\varepsilon_t \quad (\text{A15})$$

describe the dynamics of the system when the asset price is non-decreasing, i.e. when the monetary policy reaction to the asset price is zero. Further, let

$$0 = A^*E_t s_{t+1} + B^*s_t + C^*s_{t-1} + D^*\varepsilon_t \quad (\text{A16})$$

denote the equivalent system when the asset price is decreasing and monetary policy involves a non-zero reaction to the asset price. The vector  $s$  contains all the variables in log-deviations from their steady state values:  $s_t = [\hat{K}_t, \hat{n}_t, \hat{q}_t, \hat{R}_t, \hat{C}_t, \hat{H}_t, \hat{\lambda}_t, \hat{f}_t, \hat{Y}_t, \hat{I}_t, \hat{w}_t, \hat{\pi}_t, \widehat{mp}_t, \widehat{mc}_t]'$ . The matrices  $\bar{A}, \bar{B}, \bar{C}$ , and  $A^*, B^*, C^*$  are  $N \times N$  coefficient matrices,



where  $N = 14$  is the number of variables. Finally,  $\varepsilon_t = [\varepsilon_t^a, \varepsilon_t^r]'$  is the vector of shocks, and  $\bar{D}$  and  $D^*$  are  $N \times M$  coefficient matrices, with  $M = 2$  representing the number of shocks. The elements of the coefficient matrices derive from the log-linear system of equations presented above. Note that the only difference between the two systems is the reaction of monetary policy to asset price changes; i.e., whether  $\phi_q = 0$  in Eq. (A12) or not. This affects only the matrices multiplying  $s_t$  and  $s_{t-1}$ . In other words,  $\bar{A} = A^*$ , and  $\bar{D} = D^*$ . Further, the matrices  $\bar{B}$  and  $B^*$  differ in only one entry, and the same is true for  $\bar{C}$  and  $C^*$ : If the monetary policy reaction function is listed as the  $n$ th equation in the system, and the price of capital appears as the  $m$ th variable in the vector  $s$ , then these matrices differ only in the  $(n, m)$ th entry.

As each of these two systems are linear, they can be solved separately using well-known methods such as the Toolkit method of Uhlig (1999), which we use, or the Gensys method of Sims (2002). The solutions can then also be written on matrix form, as the evolution of the endogenous variables are fully described by the lagged values of the state variables and the realizations of the shocks. Hence, the solutions to the above systems are, respectively:

$$s_t = \bar{P}s_{t-1} + \bar{Q}\varepsilon_t, \quad (\text{A17})$$

$$s_t = P^*s_{t-1} + Q^*\varepsilon_t. \quad (\text{A18})$$

Assume that a shock hits the economy in period 0. As the economy starts out in the regime with no reaction to stock price changes, the first regime change will occur the first time the change in the asset price ( $\Delta q_t = q_t - q_{t-1}$ ) becomes negative. Depending on the shock, this may happen on impact or after a number of periods.<sup>26</sup> Once the regime has shifted, it may shift back, or it may remain in the new regime.<sup>27</sup> In principle, an arbitrary number of regime shifts might take place, depending on the evolution of the asset price.

In order to illustrate the idea behind the solution method, consider the evolution of the asset price following a positive technology shock; the lower left panel of Fig. 1 at the end of the main text.<sup>28</sup> Evidently, this impulse response involves two turning points; which we call  $T_1$  and  $T_2$ , i.e. points where the sign of the change in the asset price switches. After the second turning point, the stock price is increasing, so the dynamics of the economy are described by the solution to the model with no reaction to asset prices (and no further shocks):

$$s_t = \bar{P}s_{t-1}, t > T_2. \quad (\text{A19})$$

Consider now the dynamics for  $T_1 < t \leq T_2$ , for which the monetary policy reaction to asset prices is non-zero. We use backward induction to trace out the evolution of the endogenous variables in these periods. As no shocks are assumed to hit the economy outside period 0, it follows from (A19) that  $s_{T_2+1} = \bar{P}s_{T_2}$ . This is useful in the last period before the shift ( $t = T_2$ ), where the following is true:

$$0 = \bar{A}E_t s_{T_2+1} + B^*s_{T_2} + C^*s_{T_2-1} \iff$$

$$s_{T_2} = \Gamma_1 s_{T_2-1}, \Gamma_1 \equiv -(\bar{A}P + B^*)^{-1}C^*. \quad (\text{A20})$$

In similar fashion, we can derive an expression for the second-last period before the shift ( $t = T_2 - 1$ ). Let  $A = -(\bar{B}^*)^{-1}\bar{A}$ , and  $C = -(\bar{B}^*)^{-1}C^*$ . Then:

$$0 = \bar{A}E_t s_{T_2} + B^*s_{T_2-1} + C^*s_{T_2-2} \iff$$

$$s_{T_2-1} = (I - A\Gamma_1)^{-1}Cs_{T_2-2}. \quad (\text{A21})$$

Thus, by recursive substitutions, we can express the endogenous variables at any point in this interval as a function of their 1-period lagged values. In the general case, we get:

$$s_t = \Gamma_{T_2-t+1} s_{t-1}, T_1 < t \leq T_2, \quad (\text{A22})$$

where, for each  $t$ ;

$$\Gamma_{T_2-t+1} = (I - A\Gamma_{T_2-t})^{-1}C,$$

recalling the definition of  $\Gamma_1 \equiv (\bar{A}P + B^*)^{-1}C^*$ . In fact, the recursivity of the problem allows us to write  $s_t$  for each period in this interval as a function of  $s_{T_1+1}$ ; the first period in this interval:

$$s_t = \left( \prod_{i=1}^{t-1} \Gamma_{T_2-i} \right) s_{T_1+1}. \quad (\text{A23})$$

<sup>26</sup> Unless the asset price remains forever constant, however, it will happen sooner or later, as the asset price must return to its initial value.

<sup>27</sup> Of course, the economy will eventually return to its steady state, where the regime is always that of a zero reaction to stock price changes.

<sup>28</sup> The figure shows the impulse response of the asset price in the model without asymmetric policy. We first assume that the turning points under this policy are unchanged when the asymmetric policy is introduced. We then later verify that this is in fact the case.

In period  $T_1 + 1$ , the values of the endogenous variables are ‘inherited’ from the dynamics in the previous interval. For  $t \leq T_1$ , when the policy reaction to asset prices is again zero, we can similarly compute the value of  $s_t$  in each period recursively as a function of  $s_1$ . From (A22), we get the following expression, which is needed to describe the last period before this first shift:

$$s_{T_1+1} = \Gamma_{T_2-T_1} s_{T_1}. \quad (\text{A24})$$

Performing recursive operations in a similar fashion to above provides us with the following expression for  $s_t$ :

$$s_t = \Theta_{T_1-t+1} s_{t-1}, 2 \leq t \leq T_1, \quad (\text{A25})$$

where, for each  $t$ ;

$$\Theta_{T_1-t+1} = \left( I - \hat{A} \Theta_{T_1-t} \right)^{-1} \hat{C},$$

and where  $\hat{A} = -(\bar{B})^{-1} \bar{A}$ ;  $\hat{C} = -(\bar{B})^{-1} \bar{C}$ ; and:

$$\Theta_1 \equiv -\left( \bar{A} \Gamma_{T_2-T_1} + \bar{B} \right)^{-1} \bar{C}.$$

Finally, the special case where  $t = 1$  is the only time at which the shocks take on non-zero values. We use (A15) and (A25) as well as the assumption that the economy starts out in steady state in period 0, implying that  $s_0 = 0$ . We then obtain an expression for  $s_1$  as a function of the time 1-innovations:

$$0 = \bar{A} s_2 + \bar{B} s_1 + \bar{C} s_0 + \bar{D} \varepsilon_1 \iff$$

$$s_1 = \left( I - \hat{A} \Theta_{T_1-1} \right)^{-1} \hat{D} \varepsilon_1, \quad (\text{A26})$$

where  $\hat{D} = -(\bar{B})^{-1} \bar{D}$ . Finally, we obtain:

$$s_t = \left( \prod_{i=1}^{t-1} \Theta_{T_1-i} \right) \left( I - \hat{A} \Theta_{T_1-1} \right)^{-1} \hat{D} \varepsilon_1, 2 \leq t \leq T_1. \quad (\text{A27})$$

As mentioned in the main text, the model is solved in practice by making use of a shooting algorithm to find the turning points. An initial guess for each of the turning points is needed. Given the initial guess, we solve for  $s_t, \forall t$ . It is then easy to verify whether this initial guess was correct or not by simply checking whether the sign of  $\Delta q_t$  actually does shift for  $t = T_{\text{initialguess}}$ . If this is the case, we keep the solution. If not, we adjust our initial guess, and we ‘shoot’ again, until the condition is satisfied.

## Appendix B. Supplementary material

Supplementary material associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jmacro.2013.11.002>.

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