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Abstract

We study a general equilibrium model in which informational frictions impede entrepreneurs' ability to borrow and banks' ability to intermediate funds. These financial market frictions are embedded in an otherwise-standard dynamic New Keynesian model. We find that exogenous shocks have an amplified and more persistent effect on output and investment, relative to the case of perfect capital markets. The chief contribution of the paper is to analyse how these financial sector imperfections – in particular, those relating to the banking sector – modify our understanding of optimal monetary policy. Our main finding is that optimal monetary policy tolerates only a very small amount of inflation volatility. Given that similar results have been reported for models that abstract from banks, we conclude that assigning a non-trivial role for banks need not materially affect the properties of optimal monetary policy.

Key words: Banks; moral hazard; credit market frictions; price rigidities; optimal monetary policy.

JEL classification: E44; E32; E52.

Summary

Do weak banks affect the transmission mechanism of monetary policy? Does bank lending merely reflect general macroeconomic conditions, or are there important feedback effects from banks to other macro variables? More generally, how should financial sector conditions influence the conduct of monetary policy? These questions are of long-standing interest to policymakers and they form the motivation for this paper. In order to study them, we develop a framework that explicitly models the role of banks in intermediating credit flows, and takes into account some possible frictions that are likely to exist between depositors, banks and borrowers.

In our model, the amount of capital held by banks and the creditworthiness of borrowers are both important ingredients in transmitting shocks throughout the economy. To see why, suppose that an unanticipated tightening of monetary policy (or some other adverse shock) leads to a decline in output, which then lowers the profitability of firms, triggers a fall in asset prices, and causes loan losses for banks. The accompanying reductions in borrower net worth and bank capital will have two effects. First, banks will be less willing to lend to borrowers whose creditworthiness has declined. And second, depositors will view banks as riskier institutions, and will readjust their portfolios out of bank deposits. We show by simulation that these effects are able to generate a significant second-round cutback in the flow of lending which exacerbates the initial downturn.

Intuitively, we might expect there to be a role for monetary policy in mitigating the second-round effects generated by these frictions. For instance, by aggressively cutting interest rates in a downturn, the central bank might be able to check the falls in asset prices and net worth associated with the shock, thereby partly cushioning the impact on aggregate demand. The cost of acting in this way, however, is higher inflation – at least in the short term. A key question for policymakers is therefore: how much of an increase in inflation volatility should be tolerated in order to reduce the volatility of output growth in this way?

The chief contribution of this paper is to tackle this question. We proceed in two steps. First, we assess the performance of monetary policy strategies that respond in a mechanical way to 'financial' variables such as asset prices or credit flows over-and-above consumer price inflation. It turns out that these simple monetary policy rules perform poorly if the goal of policy is maximising the wellbeing of economic agents in the model. Second, we use numerical techniques

to analyse the properties of the 'optimal' monetary policy implied by the model. Our main finding is that a central bank acting in this optimal way will tolerate only a very small amount of inflation volatility. Furthermore, the 'trade-off' implied by our model is very steep in the sense that the reduction in output growth volatility achieved by allowing inflation to become more volatile is very small. Given that similar results have been reported for models that abstract from banks – and in fact credit market imperfections altogether – we conclude that assigning a non-trivial role for these frictions need not materially affect optimal monetary policy. This suggests that policies that work well in 'normal' times are likely to continue working well in a situation where weak banks are limiting the expansion of credit.

‘*Traditionally, most economists have regarded the fact that banks hold capital as at best a macroeconomic irrelevance and at worst a pedagogical inconvenience.*’ *Friedman, B (1991).*

1 Introduction

The current generation of workhorse models used for monetary policy analysis typically abstract from imperfections in financial markets. Firms and households can borrow freely at riskless interest rates. And financial intermediaries, if they are explicitly modelled, are nothing more than a veil. In this paper, we relax these assumptions and study an environment in which informational frictions impede the smooth functioning of financial markets. These frictions generate an important role for banks in ensuring the efficient allocation of funds. We use the framework to analyse the implications of this bank-centric view of the economy for the design of monetary policy.

A common justification for abstracting from banks is that the increasing sophistication of financial markets have made borrowers less intermediary-dependent in recent years. One counter-argument to this is that banking crises, when they occur, are typically extremely costly events. Hoggarth, Reis and Saporta (2002) for instance estimate that average cumulative output losses following crises are in the order of 15%-20% of annual GDP. Some authors have found that loan supply disturbances affect real activity in more normal times too. Peek and Rosengren (1997) for instance find that capital shortages at Japanese banks adversely affected US real estate investment in the early 1990s. The evidence, however, is not clear-cut: Driscoll (2004) for example finds little connection between shifts in bank loan supply and US states’ personal income.[1] Yet another set of studies have found cross-sectional patterns in bank behaviour that are difficult to reconcile with theories based on perfect capital markets. For example, Kashyap and Stein (1995, 2000) demonstrate that lending by ‘small’ banks is more sensitive to a change in monetary policy than lending by their larger counterparts. The presumption is that, with less liquid balance sheets, small

(1) The macroeconomic impact may be a non-linear function of the magnitude of the shock to loan supply. Ashcraft (2005a), for instance, finds little relationship between state-level real income and loan supply following a shock to monetary policy. When focusing on bank failures, however, he finds significant and apparently permanent effects on real activity (see Ashcraft (2005b)).

banks are less able to shield their lending from such shocks.[2]

In this paper, we develop a small quantitative general equilibrium model in which banks serve a meaningful role in intermediating credit. And we use the model to study the properties of a range of alternative monetary policies. The exercise requires us to take a stand on three key questions:

- First, what frictions are banks helping to overcome?
- Second, what drives feedback between the financial system and real economic activity?
- And third, what frictions give the central bank leverage over the real economy?

The role for banks in our model stems from an asymmetric information problem between borrowers and lenders: borrowers, we assume, are tempted to divert resources towards privately beneficial activities (like engaging in unprofitable takeovers, appointing family and friends to key positions in the firm etc). By monitoring borrowers' actions, banks can mitigate the deadweight losses imposed by this agency problem.[3]

The net worth of borrowers and the amount of capital held by banks both matter for real activity in our model. The need to hold capital/net worth also emanates from an asymmetric information problem. Only entrepreneurs with enough capital at stake will be motivated to act diligently. And likewise for banks: monitoring is a costly activity, so banks will be tempted to devote fewer resources to it than is required. Only those banks with sufficient capital at stake will be trusted to be conscientious monitors.[4] Fluctuations in capital/net worth therefore feed back onto real investment and output.

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(2) Ashcraft (2005a) finds that affiliation with a multi-bank holding company significantly lowers the sensitivity of loans to monetary policy. Similarly, Ehrmann and Worms (2004) caution against the use of size as a proxy for liquidity in financial systems where bank networks are prominent (eg Germany).
Other studies exploit cross-sectional differences in bank capitalisation as an identification device. For instance, Kishan and Opiela (2000) report evidence that loan growth of highly leveraged banks is more responsive to monetary policy than the loan growth of well-capitalised banks.
(3) The focus on monitoring clearly abstracts from a host of other important functions served by the banking sector (such as liquidity provision, payment services etc). We follow this approach for reasons of tractability, rather than from a belief that monitoring is more important than these other functions *per se*.
(4) This follows the framework of Holmstrom and Tirole (1997). Notice that the need for banks to hold capital in this model has nothing to do with regulatory policy.

Our model builds on earlier work by Chen (2001).[5] The first contribution of this paper is to extend this work in order for it to be suitable for monetary policy analysis. The standard framework for monetary policy research in recent years has been dynamic general equilibrium models with nominal rigidities. We follow that approach here and assume that the real effects of monetary policy derive from frictions in adjusting goods prices.

The paper proceeds as follows. After running through the details of the model, we use impulse response analysis to analyse how credit frictions influence its dynamic properties. We find that credit constraints bring about an amplified, and more persistent response of macroeconomic variables (notably output) to technology, monetary and net worth shocks, relative to the benchmark of perfect capital markets. Amplification is not a universal result in the literature on financial frictions. Bernanke *et al* (2000), for instance, report a similar degree of output amplification as we do. But Carlstrom and Fuerst (1996, 2001) find that credit frictions dampen the initial impact on output, but generate greater persistence thereafter. As we discuss below, these differences can be traced to the greater volatility of asset prices in our model and Bernanke *et al*'s.

We then turn to the normative question of how monetary policy should be conducted in this model. We approach this question in two steps. First, we ask whether simple Taylor-type rules augmented to include 'financial' variables such as asset prices or credit growth provide a sensible way of conducting monetary policy in the model. In line with the conclusions drawn by Bernanke and Gertler (2001), Gilchrist and Leahy (2002) and others, we find that they do not: mechanically responding to asset prices and/or credit growth is detrimental to welfare relative to a policy of strict price stability. Second, we search within a broad family of rules for the optimal monetary policy that maximises the representative household's expected utility. We find that optimal monetary policy does not *fully* stabilise the price level following a real disturbance. Rather, it takes a slightly countercyclical stance, smoothing through some of the inefficient fluctuations that arise from such shocks. Quantitatively, however, the amount of inflation tolerated by the optimal policy is very small and roughly comparable to what is found by Collard and Dellas (2005) for the case of tax distortions. Furthermore, the volatility of real variables under the optimal rule is quantitatively very similar to that under full price stability.

(5) Meh and Moran (2004) study a general equilibrium model with banking sector frictions similar in spirit to ours. These authors show how the banking frictions outlined in the text can generate countercyclical capital-asset ratios as observed in the data.

Our paper is related to a recent study by Faia and Monacelli (2005), who study the performance of simple rules in the financial accelerator model of Bernanke *et al* (2000). They find strict inflation targeting to be the welfare maximising policy in that model. Our approach differs from theirs in that the class of rules that we consider is much more general. In particular, we allow the central bank to respond to all the relevant state variables of the economy. Nevertheless, our results are complementary to theirs in that we find only very small deviations from full price stability under the optimal policy. Assigning a non-trivial role for banks, therefore, need not materially affect the properties of optimal monetary policy. Another paper which shares a similar motivation to ours is Vlieghe (2005), which examines optimal monetary policy in a monetised, sticky price version of Kiyotaki (1998). The degree of inflation volatility found by Vlieghe (2005) under the optimal Ramsey plan is similar to that found here. But, in contrast to our findings, this small amount of inflation volatility is associated with much lower volatility in output than under full price stability.

The rest of the paper is organised as follows. Section 2 introduces the model environment. Section 3 explains the structure of financial contracts. Section 4 outlines a baseline monetary policy rule used in the initial part of the paper. Section 5 discusses aggregation issues and lists the model's equilibrium conditions. Section 6 details our calibration. Section 7 analyses impulse responses from the model following shocks to bank capital, monetary policy, and technology. Section 8 analyses optimal monetary policy. Finally, Section 9 concludes.

2 Structure of the model

2.1 Overview

We begin with a brief overview of the basic structure of our model. There are four agents: households/depositors, entrepreneurs, financial intermediaries ('bankers'), and wholesalers. Households, bankers and entrepreneurs have distinct preferences over the economy's consumption good.[6] The production of this good involves two tiers. At the initial tier, entrepreneurs and households use capital to produce an 'intermediate' good. Entrepreneurs, we assume, are more skilled at doing this than households. But imperfections in the economy's credit market imply that entrepreneurs end up holding too little of the capital stock in equilibrium. By implication, the fraction of the capital stock held by entrepreneurs at any point in time has a first-order effect on

(6) Treating households, bankers and entrepreneurs as distinct from one another is a simplification that facilitates the modelling of a credit market.

the economy's productive capacity.[7]

At the second tier we introduce price stickiness. In the New Keynesian literature, it is commonplace to assume that producers of the intermediate good are imperfect competitors. This is a useful assumption because imperfect competitors face non-trivial pricing decisions – clearly a necessary ingredient in any coherent theory of price stickiness. However, assuming imperfect competition between entrepreneurs would significantly complicate the structure of our model. To get round this problem, we borrow an idea from Bernanke, Gertler and Gilchrist (2000) and assume that imperfect competition and price rigidity occurs one level down the supply chain, at the wholesale level. Wholesalers purchase the intermediate good from households and entrepreneurs, differentiate it (eg paint it different colours), and sell it on at a markup over marginal cost to a competitive retail sector. Retailers then simply aggregate the differentiated goods into final output, which is then either consumed or invested. Neither wholesalers nor retailers play any further role in the model.

At the end of each period, new capital goods are produced by competitive capital-goods producers. Capital producers use a concave technology to transform inputs of final output ('investment') and rented capital into new capital goods. The concavity of their production function is analogous to assuming convex costs of adjusting the capital stock. And it implies that the relative price of new capital goods may deviate from unity in the short run.

We now proceed by describing the decision problems of each agent in more detail.

2.2 Households

Households are infinitely lived and have preferences over consumption C^h, leisure $1 - N$ and real money balances m.[8] The objective of the representative household is to maximise the lifetime

(7) This dual sector set-up is somewhat stylised, but may be thought of as corresponding to the following scenario. The less productive but unconstrained production by households resembles that of large, well-established companies who can borrow cheaply in financial markets. Conversely, the high-return but constrained production by entrepreneurs resembles that of small firms and start-ups, who typically have greater trouble accessing finance.
(8) We take $H(m)$ to be small. This is intended to capture the idea that cash is used for very few transactions in the steady state. This 'cashless limiting economy' (see Woodford (1998)) is an attractive approach in a model such as ours, where bank deposits form a significant fraction of households' portfolios.

utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_t^h\right)^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} + \frac{\chi}{1+\psi}(1-N_t)^{1+\psi} + H\left(m_t\right) \right] \tag{1}$$

where β is the time discount factor.

In any period t, the representative household receives the following income flows: a wage of ω_t per unit of labour N_t supplied; a gross real interest rate of r_{t-1}^d on its deposits of the previous period D_{t-1}; a price of υ_t per unit of intermediate good $G\left(K_{t-1}^h\right)$ sold to wholesalers; lump-sum profits from the monopolistic wholesaler Π_t; plus a real transfer tr_t from the central bank. The household may also have cash holdings carried over from the previous period. These resources are either consumed, or used to augment the household's holdings of capital, deposits or cash. This constraint on the flow-of-funds is formalised as follows:

$$q_t\left(K_t^h - (1-\delta)K_{t-1}^h\right) + D_t + C_t^h + m_t =$$
$$r_{t-1}^d D_{t-1} + \omega_t N_t + \upsilon_t G\left(K_{t-1}^h\right) + \Pi_t + tr_t + \frac{m_{t-1}}{\pi_t}$$

δ here denotes the depreciation rate of physical capital, and π_t denotes the gross inflation rate P_t/P_{t-1} (P_t being the aggregate price index).

The first-order conditions with respect to K_t^h, D_t and N_t are as follows:

$$q_t\left(C_t^h\right)^{-\frac{1}{\sigma}} = \beta E_t\left(C_{t+1}^h\right)^{-\frac{1}{\sigma}}\left[(1-\delta)q_{t+1} + \upsilon_{t+1}G'\left(K_t^h\right)\right] \tag{2}$$

$$\left(C_t^h\right)^{-\frac{1}{\sigma}} = \beta E_t r_t^d \left(C_{t+1}^h\right)^{-\frac{1}{\sigma}} \tag{3}$$

$$\chi(1-N_t)^{\psi} = \omega_t\left(C_t^h\right)^{-\frac{1}{\sigma}} \tag{4}$$

In the analysis that follows, the central bank is assumed to use the short-term nominal interest rate as its policy instrument. We therefore omit the first-order condition for cash holdings from the list of equilibrium conditions, as in this model, it merely serves to recursively record the supply of money required to support the desired interest rate of the central bank.

2.3 *Entrepreneurs*

There is a continuum of risk-neutral entrepreneurs. At the beginning of period t, entrepreneurs have access to a stochastic constant-returns-to-scale production technology that transforms capital into intermediate goods in $t+1$. An initial outlay of one unit of capital returns R units of the intermediate good if the project is successful, and zero otherwise.[9] Capital is assumed to depreciate by δ in the former case, and fully in the latter.

Investment is subject to moral hazard in that the entrepreneur privately chooses the probability of his or her project succeeding. The entrepreneur can choose to be either diligent, or to 'shirk'. If the entrepreneur acts diligently, the probability of the project succeeding is high and denoted by p. If the entrepreneur shirks, however, the probability of the project succeeding falls to p' $(p - p' \equiv \Delta p > 0)$. Enterpreneurs are nevertheless tempted to shirk to enjoy private benefits.[10] We assume there are two grades to shirking: low-level shirking yields private benefits of b (per unit of capital under the entrepreneur's control), whereas high-level shirking offers higher private benefits B $(B > b)$. For simplicity, we assume that the distribution of returns is unaffected by which type of shirking the entrepreneur engages in. So all else equal, entrepreneurs will always prefer high-level shirking to the low-level variety. The table below summarises the options open to the entrepreneur.

PROJECT DETAILS

project	*probability of success*	*private benefits*
I	p	0
II	p'	b
III	p'	B

We assume that this technology is only socially worthwhile when in the hands of an entrepreneur who is acting diligently. To see how financial contracts implement this outcome, denote by f_t the

(9) Returns in this model are verifiable at zero cost.
(10) Private benefits capture the idea that the entrepreneur gets some kind of non-monetary return from some projects. A common interpretation is that they capture effort. Lower effort is clearly a benefit to the entrepreneur, but leads to a lower probability of success.

expected per unit return that is pledged to financiers.[11] The utility an entrepreneur can expect from acting diligently is $pE_t\,(v_{t+1}R - f_t + (1-\delta)\,q_{t+1})$. While the expected utility from high-level shirking is $p'E_t(v_{t+1}R - f_t + (1-\delta)q_{t+1}) + B$. The entrepreneur will choose not to shirk, therefore, if and only if:

$$\begin{aligned} &pE_t(v_{t+1}R - f_t + (1-\delta)\,q_{t+1}) \geq \\ &p'E_t(v_{t+1}R - f_t + (1-\delta)q_{t+1}) + B \end{aligned} \tag{5}$$

Rearranging, we find the maximum return that can be pledged to outsiders without destroying entrepreneurial incentives:

$$f_t \leq \overline{f}_t \equiv E_t\,(v_{t+1}R + (1-\delta)q_{t+1}) - \frac{B}{\Delta p} \tag{6}$$

This condition simply states that entrepreneurs who attempt to pledge 'too much' of the expected project return will be viewed as not having a sufficient financial interest in the success of their projects. Notice that higher expected asset prices and/or intermediate goods prices relax the constraint (ie $\overline{f}_t$ goes up). Entrepreneurs can therefore pledge more and hence borrow more in 'good times'.[12]

The lifespan of entrepreneurs is uncertain: they face a constant probability π^e of surviving to the next period.[13] Dying entrepreneurs are replaced by new entrepreneurs in every period so that the mass of entrepreneurs remains constant. The lifetime utility of a typical entrepreneur is linear in the sum of his or her consumption c_t^e and the private benefits $\mathcal{B} \in \{0, b, B\}$ he or she enjoys:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(c_t^e + \mathcal{B}k_{t-1}^e\right) \tag{7}$$

where k_{t-1}^e denotes the entrepreneur's holdings of physical capital at the beginning of period t.

Each period, surviving and newborn entrepreneurs receive an endowment of final output, e^e.[14]

(11) Note that agents in the economy are assumed to have limited liability. This implies (a) that no payment can be made if the project fails, and (b) that f_t can be no larger than $v_{t+1}R + (1-\delta)q_{t+1}$.
(12) It is instructive to compare this expression to that found in Kiyotaki and Moore's (1997) model. The limited ability of entrepreneurs to commit in that model means they can pledge no more than the expected value of their collateral, ie $\overline{f}_t \equiv (1-\delta)\,E_t q_{t+1}$.
(13) The purpose of this assumption is to preclude the possibility that the entrepreneurial sector as a whole will eventually accumulate sufficient net worth to become self-financing (see Carlstrom and Fuerst (1996)).
(14) The role of the endowment is to provide some own funds for those entrepreneurs who would otherwise have none (ie newly born entrepreneurs and entrepreneurs whose projects failed in the previous period). This allows those entrepreneurs to begin operations. The calibrated value of the endowment is extremely small, however, and plays no role in the dynamics of the model.

The net worth of a typical entrepreneur in period t is given by:

$$w_t = \begin{cases} \upsilon_t R k_{t-1}^e + (1-\delta)\, q_t k_{t-1}^e - f_{t-1} k_{t-1}^e + e^e & \text{if successful in } t \\ e^e & \text{otherwise} \end{cases}$$

Surviving entrepreneurs use their own wealth w_t and a loan l_t from the bank to fund purchases of new physical capital:

$$q_t k_t^e = w_t + l_t^d \quad \textbf{(8)}$$

With linear preferences, the entrepreneur only cares about the present discounted value of her consumption. In the neighbourhood of a steady state in which the credit constraint binds, the agency problem implies that the expected rate of return from accumulating capital exceeds the discount factor.(15) Entrepreneurs therefore choose to postpone consumption and accumulate net worth until the period in which they die. They then consume their entire resources before exiting.

2.4 Banks

We assume a large number of risk-neutral banks. Banks play a distinct role in the model because of their ability to monitor. By spending a certain amount of resources c proportional to the project scale under their supervision, they can distinguish B-projects from the others. Monitoring is valuable to entrepreneurs because it reduces their opportunity costs of acting diligently by $B - b$. Lower opportunity costs raise $\overline{f}_t$, the maximum pledgeable per unit return:

$$f_t \leq \overline{f}_t \equiv E_t\left(\upsilon_{t+1} R + (1-\delta) q_{t+1}\right) - \frac{b}{\Delta p} \quad \textbf{(9)}$$

All else equal, this raises the amount by which entrepreneurs can leverage their projects.

Banks, however, also face a moral hazard problem in that depositors cannot observe whether monitoring actually takes place. In order to ensure that it does, a second incentive constraint must be satisfied, this time regulating the share of the return that must be paid to the bank, $0 < R_t^b < 1$:

$$p R_t^b f_t - c \geq p' R_t^b f_t \quad \textbf{(10)}$$

Rearranging, we find the following expression for R_t^b:

$$R_t^b \geq \frac{c}{\Delta p f_t} \quad \textbf{(11)}$$

(15) To see this define, $\Omega \equiv p\left(\upsilon R + (1-\delta) q - f\right)$ as the return an entrepreneur can expect in the economy's steady state. In the aggregate, the expected rate of return on entrepreneurial capital is therefore $\frac{\Omega K^e}{\pi_e \Omega K^e + e^e}$. Since $e^e \approx 0$ the return on entrepreneurial net worth is $1/\pi^e$. Provided that π^e is sufficiently small relative to β, therefore, entrepreneurs will want to postpone consumption until death in the steady state.

The intuition here is analogous to that behind equation **(9)**: in order to be induced to carry out costly monitoring, the bank must have a sufficient financial interest in the success of the project. All else equal, this acts to lower the amount entrepreneurs can borrow against their projects.

The choice between direct finance (ie no monitoring) and indirect finance (ie being monitored) is determined by the magnitude of c relative to $B - b$. For monitoring to exist in equilibrium, it must be the case that the gains from intermediated finance – lower opportunity costs of not shirking – outweigh the delegation costs of providing the bank with the necessary incentives to monitor. Banks can lower the delegation costs by injecting some of their own net worth (or 'capital') into projects they monitor.(16) We calibrate the model in such a way that banks must do this for there to be a cost advantage in monitoring.

Like entrepreneurs, bankers are also taken to face an uncertain horizon. A typical banker maximises the following lifetime utility:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(c_t^b - ck_t^e\right) \quad \textbf{(12)}$$

where c_t^b is the banker's consumption.

Banks offer risk-free deposits to the household sector. For a deposit of d_t in period t the household sector will receive $p(1 - R_t^b) f_t k_t^e$ in repayment in $t + 1$. In order for this to be consistent with the assumption that each bank's assets are perfectly correlated, we follow Carlstrom and Fuerst (1996) by assuming the existence of a mutual fund that diversifies the idiosyncratic risk inherent in the project technology.(17)

Each period, surviving and newborn banks receive an endowment of final output, e^b. The net worth of a typical bank in t is given by:

$$a_t = \begin{cases} R_{t-1}^b f_{t-1} k_{t-1}^e + e^b & \text{if project successful in } t \\ e^b & \text{otherwise} \end{cases}$$

(16) Diamond (1984) shows that if banks hold perfectly diversified loan portfolios, delegation costs asymptotically fall to zero as the number of projects being monitored increases. In this case, banks can be induced to monitor without holding any own capital. We implicitly make the extreme opposite assumption: that project returns within a bank's loan portfolio are perfectly correlated.

(17) This works in the following way. Households make deposits at the mutual fund. The mutual fund transfers these resources to the banking sector for use in credit extension. By the law of large numbers, a certain fraction p of the banking sector's assets will yield a positive return. This return is then paid to the mutual fund, who in turn distributes it back to households.

Banks finance loans l_t^s to entrepreneurs with their own net worth (net of monitoring costs) and deposits from households:

$$l_t^s = a_t - ck_t^e + d_t \tag{13}$$

Finally, like entrepreneurs, banks also find it optimal to postpone consumption and accumulate net worth until the period in which they exit the economy. Note that bankers can accumulate net worth over time without holding the durable good (capital) in our economy. The fact that entrepreneurs' projects are funded in t and mature in period $t+1$ allows bankers to accumulate wealth over time by financing these projects period after period.

2.5 Wholesalers, retailers and price-setting

There is a continuum of imperfectly competitive wholesalers indexed by z. Wholesale firms transform intermediate goods $M_t(z)$ and labour $N_t(z)$ into differentiated wholesale products $Y_t(z)$. The production function they employ is subject to exogenous, serially correlated variations in technology T_t:

$$Y_t(z) = T_t M_t(z)^{\gamma} N_t(z)^{1-\gamma} \tag{14}$$

$$\log T_t = \rho \log T_{t-1} + \upsilon_t \tag{15}$$

Cost minimisation by firm z gives rise to the following first-order conditions:

$$\omega_t = X_t (1-\gamma) T_t \left(\frac{M_t(z)}{N_t(z)}\right)^{\gamma} \tag{16}$$

$$\upsilon_t = X_t \gamma T_t \left(\frac{M_t(z)}{N_t(z)}\right)^{\gamma-1} \tag{17}$$

where X_t denotes real marginal cost. Since all firms optimise against the same vector of input prices, marginal cost must be equal across wholesalers.

A competitive 'retailer' uses these varieties $Y_t(z)$ as inputs into production of a homogeneous final output good Y. The production function of the retailer is given by the Dixit-Stiglitz index:

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{\epsilon-1}{\epsilon}} dz\right]^{\frac{\epsilon}{\epsilon-1}} \tag{18}$$

where $\epsilon > 1$.

We introduce price stickiness by following a widely used modelling convention devised by Calvo (1983). In any given period, wholesale firms are permitted to reset their prices only with probability $1-\theta$. This probability is constant, and independent of when the firm last reset its price. Firms that are not permitted to post new prices in t are required to maintain prices they were quoting in $t-1$. A firm which is free to choose a new price $P_t^*(z)$ in t will do so to maximise expected real profits:

$$\max_{P_t^*(z)E} E_t \sum_{i=0}^{\infty} (\theta\beta)^i \left(C_{t+i}^h\right)^{-\frac{1}{\sigma}} \left\{ \left[\frac{P_t^*(z)}{P_{t+i}}\right]^{1-\epsilon} Y_{t+i} - X_{t+i} \left[\frac{P_t^*(z)}{P_{t+i}}\right]^{-\epsilon} Y_{t+i} \right\} \quad \textbf{(19)}$$

The firms that adjust their price in t face identical decision problems. So all choose the same P_t^*:

$$P_t^* = \frac{\epsilon}{\epsilon-1} \cdot \frac{E_t \sum_{i=0}^{\infty} (\theta\beta)^i \left(C_{t+i}^h\right)^{-\frac{1}{\sigma}} X_{t+i} P_{t+i}^{\epsilon} Y_{t+i}}{E_t \sum_{i=0}^{\infty} (\theta\beta)^i \left(C_{t+i}^h\right)^{-\frac{1}{\sigma}} P_{t+i}^{\epsilon-1} Y_{t+i}} \quad \textbf{(20)}$$

As is well known, the consumption-based price index P_t in this case evolves according to:

$$P_t = \left[\theta P_{t-1}^{1-\epsilon} + (1-\theta)\left(P_t^*\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}} \quad \textbf{(21)}$$

2.6 The capital-goods producing sector

New capital goods are produced at the end of each period. This production is carried out by a continuum of competitive capital-goods producing firms indexed by j. The production of new capital goods requires inputs of existing undepreciated capital (rented from households and entrepreneurs), and final output ('investment') $I_t(j)$. The production function is concave in investment:

$$Y_t^k(j) = \mu I_t(j)^{\phi} \left((1-\delta) K_{t-1}(j)\right)^{1-\phi}$$

where $0 < \phi < 1$, and μ is a constant.

Firm j chooses how much to invest, and how much of the existing capital stock to rent (at rate z_t) in order to maximise profits, $q_t Y_t^k(j) - z_t((1-\delta) K_{t-1}(j)) - I_t(j)$. The first-order conditions for this problem are:[18]

$$1 = \phi q_t \mu \left(\frac{I_t(j)}{(1-\delta) K_{t-1}(j)}\right)^{\phi-1} \quad \textbf{(22)}$$

$$z_t = (1-\phi) q_t \mu_t \left(\frac{I_t(j)}{(1-\delta) K_{t-1}(j)}\right)^{\phi} \quad \textbf{(23)}$$

The concavity of the production function gives rise to a variable price of capital q_t that is increasing in the investment to capital ratio.

(18) In general equilibrium, the rental rate on capital z_t flows to the owners of the capital stock each period, ie households and entrepreneurs. Given that z_t is close to zero in equilibrium, however, we ignore it here in order to streamline the description of the model.

Due to the linear homogeneity of the production function, all firms choose the same ratio of investment to capital. The aggregate capital stock therefore evolves according to:

$$K_t = \mu I_t^{\phi} \left((1-\delta) K_{t-1} \right)^{1-\phi} + (1-\delta) K_{t-1} \qquad \textbf{(24)}$$

3 The financial contract

In order to keep the model tractable, we follow Carlstrom and Fuerst (1996) by assuming that there exists enough anonymity between agents that only one period contracts are feasible. The contract specifies what each of the participants invests in the project, and how the project return is divided among these parties, contingent on the project outcome.

We limit attention to a contract that maximises the entrepreneur's return subject to incentive constraints of entrepreneurs **(9)** and bankers **(11)**, as well as a participation constraint for depositors:

$$r_t^d \leq \frac{p_H(1-R_t^b) f_t K_t^e}{D_t} \qquad \textbf{(25)}$$

If we think of households as also being able to trade in an alternative riskless asset (eg short-term government debt in zero net supply), then **(25)** can then be interpreted as a constraint governing household participation in the financial contract.[19]

The contract we focus on has the following structure: entrepreneurs invest all their net worth w; banks invest a; and households put up the difference $(q+c)\, k^e - w - a$. If the project succeeds, the per unit return is divided so that the constraints **(9)**, **(11)**, and **(25)** bind:

$$f_t = E_t \left[v_{t+1} R + (1-\delta)(q_{t+1} + z_{t+1}) \right] - \frac{b}{\Delta p} \qquad \textbf{(26)}$$

$$R_t^b = \frac{c}{\Delta p F_t} \qquad \textbf{(27)}$$

$$r_t^d = \frac{p_H(1-R_t^b) f_t K_t^e}{D_t} \qquad \textbf{(28)}$$

If the project fails, none of the parties receives payment.

Notice that under the terms of this contract, entrepreneurs bear the entire aggregate risk inherent in the project, ie the payment f_t is the same regardless of the realised values of v_{t+1} or q_{t+1}. In

(19) A similar participation constraint has to hold for bankers. In the steady state, our model implies that bankers obtain a rate of return which exceeds the rate of return on their outside option. Therefore, the participation constraint for bankers is non-binding in the neighbourhood of the steady state and can be dropped.

consequence, households earn a risk-free return on their deposits.[20] Combining **(28)** with **(8)**, **(13)**, **(26)** and **(27)** gives:

$$k_t^e = \frac{a_t + w_t}{\Xi_t} \tag{29}$$

where Ξ_t is defined as:

$$\Xi_t \equiv q_t + c - \frac{p}{r_t^d}\left(\overline{f}_t - \frac{c}{\Delta p}\right)$$

(29) is a key equation in the model. It relates equilibrium purchases of capital by an entrepreneur to the sum his or her net worth and the capital invested in his or her project by the banker. $\Xi_t > 0$ is clearly a necessary condition for credit constraints to be binding. The intuition is that Ξ_t is the difference between the per-unit cost of investing ($q_t + c$), and the maximum discounted return that can be pledged to depositors without destroying incentives. Were Ξ_t to be negative, depositors would be willing to finance the first best allocation without the need for entrepreneurs' and banks' own funds. The economy would then behave *as if* all agents had perfect information. In the analysis that follows, we restrict ourselves to parameter choices in which Ξ_t is strictly positive and sufficiently large so that entrepreneurs are unable to finance their desired capital holdings in the steady state.

The timing of events within a given period t can be summarised as follows.

1. Projects installed in period $t - 1$ succeed or fail. Project returns are shared according to the contract.
2. Aggregate shocks are realised.
3. Final goods are produced and factor payments for labour and intermediate goods input are made.
4. New capital goods are produced.
5. Some entrepreneurs and bankers receive a signal to exit the economy. These agents consume all their net worth prior to exiting.
6. The new generation of entrepreneurs and bankers enters the economy. Bankers and entrepreneurs receive their endowments.
7. Households decide how much to consume, how much to save, and how to allocate their savings.

(20) Since households' labour income is risky, a state-contingent return on households' deposits that is negatively correlated with labour income would be strictly preferred to the non-contingent pay-off received here. We do not pursue this here, however, as deposit contracts observed in practice are typically non-contingent.

8. Financial contracts are signed.
9. Entrepreneurs choose project type. Banks choose whether to monitor or not.

4 Monetary policy

In part of the analysis that follows, we make the simplifying assumption that the central bank adjusts the nominal interest rate via the following simple Taylor-type rule:[21]

$$r_t^n = \left(\frac{1}{\beta}\right)^{1-\rho_r} \left(r_{t-1}^n\right)^{\rho_r} \pi_t^{(1-\rho_r)(1+\kappa)} e^{u_t} \quad \textbf{(30)}$$

In log-linear form, rules of this type have been employed in a number of studies. The degree of inertia in the rule is controlled by the parameter ρ_r. $(1+\kappa)$ gives the long-run response of the nominal interest rate to a change in inflation. u_t denotes a monetary policy shock. A standard Fisher equation links the policy instrument to the real rate of return on deposits.

5 Equilibrium

Aggregating across individual agents is straightforward here because we have been careful to make assumptions that ensure agents have decision rules that are linear in their net worth. So, despite there being substantial heterogeneity in banks' and entrepreneurs' net worth, all that matters is the aggregate quantity of each.

We use upper-case letters to denote economy-wide aggregate quantities. Aggregating equation **(29)** across entrepreneurs and bankers gives:

$$K_t^e = \frac{A_t + W_t}{\Xi_t} \quad \textbf{(31)}$$

Aggregate entrepreneurial consumption and net worth (denoted by upper-cases) are given by:

$$C_t^e = (1-\pi^e)\, p\left[v_t R + (1-\delta)q_t - f_{t-1}\right] K_{t-1}^e \quad \textbf{(32)}$$

$$W_t = \pi^e p\left[v_t R + (1-\delta)q_t - f_{t-1}\right] K_{t-1}^e + e^e \quad \textbf{(33)}$$

Similarly, aggregate consumption and net worth by bankers is given by:

$$C_t^b = \left(1-\pi^b\right)\left[p f_{t-1} K_{t-1}^e - r_{t-1}^d D_{t-1}\right] \quad \textbf{(34)}$$

$$A_t = \pi^b \left[p f_{t-1} K_{t-1}^e - r_{t-1}^d D_{t-1}\right] + e^b \quad \textbf{(35)}$$

(21) This is not meant to imply that simple feedback rules of this sort are an accurate description of how monetary policy is set in the United Kingdom or elsewhere. Rather, such rules offer a convenient benchmark with which to analyse one's model given their widespread use in the literature.

To close the model, we specify market-clearing conditions for consumption goods, capital goods, intermediate goods and credit:

$$Y_t + e^b + e^e - cK_t^e = C_t^e + C_t^b + C_t^h + I_t \tag{36}$$

$$K_t = K_t^e + K_t^h \tag{37}$$

$$M_t = pRK_{t-1}^e + G(K_{t-1}^h) \tag{38}$$

$$q_t K_t^e - W_t = A_t + D_t - cK_t^e \tag{39}$$

We end the discussion of equilibrium with a comment on the production function for final output. As first pointed out by Yun (1996), the following relation between aggregate factor inputs M_t, N_t and aggregate output Y_t must hold:

$$Y_t \equiv \left[\int_0^1 Y_t(z)^{\frac{\epsilon-1}{\epsilon}} dz \right]^{\frac{\epsilon}{\epsilon-1}} = \frac{T_t}{\tilde{P}_t} M_t^{\gamma} N_t^{1-\gamma} \tag{40}$$

where $\tilde{P}_t$ is a 'price dispersion' term, capturing the efficiency costs of that follow from our assumption that only a fraction of wholesalers are permitted to reset their prices in any given period.(22) $\tilde{P}_t$ evolves as:

$$\tilde{P}_t = (1-\theta) \left(\frac{P_t^*}{P_t} \right)^{-\epsilon} + \theta \left(\frac{P_{t-1}}{P_t} \right)^{-\epsilon} \tilde{P}_{t-1} \tag{41}$$

General equilibrium in this model is a price system $\left\{ P_{t-1}, P_t^*, \tilde{P}_{t-1}, \omega_t, q_t, \upsilon_t, r_t^d, r_{t-1}^n \right\}_{t=0}^{\infty}$ and an allocation $\left\{ X_t, Y_t, N_t, M_t, I_t, C_t^h, C_t^e, C_t^b, D_t, f_{t-1}, R_t^b, K_{t-1}, K_{t-1}^e, K_{t-1}^h, A_t, W_t \right\}_{t=0}^{\infty}$ that satisfy the following equations: **(2)**, **(3)**, **(4)**, **(16)**, **(17)**, **(20)**, **(21)**, **(22)**, **(24)**, **(26)**, **(27)**, **(30)**, **(31)**, **(32)**, **(33)**, **(34)**, **(35)**, **(36)**, **(37)**, **(38)**, **(39)**, **(40)**, **(41)**, plus the Fisher equation and transversality conditions for households' asset holdings.

Finally, we define two key financial variables for use later on: firms' leverage $q_t K_t^e / W_t$ and banks' capital-asset ratios $A_t/(L_t + cK_t^e)$.

(22) Paustian (2005) argues that the use of Calvo contracts to introduce staggered price-setting may overestimate the welfare costs of inflation. Preliminary results based on a commonly used alternative scheme due to Rotemberg (1982) gave similar results however.

6 Functional forms and calibration

We calibrate the model using steady-state values for the deterministic version of the economy. We take one period to be a quarter, and set β to 0.99, consistent with a gross real interest rate of 1.04. The household production function takes the form $G(K_t^h) = \frac{\lambda}{\varepsilon}\left(K_{t-1}^h\right)^{\varepsilon}$. Capital is assumed to depreciate at the rate $\delta = 0.025$ per period. Household utility is taken to be logarithmic in leisure and consumption, implying that $\psi = -1$ and $\sigma = 1$. This assumption, together with an assumption that households work for one third of their available time (as governed by χ), yields a Frisch elasticity of labour supply of $-\frac{1-N}{\psi N} = 2$. The capital share γ is set at 0.35. The technology process is calibrated with $\rho = 0.9$, and the standard deviation of the innovation set at $\sigma_u = 0.007$.

As in Bernanke *et al* (2000), we require firms' leverage to be roughly 2 in the steady state. The fraction of total capital held by entrepreneurs in the steady state is set to 0.5. Banks' capital-asset ratios are taken to be 10%. Steady-state monitoring costs per dollar of extended credit amount to roughly 6 cents. This is in line with the findings of Harrison *et al* (1999), who report average costs of 5.85 cents for banks in 48 US states for the period 1982-94. The annualised return to bank capital is calibrated to be 10%. To match these features, we set $\varepsilon = 0.5$, $c = 0.03$ and $\lambda = 1$. The per-unit net return R is set at 22.5 and $b = 0.35$. We follow Carlstrom and Fuerst (1996) and set the quarterly failure rate at 1%, requiring $p = 0.99$. The difference in success probabilities, Δp, is taken to be 0.35.(23) We choose ϕ such that the elasticity of the price of physical capital with respect to the investment to capital ratio is 0.75. This is in line with empirical estimates for OECD countries obtained by Eberly (1997) ranging from 0.51 to 1.51.

We calibrate $\epsilon = 7$, implying a markup of 16.66%, roughly consistent with the evidence in Basu and Fernald (1993) for US manufacturing. The average duration of price contract is calibrated to be 2 quarters, ie $\theta = \frac{1}{2}$. This is in line with the evidence in Bils and Klenow (2004), who find an average frequency of price adjustment of roughly 6 months when excluding temporary sales. Finally, inertia in the monetary policy rule ρ_r is set to 0.9 and the inflation response $1 + \kappa = 1.5$. The full set of parameter values are reported in the table below.

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(23) Given that shirking never occurs in the equilibrium of our model, it is impossible to calibrate Δp by looking at data. We therefore experimented with lower values for this parameter.With less difference between the average returns of acting diligently and shirking, the steady-state pay-offs to entrepreneurs and bankers (f and R^b) go up. This had little effect on the model's dynamics, however.

	Parameter	Value
Preferences:		
Subjective discount factor	β	0.99
Frisch labour supply elasticity	$\frac{1-N}{\psi N}$	2
Death probabilities	π^e, π^b	0.64, 0.6
Private benefits	b	0.35
Entrepreneurs' Technology:		
Probability of high return if diligent	p	0.99
Fall in probability of high return if shirking	Δp	0.35
High return	R	22.5
Households' Technology:		
Elasticity of household capital w.r.t. user cost	ε	0.5
Scale factor	λ	1
Bankers' Technology:		
Monitoring cost	c	0.03
Wholesalers' Technology:		
Capital share	γ	0.35
Price reoptimisation probability	θ	0.5
Capital Producers' Technology:		
Curvature parameter	ϕ	0.25
Depreciation rate	δ	0.025
Final Goods Producers' Technology:		
Demand elasticity	ϵ	7

7 The economy's response to exogenous shocks

To illustrate the general properties of the model, it is instructive to consider how the economy responds to unexpected shocks. We consider three specific shocks: an exogenous fall in bank capital; an unanticipated monetary policy tightening; and an unanticipated fall in total factor productivity. To clarify the role played by the financial frictions in the model, we also plot the responses of model variables with financial frictions 'switched off'.[24]

7.1 A shock to bank capital

We first consider an exogenous one-off fall in bank capital, ie a fall in bank capital that is not brought about endogenously by movements in supply and demand. Such a shock could be the result of a fall in the value of a bank's foreign assets. It could also result from a discovery of fraud. More generally, our interest in this shock stems from a desire to isolate the incremental role played by the banking sector in generating the model's dynamics. We calibrate the shock to generate a decline in the banking sector's capital-asset ratio from 10% (its steady-state value) to 7.5% for constant loan supply.[25] Impulse responses to this shock are displayed in Chart 1 in Appendix B.

All else equal, the reduction in banks' net worth reduces the funds available for project finance. If bank frictions were turned off,[26] households would be willing to meet this financing shortfall by raising their deposits. So the shock would have no effect on the real allocation of resources. When bank frictions are binding however, depositors require that banks do not become over-leveraged, and banks as a result are forced to curtail their lending. The squeeze on credit means that entrepreneurs are able to buy less capital for use in the following period. And as entrepreneurs use the capital stock more efficiently than households, this shift lowers expected future returns, depressing the current price of capital. This reduces the value of entrepreneurs' current net worth, and as in Kiyotaki and Moore (1997), there is a negative feedback effect from net worth to asset prices, and then back from asset prices to net worth which greatly magnifies the impact of the initial shock.

The redistribution of capital acts as a supply shock to intermediate goods production. So the lower output of intermediate goods is accompanied by higher prices. This raises wholesalers' marginal costs of production. And given that higher marginal costs are expected to persist, those firms that can charge higher prices do so. The result is upward pressure on inflation as these firms attempt to restore their markups. The policy rule followed by the central bank dictates a persistent rise in

(24) This frictionless reference model is sketched in Appendix A. The model's deep parameters are left unchanged. The sole difference is that the reference model assumes that monitoring and project choice are observable and contractable.

(25) Because banks are highly leveraged institutions, this corresponds to a relatively large fall in bank net worth, ie the shock is in the region of a 25% drop in bank net worth relative to steady state.

(26) This could be a scenario in which monitoring by banks can be costlessly observed. It could also correspond to a scenario in which monitoring involves no resource cost for the bank.

nominal interest rates to contain this inflationary pressure. And after an initial fall, there is a prolonged rise in the real interest rate.

The variation in asset prices following this shock directly affects banks' incentives to monitor and entrepreneurs' incentives to put in high effort. For example, the high price of intermediate goods υ along the transition path means that banks can be induced to monitor with a smaller promised return R^b. Banks are therefore permitted to hold lower capital-asset ratios during this period. High expected intermediate goods prices also make entrepreneurs less willing to misbehave, but the effect of this is partly offset by lower expected asset prices q. Overall, entrepreneurs find they can pledge a greater portion of their projects' expected returns to outsiders and this partly cushions the adverse effect of the shock.

Output falls by 0.6% at its trough.(27) And although the shock only lasts for one quarter, it takes roughly 10 further quarters for the effect of the shock to die away. These effects are broadly comparable to those reported by authors who have examined wealth redistribution shocks between households and entrepreneurs.(28)

7.2 Monetary policy shock

We next consider an expansionary monetary policy shock that corresponds to a 25 basis points reduction of the annualised nominal interest rate. Chart 2 in Appendix B illustrates the impulse responses of several variables to this shock.

The monetary expansion immediately increases nominal aggregate demand. Given that some firms cannot adjust their prices, inflation erodes their markup and they increase production to meet this demand. That generates a sharp increase in labour demand, which drives up the marginal productivity and hence relative price of intermediate goods. Entrepreneurs' projects therefore become more valuable. And this boosts both their own net worth and the net worth of banks, leading to an expansion in loan supply. Loan supply is boosted further by the reduction in the real interest rate. The lower opportunity cost draws deposits into the financial system, increasing the

(27) It should be noted that large variations in bank capital are necessary to generate sizable fluctuations in macroeconomic variables in this model. For further discussion of this property of the model, see Aikman and Vlieghe (2004).

(28) For example, Carlstrom and Fuerst (1996) find that a 0.1% redistribution of the steady-state capital stock in their model from households to entrepreneurs yields a 1.4% increase in output that lasts for approximately 10 quarters.

resources available for entrepreneurial finance. From this point on, the shock is propagated in a qualitatively similar way to the bank capital shock described earlier.

The output effect of the monetary shock is both amplified and more persistent (as measured by the half life) in the full model relative to the frictionless benchmark. In particular, the initial response of output to the monetary impulse is about 50% greater when the credit constraint is binding. Bernanke *et al* (2000) report a similar degree of amplification based on their model. Clearly the model does not provide a complete theory of the transmission mechanism however. The major point of discrepancy is that the peak responses of consumption and output occur immediately, whereas VAR studies typically find hump-shaped responses of these variables (see for instance Christiano, Eichenbaum and Evans (2005)). Given the simplicity of the real side of the model, however, this is hardly surprising.

7.3 Technology shock

Impulse responses to an unanticipated 1% fall in total factor productivity T_t are displayed in Chart 3 in Appendix B. The immediate effect of the adverse shock to technology is to lower the demand for intermediate goods, and with it, their price. Investment projects installed in $t-1$ are therefore less productive than anticipated. The net worth of all investing agents suffers as a result. From this point on, the shock is propogated in a qualitatively similar way to the previous shocks examined. And as in those cases, the second-round effects generated by the financial frictions embedded in this model both amplify and add persistence to the response of output to the shock.

It should be noted that the amplification of shocks is not a universal result in the literature. In particular, Carlstrom and Fuerst (2001) find that credit frictions initially *dampen* the response of output to technology and monetary shocks, but generate greater persistence thereafter. The proximate cause of these differing results is that the net worth of constrained agents is much more volatile in our framework than in Carlstrom and Fuerst's. This in turn can be traced to the behaviour of asset prices, which are an order of magnitude more volatile here than in Carlstrom and Fuerst's model. This feature of our model derives from the assumed degree of concavity in the technology for producing new capital goods, as controlled by the parameter ϕ.[29] As $\phi \to 1$, the amplification effect in our model vanishes and the dynamics of our model following a productivity disturbance resemble those in Carlstrom and Fuerst (2001).

8 How should monetary policy be conducted in the face of this financial friction?

The above analysis illustrated the gap between the efficient behaviour of our economy and its behaviour with financial frictions turned on. This inefficiency gap gives rise to a potential role for monetary policy. In particular, it might be beneficial (in terms of a welfare criterion corresponding to the utility of agents in the model) for monetary policy to use its leverage over real activity to smooth through some of the inefficient fluctuations arising from the credit constraint. While the central bank obviously cannot directly influence the origins of the moral hazard problems faced by agents in the economy, it may be able to influence incentive constraints indirectly. For instance, by stimulating nominal demand in the face of an adverse productivity shock, the central bank can mitigate the fall in asset prices, and therefore much of the 'second-round' effects associated with this shock. The cost of acting in this way, however, is higher inflation, which is detrimental to the welfare of agents in the economy because of its distortionary effect on the retailer's input demands (see equation **(18)**).

The literature on welfare-based monetary policy in models with sticky prices has made a case for price stability. Khan *et al* (2003) analyse a monetary model in a cash-credit goods set-up, with staggered price-setting and no capital accumulation. They show that optimal monetary policy tolerates only very small departures from full price stability in an environment with several distortions. Collard and Dellas (2005) reach a similar conclusion analysing a monetary model with tax distortions and capital accumulation. Here, we ask: do the large cyclical variations in the 'inefficiency gap' (ie the gap between actual and efficient levels of real activity) that are induced by moral hazard in financial contracts give rise to more significant departures from price stability than were found in the aforementioned studies?

To study this question, we proceed in two steps. First, we analyse the welfare implications of

(29) Our assumption that entrepreneurs have access to a linear technology is also important for generating persistence. As discussed by Cordoba and Ripoll (2004), concave production technologies impose a natural limit on amplification. Amplification requires large productivity differences between constrained and unconstrained agents. Such a productivity gap can only appear if constrained agents hold a small fraction of the collateral in the economy, implying that their share of total production must be small.

appending certain financial variables to the simple policy rule considered thus far. Second, we compare how a rule that perfectly stabilises the inflation rate fares in welfare terms relative to an 'optimal' rule that maximises the welfare of the representative household.

8.1 Computing welfare

A standard way of measuring the welfare effect of a policy change from, say, A to B is by the 'equivalent variation' of B, ie the amount of extra consumption an agent would need under policy B to be indifferent between A and B. To illustrate how equivalent variations can be calculated in our model, let monetary policy rule i yield welfare of V^i. And let the sequences of consumption and labour supply associated with i be denoted as $\{C_t^i, N_t^i\}_{t=0}^{\infty}$, $i = A, B$. The equivalent variation ξ of the consumption sequence under A, that makes the household at least as well off as under the B, is implicitly given by:

$$V^B = E_0 \sum_{t=0}^{\infty} \beta^t \frac{\left[(1+\xi)C_t^A\right]^{1-\frac{1}{\sigma}}}{1-\frac{1}{\sigma}} + \frac{\chi}{1+\psi}\left(1 - N_t^A\right)^{1+\psi}$$

Under logarithmic utility, this simplifies to $V^B = \frac{\log(1+\xi)}{1-\beta} + V^A$. It follows that $\xi = \exp((1-\beta)(V^B - V^A)) - 1$.

To compute V^i, we use the numerical solution techniques described in Schmitt-Grohé and Uribe (2004b) and Collard and Juillard (2001). These techniques are based on a second-order Taylor approximation of the model equations around the deterministic steady state.

8.2 Simple instrument rules

In this section, we analyse the welfare effects of simple monetary policy rules of the following log-linear form:

$$\hat{r}_t^n = (1-\alpha_0)(\alpha_1 \hat{\pi}_t + \sum_{j=2}^{J} \alpha_j \hat{g}_{jt}) + \alpha_0 \hat{r}_{t-1}^n$$

where g_{jt} represents additional variables that the central bank might wish to respond to over and above inflation. A prominent question in the literature is whether monetary policy should respond to financial variables such as asset prices or credit aggregates. While Bernanke and Gertler (2001) and Gilchrist and Leahy (2002) argue that a response to asset prices in an interest rate rule is not warranted, they do not formally analyse the welfare performance of such rules based on an explicit model-consistent welfare measure. Here, we consider the implications of including asset prices and the growth rate of credit into the central bank's reaction function. Similar conclusions were obtained using the level of credit instead of its growth rate.

Chart 4 in Appendix B plots the percentage gain in welfare under our proposed simple rule, relative to a rule that completely stabilises inflation (our V^B from the preceding section). Conditional on the parameters α_1 and α_0, a mechanical response to credit growth and/or asset prices is detrimental to welfare relative to a policy of fully stabilising inflation. The welfare loss stems from the dispersion of output across producers of differentiated goods as indicated by equation **(40)**. Our formal welfare analysis therefore supports the position taken by Gilchrist and Leahy (2002): the presence of financial frictions does not suffice to imply that optimal policy can be well approximated by a simple Taylor-type rule augmented with asset prices and/or credit growth.

8.3 Optimal instrument rules

How does a rule that fully stabilises inflation fare relative to an 'optimal' rule that maximises the welfare of the representative household? We take up this question in this section. We define an optimal rule as one that responds log-linearly to all the state variables in the model. Given that all endogenous variables are functions of the state variables, our approach is quite general and similar in spirit to that taken by Collard and Dellas (2005).(30) The optimal rule maximises the welfare measure by choosing coefficients in the following reaction function:

$$\hat{r}_t^n = c_0 \hat{\pi}_t + \sum_{j=1}^{J} c_j \hat{S}_{j,t-1} + c_{J+1} e_t$$

According to this rule, the nominal interest rate reacts to current inflation, to all endogenous state variables $S_{j,t-1}$, and to the current period exogenous shock e_t.(31)

For all computed welfare measures, we study a decomposition into mean and variance based on

(30) These authors also allow for a reaction to crossproducts of the states. We experimented with crossproducts and further lags of the states and this generated only a very small gain in welfare relative to the rule considered above. We therefore chose to ignore these terms in order to save on computational time. Another difference between our approach and that of Collard and Dellas (2005) is that we optimise the coefficients of our rule for each shock, whereas Collard and Dellas (2005) find a rule which is optimal given the full variance-covariance matrix of the disturbances.
(31) The response to inflation is added to ensure determinacy and for numerical stability. We impose that $c_0 = 10$. This ensures that the optimisation is initialised in a promising region of the parameter space. This is not a binding restriction, however, as the optimisation routine is free to 'undo' too strong a response to inflation via an appropriate reaction to the states.

the following second-order Taylor approximation to household expected utility:

$$\mathrm{E}\{U(C_t, N_t)\} = a_1\mathrm{E(C)} - a_2\mathrm{VAR}(C) - a_3\mathrm{E}(N) - a_4\mathrm{VAR}(N) + \mathcal{O}(||\xi||^3)$$

Here $a_1, ..., a_4$ are coefficients and $\mathcal{O}(||\xi||^3)$ denotes constants and terms of higher than second order in the amplitude of the exogenous shocks. We decompose welfare into means and variances of consumption and labour, as in Collard and Dellas (2005) and compute welfare for three monetary policy rules: full price stability (henceforth FPS); our baseline monetary rule (BMR) – equation **(30)** with the variance of the shock process set to zero; and the optimised monetary rule (OMR).

The following table depicts the welfare effects of shocks to bank's net worth and to technology under the three aforementioned monetary policy rules.(32) We also report the standard deviation (SDV) of inflation in order to measure the departure from full price stability in each case. The last column expresses the welfare gain relative to a policy of full price stability:

WELFARE COMPONENTS

	$SD(C)$	$SD(N)$	$E(C)$	$E(N)$	$SD(\pi)$	-100ξ
Bank net worth shocks:						
BMR	0.00229	0.00060766	1.0442545	0.3228945	0.00086	−0.0007
FPS	0.00304	0.00071266	1.0442657	0.32289514	0	0
OMR	0.00283	0.00065809	1.0442736	0.32289759	0.00035	0.0002
Technology shocks:						
BMR	0.022147	0.00063566	1.0444055	0.32289436	0.0036	−0.0413
FPS	0.024036	0.00034722	1.0445947	0.32289365	0	0
OMR	0.024051	0.00045403	1.0446017	0.32289759	0.00025	0.0002

Two broad conclusions can be drawn from these results. First, the simple baseline rule (BMR) yields a very similar level of welfare to the rule that completely stabilises inflation (FPS). This is in line with findings of Schmitt-Grohé and Uribe (2004a) who find that whether the central bank

(32) Bank capital shocks are modelled as innovations to **(35)** with a standard deviation of 0.007. This calibration implies that output is largely driven by technology shocks: only 5% of the forecast error variance decomposition is due to bank net worth shocks. Financial variables are more strongly affected by this shock. Roughly 12% of forecast error variance is due to the net worth shock.

targets inflation strongly or weakly has only small effects on welfare, provided the rule yields a determinate equilibrium. Second, while optimal policy tolerates some deviation of inflation from its steady-state rate, these departures tend to be extremely small.[(33)]

This point can be made a different way by comparing the impulse responses to a bank capital shock under the FPS and OMR rules. As Chart 5 in Appendix B shows, the optimal response to the bank capital shock is for the central bank to induce a very modest amount of inflation on impact. Thereafter, inflation undershoots its steady-state level. This feature of optimal policy under commitment is familiar from the studies of Steinsson (2003) and Woodford (2003). The initial rise in inflation implies a lower real interest rate, which stimulates spending and strengthens labour demand relative to the case where inflation is fully stable. Asset prices therefore fall by less. This helps mitigate the adverse effect of the shock on entrepreneurs' incentives, allowing them to pledge a greater fraction of their projects' expected returns to outsiders. Quantitatively, however, the differences between the OMR and FPS rules are barely noticeable for most of the variables in the model.

This finding is complimentary to the results of Faia and Monacelli (2005), who argue that a policy of strict inflation targeting is the welfare maximising policy in the financial accelerator model of Bernanke *et al* (2000).[(34)] Assigning a non-trivial role for banks need not therefore materially affect the properties of optimal monetary policy. Another paper which shares a similar motivation to ours is Vlieghe (2005), which examines optimal monetary policy in a monetised, sticky price version of Kiyotaki (1998). The degree of inflation volatility found by Vlieghe (2005) under the optimal Ramsey plan is similar to that found above. But, in contrast to what we find, this small amount of inflation volatility is associated with much lower volatility in output than under full price stability.

(33) The table shows that it is crucial to account for the average levels of consumption $E(C)$ and labour $E(N)$ when capturing the welfare effects of monetary policy rules. For shocks to bank capital, both the BMR and OMR induce a smaller standard deviation of consumption and labour relative to full price stability. However, it is the fact the optimal rule increases the average level of consumption and the baseline rule decreases the average level of consumption that accounts for the welfare ranking.

(34) Note that unlike Faia and Monacelli (2005), however, we do not limit ourselves to a grid search over the parameters in a simple interest rate rule responding to inflation, asset prices and output.

8.4 Sensitivity analysis

The policy prescriptions from calibrated models may be sensitive to specific modelling assumptions and the particular choice of parameter values that have been adopted. In this section, we therefore consider two sensitivity exercises. The first pertains to the measure of social welfare adopted by the policymaker. The second to the severity of the moral hazard problem in the banking sector.

The choice of social welfare function in a model with heterogenous agents is non-trivial. Here, we consider the implications of allowing for non-zero weights on entrepreneurs' and bankers' utilities in the social welfare function. The table below summarises our results, with ω_h, ω_e and ω_b corresponding to the welfare weights attached to households', entrepreneurs' and bankers' respective utilities. For each set of weights, we recompute the optimal monetary policy rule, assuming that the dynamics of the model are driven solely by bank capital shocks. The final column reports the standard deviation of inflation for some arbitrarily chosen weights.[35] Our results suggest that the desirability of low inflation volatility in this economy is robust to alternative configurations of the social welfare function. Only in the extreme case where bankers' utility is the sole argument of the social welfare function does the optimal volatility of inflation increase significantly.

SENSITIVITY TO WELFARE WEIGHTS

case	ω_h	ω_e	ω_b	$SD(\pi)$
baseline	1	0	0	0.0004
1	1	0.2	0.05	0.0004
2	1	0.4	0.1	0.0004
3	1	0.8	0.2	0.0004
4	1	1	1	00005
5	0	0	0	00015

We next consider how the severity of the moral hazard problem in the banking sector affects our

(35) Recall that, unlike households who are assumed to be risk-averse, both entrepreneurs and bankers have risk-neutral preferences. Risk neutrality implies that these agents care only about the expected value of their consumption strips.

results. We calibrate higher moral hazard by increasing the monitoring cost parameter c. The logic of our model implies that a high moral hazard banking sector will be required to hold a bigger financial stake in the projects they are monitoring. And we find that raising the cost of monitoring from 3% to 5% of the scale of the project increases the required capital-asset ratio in the banking sector from 10% to 15% (in steady state). This has a neglible impact on the dynamics of inflation, however: the standard deviation of inflation under the recomputed optimal rule remains at 0.0004.

9 Conclusion

We have studied an economy in which information frictions give rise to a non-trivial role for banks in intermediating funds, and for bank capital as a key determinant of overall loan supply. These credit market frictions are embedded in a dynamic general equilibrium setting with nominal price rigidities. These frictions are shown to have a significant impact on the dynamic properties of the model, relative to the benchmark of a standard sticky price model. In particular, shocks to productivity, bank net worth, and monetary policy have an amplified and more persistent effect on output than in the case where credit market frictions are switched off.

The main results of the paper are as follows. First, the model provides little rationale for targeting either asset prices or credit growth. We find that simple rules augmented to include a response to these variables perform poorly in welfare terms, relative to a policy of strict inflation targeting. Second, the optimal monetary policy – defined as the policy which maximises the expected welfare of the representative household – does not fully stabilise inflation in response to shocks to technology and bank net worth. However, the amount of inflation volatility tolerated under the optimal policy is extremely small. This suggests that policies that work well in normal times are likely to continue working well in a situation where weak banks are limiting the expansion of credit. These results were derived from a stylised macroeconomic model that was calibrated to match certain features of the UK economy, however. And as with any such exercise, the results should be interpreted with caution.

One may wonder therefore to what extent the results are due to the particular calibration of the model. One response to this is that the near optimality of perfect price stability arises despite a calibration that arguably overstates the adverse impact of credit constraints. For instance, we have calibrated the model such that households hold one half of the capital stock in the steady state.

That allocation is far from the first best. It implies, for instance, that households' marginal product is roughly 20 times *smaller* than that of entrepreneurs. A more important concern would be that the framework on which this model is based – that of Holmstrom and Tirole (1997) – is incapable of generating really severe outcomes following shocks to bank capital. The relatively large shocks we consider in Sections 7 and 8 generated only a moderate decline in output. Whether or not our results are robust to alternative frameworks that feature a more prominent role for banks remains an open question that we wish to pursue in future research.

Appendix A: The no moral hazard reference model

In this appendix, we briefly describe a version of the model with financial frictions 'switched off', ie agents have complete information. Credit markets in this case equalise the marginal products of capital in the entrepreneurial and household sectors. Technically, giving agents symmetric information allows us to drop the incentive compatibility constraints **(9)** and **(11)** from the list of equilibrium conditions. Like households, banks and entrepreneurs in this case receive an expected return that is just sufficient to satisfy their participation constraints. The incentive to continually postpone consumption and accumulate net worth is therefore eliminated. And given linear utility, the exact time path of consumption and savings is indeterminate. Without loss of generality, we focus on the extreme case in which both the bank and entrepreneur accumulate zero net worth and consume just their endowments each period. The equilibrium conditions in this case are:

$$q_t\left(C_t^h\right)^{-\frac{1}{\sigma}} = \beta E_t\left(C_{t+1}^h\right)^{-\frac{1}{\sigma}}\left[(1-\delta)q_{t+1} + \upsilon_{t+1}G'\left(K_t - K_t^e\right)\right]$$

$$\lambda\left(K_t - K_t^e\right)^{\epsilon-1} = pR$$

$$\left(C_t^h\right)^{-\frac{1}{\sigma}} = \beta E_t r_t^d\left(C_{t+1}^h\right)^{-\frac{1}{\sigma}}$$

$$\chi(1-N_t)^{\psi} = X_t T_t(1-\gamma)\left(\frac{M_t}{N_t}\right)^{\gamma}\left(C_t^h\right)^{-\frac{1}{\sigma}}$$

$$\upsilon_t = T_t X_t \gamma\left(\frac{N_t}{M_t}\right)^{1-\gamma}$$

$$P_t = \left[\theta P_{t-1}^{1-\epsilon} + (1-\theta)\left(P_t^*\right)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}$$

$$\tilde{P}_t = (1-\theta)\left(\frac{P_t^*}{P_t}\right)^{-\epsilon} + \theta\left(\frac{P_{t-1}}{P_t}\right)^{-\epsilon}\tilde{P}_{t-1}$$

$$T_t M_t^{\gamma} N_t^{1-\gamma} = C_t^h + I_t$$

$$M_t = \frac{\lambda}{\epsilon}\left(K_{t-1} - K_{t-1}^e\right)^{\epsilon} + pRK_{t-1}^e$$

$$r_t^n = \left(\frac{1}{\beta}\right)^{1-\rho_r}\left(r_{t-1}^n\right)^{\rho}\pi_t^{(1-\rho_r)(1+\kappa)}e^{u_t}$$

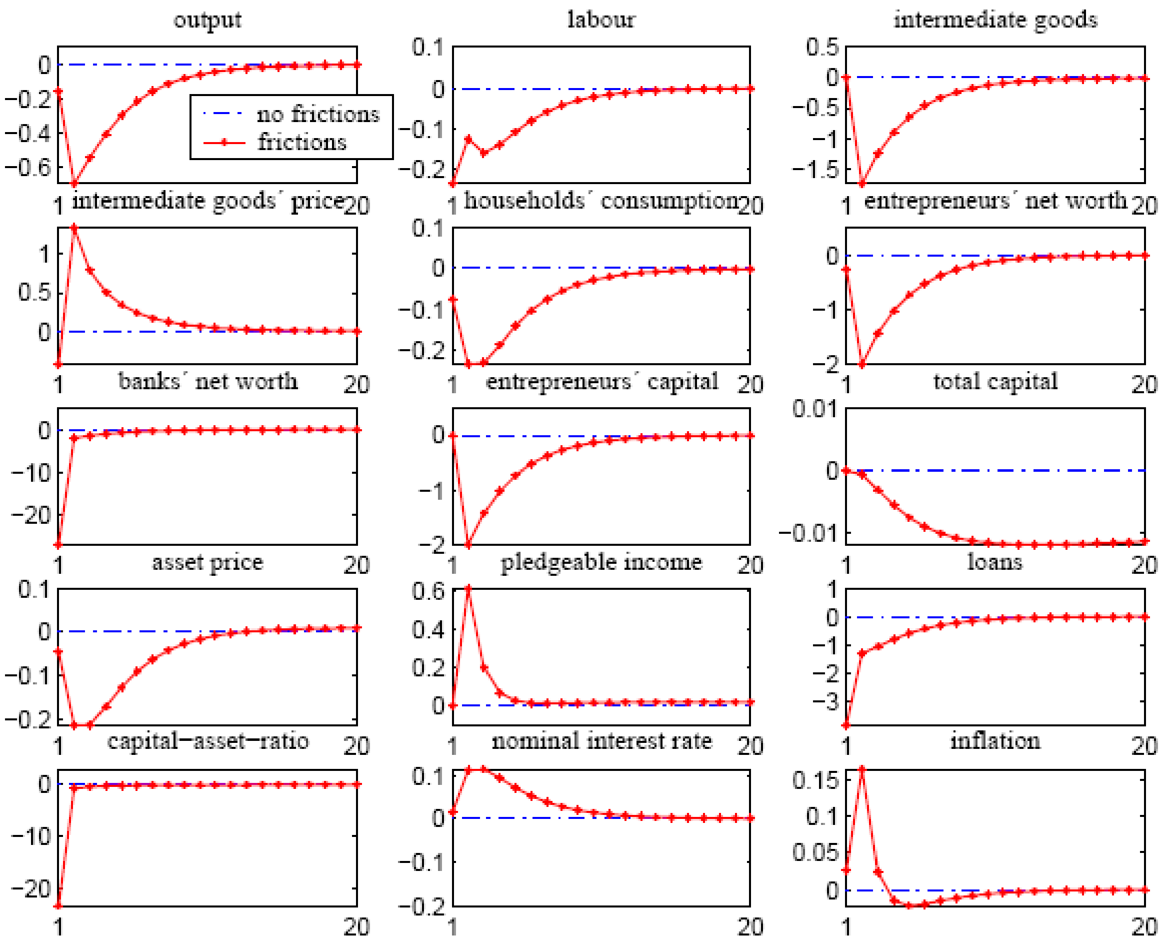
$$1 = \phi q_t \mu\left(\frac{I_t}{(1-\delta)K_{t-1}}\right)^{\phi-1}$$

$$K_t = \mu I_t^{\phi}\left((1-\delta)K_{t-1}\right)^{1-\phi} + (1-\delta)K_{t-1}$$

$$P_t^* = \frac{\epsilon}{\epsilon-1}\cdot\frac{E_t\sum_{i=0}^{\infty}(\theta\beta)^i\left(C_{t+i}^h\right)^{-\frac{1}{\sigma}}X_{t+i}P_{t+i}^{\epsilon}Y_{t+i}}{E_t\sum_{i=0}^{\infty}(\theta\beta)^i\left(C_{t+i}^h\right)^{-\frac{1}{\sigma}}P_{t+i}^{\epsilon-1}Y_{t+i}}$$

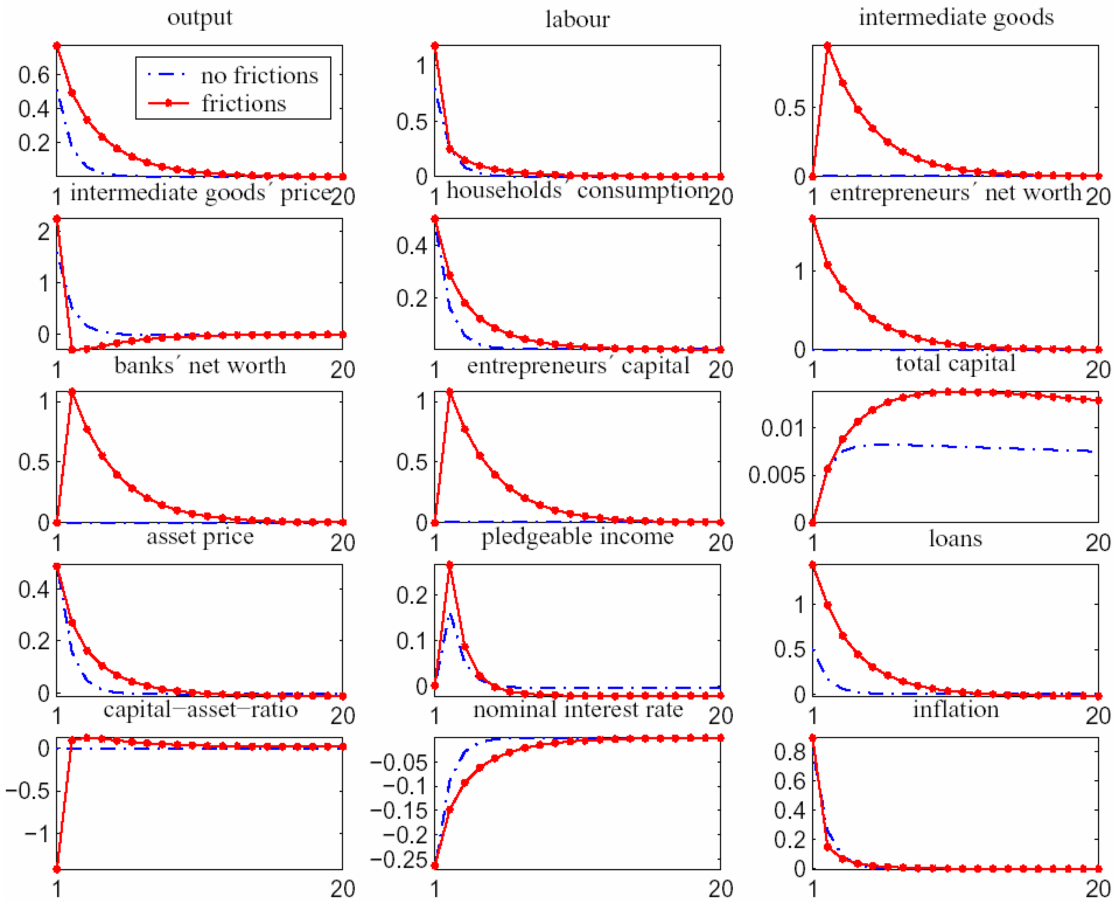
Appendix B: Charts

Chart 1: Dynamic responses to a bank capital shock



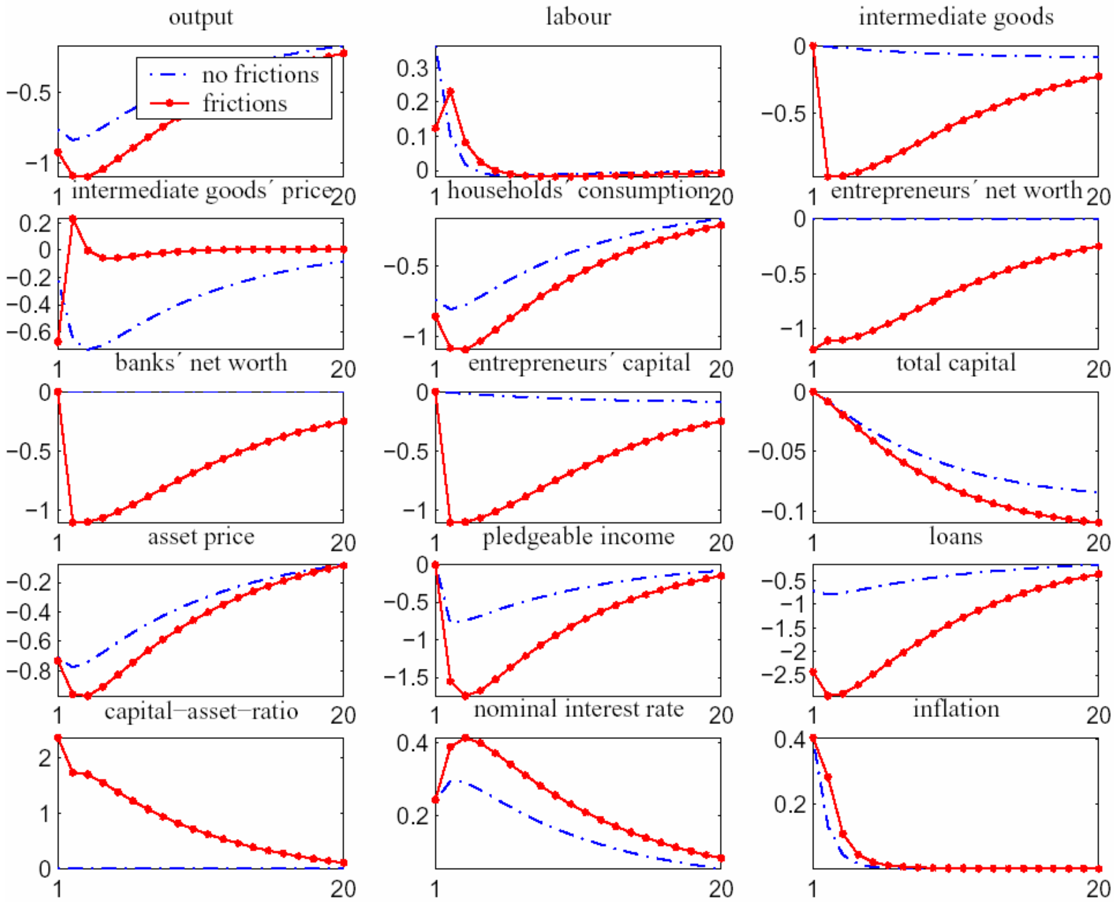
Notes: Responses to an exogenous 25% fall in bank capital. Responses are expressed as percentage deviations from the steady state. One time period is a quarter, such that the inflation rate corresponds to the quarterly change in the price level. We plot the deviations of the annualised nominal interest rate. The shock occurs in quarter 1.

Chart 2: Dynamic responses to a monetary policy shock



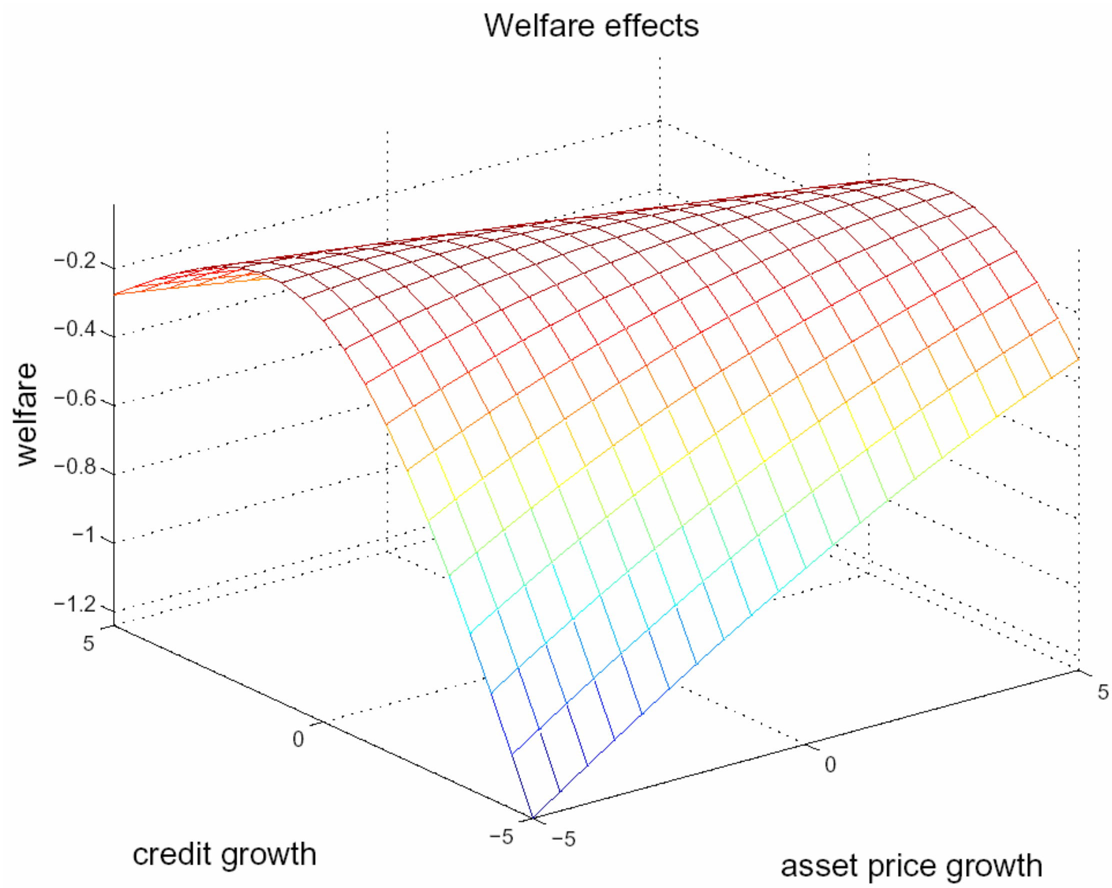
Notes: Responses to an exogenous 25 basis point fall in the annualised nominal interest rate. The timescale along the horizontal axis represents quarters. The shock occurs in quarter 1.

Chart 3: Dynamic responses to a technology shock



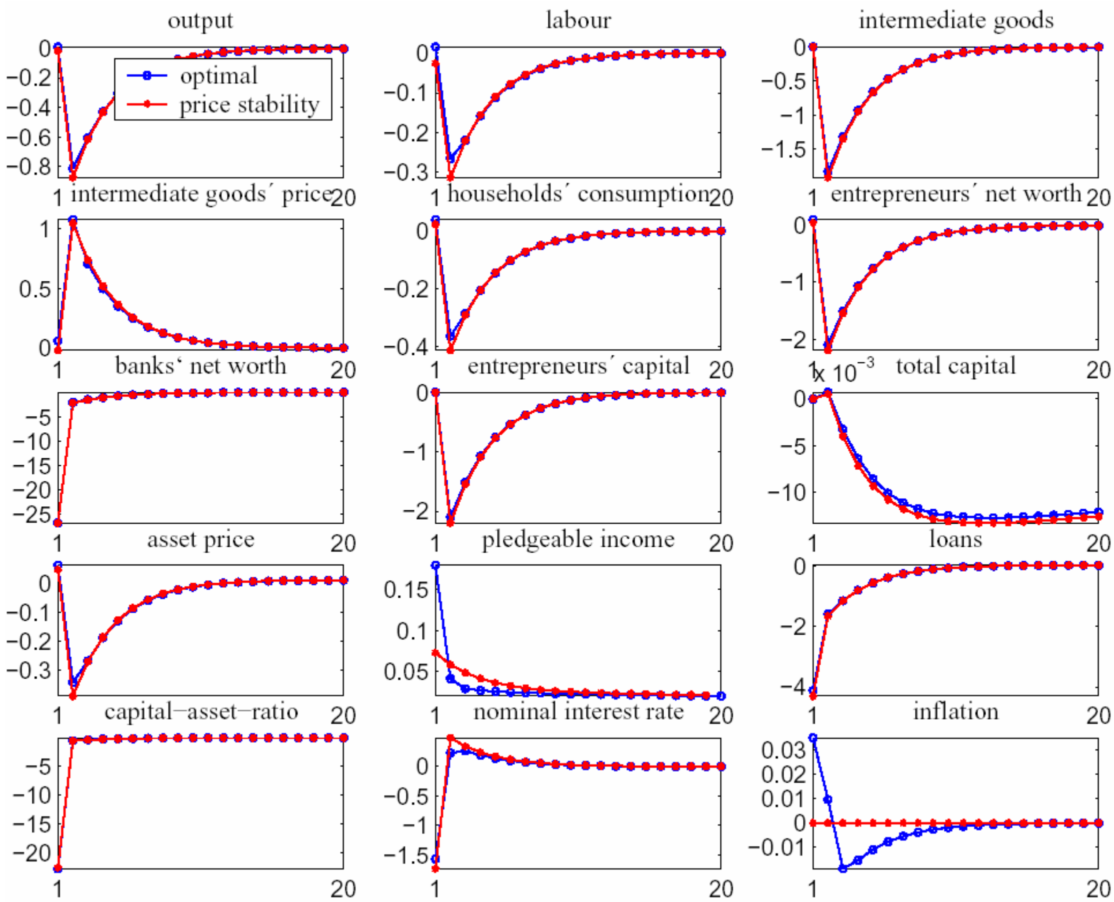
Notes: Responses to an exogenous 1% fall in the level of technology, with an autocorrelation of 0.9. The timescale along the horizontal axis represents quarters. The shock occurs in quarter 1.

Chart 4: Welfare effects of targeting asset prices and credit growth



Notes: The chart plots -100ξ as a function of the coefficients on credit growth and asset price growth in the central bank's policy rule.

Chart 5: Dynamic responses to a bank capital shock under the optimal rule and the price stability rule



Notes: Responses to a 25% fall in bank capital. The timescale along the horizontal axis represents quarters. The shock occurs in quarter 1.

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