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Imperfect credit markets: implications for monetary policy

Gertjan W Vlieghe

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Gertjan W Vlieghe[1]

Abstract

I develop a model for monetary policy analysis that features significant feedback from asset prices to macroeconomic quantities. The feedback is caused by credit market imperfections, which dynamically affect how efficiently labour and capital are being used in aggregate. I then analyse what implications this mechanism has for monetary policy. The paper offers three insights. First, the monetary transmission mechanism works not only via nominal rigidities but also via a reallocation of productive resources away from the most productive agents. Second, following an adverse productivity shock there is a dynamic trade-off between the immediate fall in output, which is an efficient response to the productivity fall, and the fall in output thereafter, which is caused by a reallocation of resources away from the most productive agents. The more the initial output fall is dampened with a temporary rise in inflation, the more the adverse future effects of the reallocation of resources are mitigated. Third, in a full welfare-based analysis of optimal monetary policy I show that it is optimal to have some inflation variability, even if the only shocks in the economy are productivity shocks. The optimal variability of inflation is small, but the costs of stabilising inflation too aggressively can be large.

JEL classification: E52, E44.

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Summary

This paper aims to address the following questions. If credit markets do not work perfectly, how does that affect the overall economy? Furthermore, if monetary policy can influence the level of economic activity in the short run, how should monetary policy be set optimally in the presence of credit market imperfections? This is a timeless issue, but of course the global financial crisis that started in 2007 has renewed interest in the topic of credit frictions and monetary policy.

It is thought that credit markets may not operate perfectly because of limitations on how much information a lender has about the quality of the borrower, or limitations on how well contracts between lenders and borrowers can be enforced. One consequence of such credit market imperfections might be that borrowing can only take place (or take place more cheaply) against collateral, such as land, buildings and machines. If that is the case, then changes in the value of collateral will affect the ability of firms and households to borrow. This could have important consequences for aggregate economic activity.

I consider in particular a case where there are two types of firms, those with high productivity and those with low productivity. Ideally, those with low productivity would lend all their resources to high productivity firms, so that high productivity firms can carry out all production. But when there are collateral constraints, some production is also carried out by low productivity firms. The total level of output is therefore determined by how much of the economy's productive resources are held by the high productivity firms. High productivity firms still end up borrowing from low productivity firms, but not as much as would be desirable in the absence of borrowing constraints.

Following a shock that reduces current output or the price of capital (which is used as collateral), the net worth of high productivity firms falls by more than the net worth of low productivity firms, because high productivity firms are highly leveraged. This means that high productivity firms can afford less capital for production in the following period. Because capital shifts to those with lower productivity, this reduces expected future returns on capital, which depresses the value of capital today, and exacerbates the initial redistribution of net worth. Output falls further in the subsequent period, as the economy's resources are now used much less efficiently. It takes time for the high productivity firms to rebuild their share of the capital stock, and output

is therefore depressed for many periods, even if the initial disturbance only lasted a single period.

How does this mechanism interact with monetary policy? First, the transmission mechanism of interest rates in this model works through sticky goods prices as well as a reallocation of resources to less efficient producers. So the output response to monetary shocks is larger than in a model without borrowing constraints. Second, when responding to productivity shocks, the monetary policy maker faces a trade-off. It is efficient for output to fall immediately following an adverse productivity shock. So, considered in isolation, there is no reason for a monetary policy maker to offset the initial output fall by letting inflation rise temporarily. But the presence of borrowing constraints means that there is a trade-off between short-term inflation and output fluctuations because of their effect on future output. The larger the immediate fall in output, the larger the reallocation of resources away from the most productive firms, which will lead to future output being inefficiently low. By allowing inflation to rise temporarily and thereby dampening the initial output fall, monetary policy can mitigate inefficiently large future output fluctuations in subsequent periods.

But monetary policy cannot accommodate inflation too far, as inflation expectations must remain anchored, and inflation variability itself is costly too. So this begs the question of how much inflation variability it is optimal to tolerate. I answer this question formally by assuming that the monetary policy maker maximises the welfare of the private sector. There are two frictions in the economy: credit market frictions and sticky prices. The policymaker has a single instrument available, the nominal interest rate, to offset the inefficiencies generated by these frictions. I find that the cost of responding to inflation too aggressively can be large, by creating excessive variability in output. By allowing only a small amount of inflation variability, policy can achieve a large reduction in output variability.

This trade-off between inflation variability and output variability is consistent with the remit of the Monetary Policy Committee, which aims for price stability partly as a precondition for the wider economic goal of economic stability. Thus in this paper we are able to provide a new aspect of the transmission mechanism that supports that remit.

1 Introduction

This paper[1] aims to address the following questions. If credit market imperfections are an important feature of the economy, how might they affect the economy's response to shocks? Furthermore, if monetary policy can influence real outcomes in the short run, how should monetary policy be set optimally in the presence of credit market imperfections? This is a timeless issue, although naturally the global financial crisis that started in 2007 has greatly renewed interest in the topic of credit frictions and monetary policy.

The model economy consists of *ex-ante* identical entrepreneurs who can produce intermediate goods using capital, which is in fixed supply (eg, land), a variable input (eg, inventories) and labour. Using the approach of Kiyotaki (1998), I assume that some entrepreneurs are more productive than others, but spells of high productivity do not last, and arrive randomly. In equilibrium, high productivity entrepreneurs borrow from low productivity entrepreneurs. Low productivity entrepreneurs therefore also become investors, and high productivity entrepreneurs become borrowers. The larger the net worth of the borrower, the more capital he can buy. Moreover, since capital serves as collateral as well as a factor of production, an increase in the value of capital will increase the net worth of a producer who already had some capital installed and will therefore allow him to invest more.

In this model economy the wealth distribution has important effects on aggregate output. Following a shock that reduces current output and/or the price of capital, the net worth of producers falls by more than the net worth of investors, because producers are highly leveraged. This means that producers can only afford to buy a lower share of the total capital stock for production in the following period. Because capital shifts to those with lower productivity, this reduces expected future returns, which depresses the value of capital today, and exacerbates the initial redistribution of wealth from producers to investors. Output falls further in the subsequent period, as the economy's resources are now used much less efficiently. It takes time for the producers to rebuild their share of the wealth distribution to its steady-state level, and output is therefore below its steady-state level for many periods, even if the initial disturbance only lasted a single period.

[1]It draws on work included in Vlieghe (2006).

To allow monetary policy to influence aggregate real outcomes, there has to be some friction, or non-neutrality, preventing instantaneous adjustment of prices, wages, debt contracts or asset portfolios. My approach is to assume that product prices cannot fully adjust.

How does the credit mechanism interact with monetary policy? First, the transmission mechanism of monetary shocks works through nominal rigidities as well as a reallocation of resources to less efficient producers. So the output response to monetary shocks is larger than in a model without credit imperfections. Moreover, the fall in output will manifests itself as a fall in measured total factor productivity, even though firm-level productivity has remained unchanged. Second, when responding to productivity shocks, the monetary policy maker faces a trade-off. It is efficient for output to fall immediately following an adverse productivity shock. So, considered in isolation, there is no reason for a monetary policy maker to offset the initial output fall by allowing inflation to rise temporarily. But the presence of credit frictions means that there is a dynamic trade-off between dampening the immediate fall in output by allowing inflation to rise temporarily, and reducing future falls in output. The larger the immediate fall in output, the larger the reallocation of resources away from the most productive agents, which will lead to future output being inefficiently low. By allowing inflation to rise temporarily and exploiting nominal rigidities to dampen the initial output fall, monetary policy can mitigate inefficiently large future output fluctuations.

The question is then how much inflation variability it is optimal to tolerate, because inflation variation also imposes costs on the economy in the form of deviations from a fully optimal path. This paper assumes that a monetary policy maker tries to maximise the welfare of the private sector agents. There are two frictions in the economy: credit market frictions and sticky prices. The policymaker has a single instrument available, the nominal interest rate, to offset the inefficiencies generated by these frictions. The key finding is that, by allowing a small amount of inflation variability, policy can achieve a large reduction in output variability. In other words, the cost of responding to inflation too aggressively can be large.

This trade-off between inflation variability and output variability is consistent with the remit of the Monetary Policy Committee, which aims for price stability partly as a precondition for the wider economic goal of economic stability.[2] Thus in this paper we are able to provide a new

[2]Specifically, the Bank's monetary policy objective is to deliver price stability - low inflation - and, subject to that, to support the

aspect of the transmission mechanism that supports that remit.

The remainder of this paper is organised as follows. Section 2 reviews the literature that relates to the questions studied in this paper. Section 3 presents the model in detail. Section 4 outlines the competitive equilibrium. Section 5 presents quantitative results. Section 6 describes how monetary policy should optimally be set. Section 7 analyses how sensitive the results are to variations in parameter choices and Section 8 concludes.

2 Related literature

There is a vast theoretical and empirical literature that investigates the qualitative and quantitative importance of credit frictions in the propagation of shocks. Gertler (1988) gives a useful overview of the literature up to that date, and Schiantarelli (1996) and Hubbard (1998) specifically review the empirical micro-evidence. A number of papers have embedded credit frictions into dynamic macro models. Carlstrom and Fuerst (1997) and (1998) use a costly state verification mechanism in an otherwise standard real business cycle model. They find that the effect of shocks on output can be either amplified or dampened, depending on which sector of the economy the financial constraint applies to. They also find that in their particular set-up there is either amplification or increased persistence, but not both. Kocherlakota (2000) constructs a highly simplified version of a credit constrained economy to show that the amount of amplification is related to the share in production of the collateralisable asset, and that the degree of amplification that can plausibly be achieved in his setting is small.

Kiyotaki and Moore (1997) also examine the effect of credit market frictions on business cycle dynamics, but instead of putting constraints on information, they put constraints on contracting, in the sense that borrowers cannot commit to repay. Following an adverse shock, there is a redistribution of capital from highly productive agents to less productive agents, and this results in an amplified and persistent drop in output following a small and temporary drop in productivity. Kiyotaki (1998) extends this mechanism by considering a situation where agents are not permanently stuck in a high or low productivity state, but their productivity state changes stochastically. This leads to added richness in the dynamics, as the persistence of the stochastic

Government's economic objectives including those for growth and employment. Price stability is defined by the Government's CPI inflation target of 2%.

productivity switching process affects the dynamics of aggregate output. Cordoba and Ripoll (2004) generalise the set-up of Kiyotaki and Moore (1997), and point out that substantial amplification of output fluctuations is a knife-edge type of result, that takes place only in a limited region of the parameter space. A set of papers that includes Kehoe and Levine (1993), Kocherlakota (1996), Alvarez and Jermann (2000) use a more general constraint on contracting, where multi-period and state-contingent financial contracts are possible as long as the borrower has the incentive to repay in every state of the world. However, earlier models generally feature exogenous income processes in order to make them tractable. Cooley, Marimon and Quadrini (2004) who embed this contracting structure in a model with production. They find that productivity shocks cause highly amplified output fluctuations when there are incentive constraints on financial contracting. Jermann and Quadrini (2002) propose a model with limitations on contracting where an endogenous firm size distribution interacts with borrowing constraints to produce aggregate fluctuations. Expectations about future productivity causes a rise in asset prices, which eases borrowing constraints. That concentrates capital in smaller, constrained firms, which are more productive due to diminishing returns to scale, leading to increased aggregate output.

There is some empirical literature that finds evidence for a Kiyotaki and Moore type mechanism of reallocation across different producers. Eisfeldt and Rampini (2005) find that the amount of capital reallocation across firms is procyclical, and that the dispersion of productivity across firms is countercyclical. These two facts are consistent with a model where capital needs to flow to the producers with the highest productivity, but these flows can more easily happen during cyclical upturns, when informational or contractual frictions are smaller. A second empirical paper that is directly relevant to this framework is Barlevy (2003), who shows that highly productive firms tend to borrow more, again consistent with a framework where credit needs to flow from low to high productivity firms, making highly productive firms highly indebted.

All the models discussed so far are real models. There is no role for money or monetary policy. Bernanke, Gertler and Gilchrist (1999) introduce the costly state verification mechanism into a New Keynesian business cycle model, ie, into a real business cycle framework with nominal rigidities added. They use this model to analyse macroeconomic dynamics resulting from a wide range of shocks including monetary policy shocks, and find that, compared to a version of the model that has no financial frictions, the investment response to shocks is amplified and more

persistent, leading to an amplified and more persistent response of aggregate output. Bernanke and Gertler (2001) then use the Bernanke, Gertler and Gilchrist (1999) framework to ask whether monetary policy should respond to asset prices as well as to inflation and the output gap. In particular, they investigate whether a monetary policy rule that includes asset prices performs better than one that does not. They find that there is very little benefit to be had, in terms of minimising an *ad hoc* loss function, from letting monetary policy makers respond to asset prices.

Gilchrist and Leahy (2002) analyse whether the optimal policy prescription changes when a credit mechanism of the type of Bernanke, Gertler and Gilchrist (1999) is an important feature of the economy. They conclude that in the case of a gradual productivity increase (which is akin to a demand shock, as the bulk of the productivity increase occurs in the future), it is sufficient for monetary policy simply to respond to inflation. But in the case of shocks to net worth, responding more strongly to inflation causes output to deviate further from its optimal path, so there is a trade-off between inflation and output variability. They conclude, as many others have done, that there is little benefit from monetary policy responding to asset prices, but they speculate that it may well pay to respond to net worth or the spread between risky and risk-free interest rates.

Iacoviello (2005) carries out a similar analysis, based on the credit frictions framework of Kiyotaki and Moore (1997), and also concludes that there is little benefit to be derived from monetary policy that responds directly to asset prices. Aikman and Paustian (2006) also combine imperfect credit markets with a New Keynesian model, and base their credit frictions on the banking model of Chen (2001). They examine the implication for optimal monetary policy. They find that credit frictions do not materially change the prescription for monetary policy, and the welfare costs of pursuing a policy of simple price stability is very small. Faia and Monacelli (2007) incorporate the mechanism of Carlstrom and Fuerst (1997) into a New Keynesian framework and evaluate the effect of changing the monetary policy rule on an approximation of welfare, rather than an *ad hoc* loss function. They find responding aggressively to inflation is the best prescription.

The current paper builds on these insights, and investigates the optimal path for the economy that a monetary policy maker can achieve, ie policy is not restricted to a simple rule, if the objective is welfare maximisation, the instrument is the nominal interest rate, and the economy features both nominal rigidities and a credit mechanism along the lines of Kiyotaki (1998).

3 The environment

The model features a basic credit frictions mechanism due to Kiyotaki (1998), which is extended to allow for endogenous labour supply, monopolistic competition and a role for monetary policy.

There is a continuum of entrepreneurs. They are identical in terms of preferences. Their production technology is also identical, up to a productivity factor, which randomly switches between high (α) and low (γ). Denote those who currently have high productivity 'producers', and those who currently have low productivity 'investors'. The productivity factor follows an exogenous Markov process with transition probability matrix

$$P = \begin{bmatrix} 1-\delta & \delta \\ n\delta & 1-n\delta \end{bmatrix} \quad \textbf{(1)}$$

so the probability of switching from high productivity to low productivity is δ, and the probability of switching from low productivity to high productivity is $n\delta$. This probability matrix implies that from any initial distribution, the distribution will converge to a stationary distribution with a ratio of productive to unproductive agents of n.

Producers maximise lifetime utility given by

$$\max_{c_t} E_0 \sum_{t=0}^{\infty} \beta^t \ln c_t \quad \textbf{(2)}$$

s.t. budget constraint,

$$c_t + x_t + q_t(k_t - k_{t-1}) + z_t l_t = \frac{y_t}{\varphi_t} + \frac{b_t}{r_t} - b_{t-1} \quad \textbf{(3)}$$

production technology,

$$y_t = \alpha \left(\frac{k_{t-1}}{\sigma}\right)^{\sigma} \left(\frac{x_{t-1}}{\eta}\right)^{\eta} \left(\frac{l_t}{1-\eta-\sigma}\right)^{1-\eta-\sigma} \quad \textbf{(4)}$$

and borrowing constraint

$$b_t \leqslant E_t q_{t+1} k_t \quad \textbf{(5)}$$

The variable c_t denotes consumption, x_t denotes a non-durable input (eg inventories), k_t denotes durable capital, z_t denotes the wage paid, l_t denotes the quantity of labour employed, b_t denotes the amount of real borrowing taken out at time t and repayable at time $t+1$, q_t is the price of capital, and r_t is the real interest rate payable on borrowing b_t.

It is assumed that producers do not consume their output directly, but sell it to a monopolistically competitive retailer, who then offers the diversified goods back to producers, investors and workers with a mark-up of φ_t. That means that one unit of output produced can be sold to retailers for $1/\varphi_t$. All variables are denominated in terms of a consumption index. Define a Dixit-Stiglitz (1977) aggregate of a continuum of differentiated goods of type $z \in [0, 1]$ each with price $p(z)$

$$c_t = \left[\int_0^1 c_t(z)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta}{\theta-1}} \quad \textbf{(6)}$$

The corresponding price index, defined as the minimum cost of a unit of the consumption aggregate, is defined as

$$p_t = \left[\int_0^1 p_t(z)^{1-\theta}\right]^{\frac{1}{1-\theta}} \quad \textbf{(7)}$$

For simplicity, it is assumed that inventories are costlessly created from the consumption aggregate, so that their relative price in terms of consumption is one.

Following Kiyotaki and Moore (1997), borrowing constraints are interpreted as follows: it is assumed that when an entrepreneur has installed some capital, he invests some specific skill into that capital to generate output. The total value of his project is therefore the next period resale value of the installed capital plus the value of the output that can be generated using his specific skill. But he cannot commit to investing his specific skill: once the capital is in place, he can always choose to walk away. Because of this inability to commit to full repayment, the investor will never lend more than the resale value of capital. It is assumed that, should the value of collateral fall short of what was expected at the time the loan was taken out, the entrepreneur still repays the borrowing in full, because by the time he finds out about the realisation of the aggregate shock, he has already produced, and no longer has the opportunity to walk away.[3] Also following Kiyotaki and Moore (1997), it is assumed that, after the initial uncertainty about aggregate productivity is resolved, agents assume that future aggregate productivity is constant. In other words, their decisions are assumed to be unaffected by aggregate uncertainty.

It is useful to define $u_t \equiv q_t - E_t \frac{q_{t+1}}{r_t}$, the user cost of a unit of capital.

[3]He could still have an incentive to walk away if the debt burden exceeds not only the value of his collateral, but exceeds the value of his collateral plus current output. It is assumed that shocks are never that large.

If we assume the borrowing constraint is binding, which will be verified later, we can rewrite the budget constraint as

$$c_t + x_t + u_t k_t + z_t l_t = \frac{\alpha}{\varphi_t}\left(\frac{k_{t-1}}{\sigma}\right)^{\sigma}\left(\frac{x_{t-1}}{\eta}\right)^{\eta}\left(\frac{l_t}{1-\eta-\sigma}\right)^{1-\eta-\sigma} + q_t k_{t-1} - b_{t-1} \quad \textbf{(8)}$$

To solve this, we break up the problem into two steps. First, given last period's capital and intermediate goods, what is the optimal demand for labour?

$$\pi_t = \max_{l_t}\left\{\frac{\alpha}{\varphi_t}\left(\frac{k_{t-1}}{\sigma}\right)^{\sigma}\left(\frac{x_{t-1}}{\eta}\right)^{\eta}\left(\frac{l_t}{1-\eta-\sigma}\right)^{1-\eta-\sigma} - z_t l_t\right\} \quad \textbf{(9)}$$

It can be shown that the maximised profit after paying for labour input is

$$\pi_t = (\eta+\sigma)\frac{y_t}{\varphi_t} \quad \textbf{(10)}$$

For the second step of the producer's problem, we analyse what combination of capital and inventories he should buy to minimise expenditure, given a desired level of profits.[4]

$$m_t = \min_{k_t, x_t}\{u_t k_t + x_t\} \quad \textbf{(11)}$$

$$s.t. E_t \pi_{t+1} \geqslant \overline{\pi} \quad \textbf{(12)}$$

Let λ_t denote the Lagrangean multiplier on the profit constraint. Substituting the optimal level of labour demanded into the production function, the first-order conditions become

$$u_t = E_t\left\{\lambda_t\left(\frac{\alpha}{\varphi_{t+1}}\right)^{\frac{1}{\eta+\sigma}} z_{t+1}^{-\frac{1-\eta-\sigma}{\eta+\sigma}}\left(\frac{\sigma}{\eta}\right)^{\frac{\eta}{\eta+\sigma}}\left(\frac{x_t}{k_t}\right)^{\frac{\eta}{\eta+\sigma}}\right\} \quad \textbf{(13)}$$

$$1 = E_t\left\{\lambda_t\left(\frac{\alpha}{\varphi_{t+1}}\right)^{\frac{1}{\eta+\sigma}} z_{t+1}^{-\frac{1-\eta-\sigma}{\eta+\sigma}}\left(\frac{\sigma}{\eta}\right)^{-\frac{\sigma}{\eta+\sigma}}\left(\frac{x_t}{k_t}\right)^{-\frac{\sigma}{\eta+\sigma}}\right\} \quad \textbf{(14)}$$

This can be simplified to

$$u_t = \frac{\sigma x_t}{\eta k_t} \quad \textbf{(15)}$$

Note that λ_t is the resource cost of another unit of profit, or, in other words, $1/\lambda_t$ is the return on investment. For convenience we define this as a new variable:

$$r_t^p \equiv E_t\left\{\left(\frac{\alpha}{\varphi_{t+1}}\right)^{\frac{1}{\eta+\sigma}} z_{t+1}^{-\frac{1-\eta-\sigma}{\eta+\sigma}} u_t^{-\frac{\sigma}{\eta+\sigma}}\right\} \quad \textbf{(16)}$$

In a similar way, we can also calculate the *ex post* return from having used resources x_{t-1}, k_{t-1} and l_t in the optimal combination given u_{t-1}, z_t and φ_t. This return is equal to:

[4]The actual level of profits is irrelevant to the optimisation problem given the constant returns to scale technology.

$$r_{t-1}^{p} \equiv \left\{ \left(\frac{j}{\varphi_t} \right)^{\frac{1}{\eta+\sigma}} z_t^{-\frac{1-\eta-\sigma}{\eta+\sigma}} u_{t-1}^{-\frac{\sigma}{\eta+\sigma}} \right\} \quad \textbf{(17)}$$

In this equation, $j = \alpha, \gamma$ depending on whether the entrepreneur had high or low productivity in the previous period.

Substituting the optimal labour demand and factor demand conditions into the production function, we can now write the budget constraint as

$$c_t + m_t = r_{t-1}^{j} m_{t-1} + q_t k_{t-1} - b_t \quad \textbf{(18)}$$

This can be interpreted as a savings problem with uncertain returns (eg Sargent (1987)). The optimal decision rules for consumption and investment are linear in wealth:

$$c_t = (1-\beta)(r_{t-1}^{j} m_{t-1} + q_t k_{t-1} - b_t) \quad \textbf{(19)}$$

$$m_t = \beta(r_{t-1}^{j} m_{t-1} + q_t k_{t-1} - b_t) \quad \textbf{(20)}$$

3.1 Investors

Let lower-case variables with a prime denote the choices of an individual investor. The labour demand conditions facing the agents with low productivity, ie, the investors, are the same as those for the producers, so the maximised profits after paying the wage bill are

$$\pi_t' = (\eta + \sigma) \frac{y_t'}{\varphi_t} \quad \textbf{(21)}$$

The second step of the problem, minimising the expenditure on x_t' and k_t', is solved by maximising

$$\min_{x_t', k_t'} \left(q_t - E_t \frac{q_{t+1}}{r_t} \right) k_t' + x_t' \quad \textbf{(22)}$$

$$s.t. \pi_{t+1}' \geqslant \overline{\pi} \quad \textbf{(23)}$$

Using our earlier definition of u_t, this problem is again parallel to that faced by producers, except that the rate of return for investors is

$$r_t^{i} \equiv E_t \left\{ \left(\frac{\gamma}{\varphi_{t+1}} \right)^{\frac{1}{\eta+\sigma}} z_{t+1}^{-\frac{1-\eta-\sigma}{\eta+\sigma}} u_t^{-\frac{\sigma}{\eta+\sigma}} \right\} \quad \textbf{(24)}$$

Just as for producers, the decision rule for consumption and investment of investors is therefore also linear in wealth with the same coefficients.

3.2 Retailers

Retailers buy output and use a costless technology to turn output goods into differentiated consumption or input goods, which they sell onwards. The separation of producers and retailers is a modelling choice similar to Bernanke, Gertler and Gilchrist (1999) and is chosen to introduce monopolistic competition while maintaining tractable aggregation of producers. If producers operate directly in monopolistically competitive markets, they no longer face constant returns to scale at the firm level, and their optimisation problem will no longer yield the linear decision rules that are needed for tractable aggregation. Per period real profits for the retailers are given by

$$\Pi_t(p_t(z)) = \frac{(p_t(z) - p_t^p)}{p_t} y_t^R(z) \tag{25}$$

where p_t^p is the nominal price of output goods, so that $\frac{p_t^p}{p_t} = \frac{1}{\varphi_t}$. In other words, φ_t is the retail sector's average mark-up. Retailer output is denoted $y_t^R(z)$.

Demand for each retailer's output is given by

$$y_t^R(z) = \left(\frac{p_t(z)}{p_t}\right)^{-\theta} Y_t^R \tag{26}$$

where Y_t^R is aggregate demand for retail goods, which is given by

$$Y_t^R = \left[\int_0^1 y_t^R(z)^{\frac{\theta-1}{\theta}} dz\right]^{\frac{\theta}{\theta-1}} \tag{27}$$

In the baseline model, it is assumed that some fraction κ of retailers must set their price, $p_{2,t}(z)$, one period in advance, while the remainder can change their price, $p_{1,t}(z)$ each period. Each type of retailer maximises profits, leading to the following first-order conditions:

$$\frac{p_{1,t}(z)}{p_t} = \frac{\theta}{\theta-1}\frac{1}{\varphi_t} \tag{28}$$

$$E_{t-1}\left\{\Lambda_{t-1,t}\frac{Y_t^R}{p_t^{-\theta}}\left[\frac{p_{2,t}(z)}{p_t} - \frac{\theta}{\theta-1}\frac{1}{\varphi_t}\right]\right\} = 0 \tag{29}$$

The term $\Lambda_{t-1,t}$ is a discount factor applied at time $t-1$ to profits earned at time t. It is assumed that retailers are owned by workers, so it is the workers' discount factor that is relevant here. The

aggregate price level evolves according to:

$$p_t = \left[(1-\kappa)p_{1,t}^{1-\theta} + \kappa p_{2,t}^{1-\theta}\right]^{\frac{1}{1-\theta}} \quad \textbf{(30)}$$

I will end up working with a log-linearised model, and it is convenient to note already that the first-order conditions for retailer profit maximisation, combined with the evolution of the aggregate price level, once linearised, will give the following pricing equation:

$$\widehat{\pi}_t = E_{t-1}\widehat{\pi}_t - \frac{1-\kappa}{\kappa}\widehat{\varphi}_t \quad \textbf{(31)}$$

where $\widehat{x_t}$ denotes log deviations from the steady state.

In an extension of the model, I consider an environment where retailers face a quadratic cost of changing their price, following Rotemberg (1982). This is implemented by adding a cost term to the per period profit function so that it becomes:

$$\Pi_t(p_t(z)) = \frac{(p_t(z) - p_t^p)}{p_t} y_t^R(z) - \frac{\psi}{2}\left(\frac{p_t(z)}{p_{t-1}(z)} - 1\right)^2 \quad \textbf{(32)}$$

Adjustment cost in prices is convenient to work with in welfare analysis because we can consider equilibria where all agents set the same price. This stands in contrast to the Calvo (1983) staggered price formulation, in which different producers charge different prices, which significantly complicates aggregation. Schmitt-Grohe and Uribe (2004) use the quadratic cost formulation for welfare analysis.

This leads to the following aggregate pricing equation, or Phillips curve:

$$\begin{aligned}\pi_t(\pi_t - 1) = {} & \beta E_t\left[\frac{u_{w,t+1}}{u_{w,t}}\pi_{t+1}(\pi_{t+1}-1)\right] \\ & + \frac{\theta-1}{\psi}\left(y_t + y_t'\right)\left(\frac{\theta}{\theta-1}\frac{1}{\varphi_t} - 1\right) \quad \textbf{(33)}\end{aligned}$$

Retailers are owned by workers, so it is their marginal utility $u_{w,t}$ that determines how future profits are to be discounted. I consider only symmetric equilibria where all retailers set the same price.

3.3 Workers

There is a set of agents in the economy who have no access to productive technology, but who can work for the producers and investors. They derive utility from consumption and leisure, and their objective is to maximise

$$\max_{c_t, l_t} \sum_{t=0}^{\infty} \beta^t \ln \left(c_t - \frac{\chi}{1+\tau} l_t^{1+\tau} \right) \quad \textbf{(34)}$$

$$s.t. c_t^w + \frac{b_t^w}{r_t} = z_t l_t + b_{t-1}^w + \Pi_t \quad \textbf{(35)}$$

where l_t is the fraction of time spent on work, and Π_t are the profits from the retail sector, which is owned by the workers.[5] Setting the workers' marginal utility of leisure equal to their marginal utility of consumption, the labour supply decision is

$$z_t = \chi l_t^{\tau} \quad \textbf{(36)}$$

It is to be verified later that the interest rate on bonds is below the rate of time preference $1/\beta$. This implies that, near the stationary state, the workers will choose not to hold any bonds, and simply consume their wage and profit income. Their consumption therefore becomes:

$$c_t^w = z_t l_t + \Pi_t \quad \textbf{(37)}$$

3.4 Monetary authorities

Prices in the economy are set in money terms. I assume such a 'cashless limit' (Woodford (2003)) economy here, so that money balances, and therefore the central bank's balance sheet, approach zero. Given this assumption, it is a reasonable approximation to omit money from the agents' utility function and budget constraint. A similar approach is used, for example, by Aoki (2001) who also omits money balances from a model that allows the central bank to set nominal interest rates. The central bank simply announces the one-period nominal interest rate R_t, which

[5] Paying profits to the workers makes the model very tractable, but strictly speaking the workers would not want to own the retailers in equilibrium, because they do not want to save, as will be shown later. They are prevented from selling the retailers by assumption. An alternative would be to consider retailers as consuming agents in their own right, ie, give the retailers a utility function, so that they themselves could consume the profits from their technology of diversifying goods. Just like the workers, retailers would not want to save in equilibrium due to the low interest rate, and they would not be able to borrow against future profits because there is no collateral. So they would simply consume the profits each period. The model results would therefore be identical, but come at the expenses of more complexity.

means that it stands ready to deposit or lend any amount[6] the private sector desires at this rate, subject to a (infinitely small) spread. The spread ensures that the private sector will attempt to clear the loan market first without resorting to the central bank. No private agent would be willing to borrow at a rate higher than that offered by the central bank, and no private agents would deposit funds that receive a lower return than that offered by the central bank. This arbitrage mechanism is similar to the way actual monetary policy operates in countries such as New Zealand, Canada, the United Kingdom and Scandinavian countries, although in practice the spreads are of course not infinitely small. This environment gives rise to an arbitrage condition between real and nominal rates of return, evaluated using the marginal utility of the investors.

$$E_t \left\{ \beta R_t \frac{P_t}{P_{t+1}} \frac{1}{c'_{t+1}} \right\} = E_t \left\{ \beta r^i_t \frac{1}{c'_{t+1}} \right\} \quad \textbf{(38)}$$

The central bank is assumed to follow a simple rule for setting monetary policy,[7] by responding to current inflation. There are also random deviations from the rule, which we will interpret as monetary policy shocks.

$$\frac{R_t}{r^i} = \pi_t^{\lambda} \exp(\varepsilon_t^R) \quad \textbf{(39)}$$

4 Competitive equilibrium

We now look for a competitive rational expectations equilibrium for this model economy. This will consist of aggregate decision rules for consumption, investment, labour supply and asset holdings, and aggregate laws of motion so that market clearing and individual optimality conditions hold. As will be shown, the distribution of wealth can be summarised by the share of wealth owned by producers.[8] Let capital letters denote aggregate variables. The market clearing conditions are that

$$B_t + B'_t + B^W_t = 0 \quad \textbf{(40)}$$

[6]The central bank does not have better enforcement mechanisms for the collection of loan repayments than does the private sector. It will therefore not lend any funds to a producer who is already at the binding borrowing constraint.

[7]Sargent and Wallace (1975) showed that if the interest rate follows an exogenous path, the price level is indeterminate. However, McCallum (1981) showed that the price level can be determinate under an interest rate rule if interest rates respond to a nominal variable, such as the price level in his paper, or inflation in my case.

[8]In model simulations I will consider a stochastic process for aggregate productivity. Because each entrepreneur's problem collapses to a linear savings problem with log consumption, the fact that future returns are uncertain does not affect the consumption and savings decision. Where uncertainty might affect decision rules is that borrowers may not want to borrow up to the borrowing limit if uncertainty about future asset prices is large. In other words, they might not leverage to the maximum permitted, to reduce the risk of leveraged loss under an adverse aggregate shock. Similar to Iacoviello (2005) and Kiyotaki (1998), I only consider an approximation of the model where the borrowing constraint binds at all times.

$$K_t + K'_t = \overline{K} \tag{41}$$

and that labour supply equals labour demand. The market clearing condition goods is then: [9]

$$Y_t^R = Y_t + Y'_t \tag{42}$$

$$C_t + C'_t + X_t + X'_t + C_t^w = \frac{Y_t + Y'_t}{\varphi_t} + \Pi_t \tag{43}$$

Aggregate retailers' profits will be equal to:

$$\Pi_t = \left(1 - \frac{1}{\varphi_t}\right)\left(Y_t + Y'_t\right) - \frac{\psi}{2}\left(\pi_t - 1\right)^2 \tag{44}$$

where the quadratic term is omitted in the case of staggered pricing. Note that the individual decision rules for consumption and investment are all linear, so that we can simply sum them to obtain aggregate decision rules and laws of motion. Each agent consumes a fraction $1 - \beta$ of their wealth and reinvests a fraction β of their wealth.

The following is asserted, to be verified later: we consider equilibria near a steady state where the investors hold some capital for their own production. This has two implications. First, investors must then be indifferent between holding capital for production and bonds, so that they equalise the expected return to each

$$r_t^i = r_t \tag{45}$$

Second, because we have shown that

$$r_t^p = \left(\frac{\alpha}{\gamma}\right)^{\frac{1}{\eta+\sigma}} r_t^i > r_t^i \tag{46}$$

it follows that the borrowing constraint is indeed binding near the steady state, since producers achieve a larger return on their own productive investment than the interest rate they have to pay on the bonds they issue.

Next, it is useful to define aggregate wealth as the quantity of output available for consumption or reinvestment, ie, after paying the wage bill.

$$W_t = (\eta + \sigma)\frac{Y_t + Y'_t}{\varphi_t} + q_t\overline{K} \tag{47}$$

We also define the share of wealth held by producers as s_t. We can now write a law of motion for aggregate wealth as

$$W_{t+1} = \left[r_t^p s_t + r_t^i(1 - s_t)\right]\beta W_t \tag{48}$$

[9] This clearing condition holds only in a neighbourhood of the steady state for the staggered pricing model, due to the different aggregators for consumers and retailers. But for the quadratic adjustment cost model, all retailers choose the same output level so the aggregation is exact

Using the Markov-process for the way agents switch between having high and low productivity, the law of motion for the share of wealth can be written as

$$s_{t+1} = \frac{(1-\delta)\widetilde{\alpha} s_t + n\delta\widetilde{\gamma}(1-s_t)}{\widetilde{\alpha} s_t + \widetilde{\gamma}(1-s_t)} \quad \textbf{(49)}$$

where $\widetilde{\alpha} = \alpha^{\frac{1}{\eta+\sigma}}$ and similarly for $\widetilde{\gamma}$.

I now want to consider an aggregate disturbance to productivity. I achieve this by multiplying α and γ by a productivity disturbance ε_P. The assumed stochastic process for the productivity disturbance is that its log follows an autoregressive process with a normally distributed shock:

$$\widehat{\varepsilon}_{P,t+1} = \rho\widehat{\varepsilon}_{P,t} + \nu_{t+1} \quad \textbf{(50)}$$

The full list of model equations is listed in the appendix for ease of reference.

5 Model solution

5.1 Dynamics

The system of difference equations that constitute the full model is log-linearised around the steady state, and solved using the Schur decomposition as described in Soderlind (1999), to write the non-predetermined variables as a linear function of the predetermined variables and the shocks. The steady state is the level that aggregate variables tend to when there are no aggregate shocks. Associated with these levels for aggregate variables is a stationary wealth distribution summarised by the share of wealth owned by producers, $s_t = \overline{s}$.

We consider only non-explosive, determinate solutions. For a solution to be determinate (following Blanchard and Kahn (1980)), it is necessary for the number of eigenvalues outside the unit circle to correspond to the number of non-predetermind variables. In the calibration that I use this is indeed the case, for a monetary policy rule that responds to inflation with a coefficient greater than one.

5.2 Steady state

It is instructive to consider the expression for the steady-state interest rate:

$$r = \frac{1}{\beta}\left(\frac{\widetilde{\gamma}}{\widetilde{\alpha}s + \widetilde{\gamma}(1-s)}\right) < \frac{1}{\beta} \tag{51}$$

Since $s < 1$, the real interest rate is strictly lower than the (inverse of) the rate of time preference. At these low interest rates, workers will not wish to save, so workers choose not to participate in asset markets. This proves the earlier assertion that workers simply consume their wage and profit income in each period.

5.3 Frictionless model

Before turning to the properties of the full model, I show what the properties of the model would be without binding borrowing constraints. In that case, the efficient allocation would always be reached, in the sense that the most productive agents would always hold the entire capital stock. It can be shown that the law of motion for aggregate output is:

$$Y_{t+1} = \varepsilon_{P,t+1}^{\frac{\tau+1}{\tau+\eta+\sigma}} (Y_t)^{\frac{\eta(\tau+1)}{\tau+\eta+\sigma}} c \tag{52}$$

where c denotes a constant term that is a function of the model parameters. This implies that output dynamics are entirely driven by the exogenous process for aggregate productivity and lagged output. There is no feedback from any net worth or asset price variable in the model. The equations for the asset price and wealth are

$$q_t = \frac{\sigma\beta}{\varphi\overline{K}(1-\beta)} Y_t \tag{53}$$

and

$$W_t = \frac{\eta + \sigma - \eta\beta}{\varphi(1-\beta)} Y_t \tag{54}$$

So asset prices and entrepreneurial wealth are simply proportional to output.

5.4 Calibration

The model contains 13 parameters. Some of the parameters are standard, in the sense that they can be chosen to match key steady-state ratios in the economy. Other parameters, in particular

those specific to the credit mechanism, are more difficult to assign values to. The calibration I have chosen is designed to show how the mechanism might work, not how it most likely does work, as there is little guidance from actual observation in choosing plausible values for these parameters. Table A shows the parameter values chosen for the baseline model.

Table A: Calibrated parameter values for the baseline model

Parameter	Assigned value
β	0.99
η	0.1
σ	0.3
τ	0.5
χ	0.29
γ	0.12
κ	0.5
θ	11
λ	1.5
α/γ	1.034
n	0.0073
δ	0.5

The model is calibrated so that each period can be interpreted as one quarter of a year. The discount factor $\beta = 0.99$ is a standard choice in many general equilibrium macromodels (see eg, Cooley and Prescott (1995)). While in this model such a discount factor will lead to a lower real interest rate compared with models where there is perfect enforcement or commitment, the difference is small under the baseline parameterisation: the steady-state annual real interest rate is just under 4%. The values for $\eta, \sigma, \tau, \chi, \gamma$ were chosen to achieve a capital to output ratio of 10, a labour share in output of 0.6, hours worked of 0.31 as a fraction of total available time, and a wage elasticity of labour supply of 2, values very close again to those in Cooley and Prescott (1995) and subsequent literature. The monetary policy reaction function parameter λ is set at the value used by Taylor (1993), although the reaction function does not have exactly the same form. The rule used in this paper is certainly too simplistic to be realistic, and is used to illustrate the basic mechanisms of the model. The elasticity parameter θ determines a steady-state net mark-up for consumption goods of 0.10, corresponding to the empirical findings by Basu and Fernald (1997). The share of prices that are set one period in advance, κ, is set at 0.5. In the extended model, with a cost of price adjustment, there is a cost parameter ψ which is set as follows. Because the linearised Rotemberg pricing equation is identical to a linearised pricing equation with Calvo (1983) probabilities of price changes, the cost of price adjustment can be calibrated to

be quantitatively equivalent to a particular Calvo adjustment frequency.[10] In this model the equivalent of a Calvo probability of keeping prices fixed of $2/3$ is to set the cost parameter of price changes $\psi = 5.4$. This calibration implies that firms change their price on average every three quarters, in line with the estimates in Sbordone (2002). The extended model also features a more realistic monetary policy rule, which helps generate plausible inflation dynamics. The form of the rule in the extended model is

$$\widehat{R}_t = (1 - \rho_R)\,\lambda_\pi \widehat{\pi}_t + (1 - \rho_R)\,\lambda_\varphi \widehat{\varphi}_t + \rho_R \widehat{R}_{t-1} + \varepsilon_{R,t} \qquad \textbf{(55)}$$

In other words, monetary policy now responds gradually to inflation, and also responds to the mark-up, which is a proxy for the deviation of output from the level of output that would prevail under flexible prices (when the mark-up is constant). The calibrated values for $\{\lambda_\pi, \lambda_\varphi, \rho_R\}$ are $\{1.5, -2, 0.9\}$.

The crucial parameters for the strength of the credit mechanism are the productivity difference between producers and investors α/γ, the steady-state ratio of productive to unproductive agents n, and the probability of a highly productive agent becoming less productive, δ. The parameters n and α/γ were chosen so that productive agents hold about $2/3$ of the capital stock in steady state, the same value as that in Kiyotaki and Moore (1997). But other combinations of these parameters could achieve the same ratio, and generate either more or less persistence. The parameter δ was chosen to be low enough so that the credit mechanism generates substantial persistence, while still producing model responses that appear well behaved.

5.5 Response to aggregate productivity shock

In this section I consider the response of the model economy to aggregate productivity shocks. I compare these responses with the responses of a 'flexible price' version of the model (with $\kappa = 0$, so that all prices can be changed in each period), and also with the response of the fully efficient model, outlined in Section 5.3. Chart 1 shows the response of output, the price of capital, and aggregate entrepreneurial wealth. The units on the vertical axes are percentage deviations from steady state. The units on the horizontal axes are quarters, with the shock taking place in quarter one. The productivity shock is a 0.25% fall in aggregate productivity, which lasts only for a single period. In other words, aggregate productivity follows a white noise process.

[10]Although the calibration can be set so that the linearised pricing equations are identical, the welfare effects, and therefore the optimal monetary policy, are not necessarily identical because they are based on the non-linearised versions of the pricing equation.

Output in the efficient model falls by about 1.7 times the fall in productivity, which is the combined effect of lower productivity and lower labour inputs. After the shock, output returns fairly quickly to its steady-state value. We know from equation **(52)** that, if productivity follows a white noise process, then the persistence of output, as measured by the autocorrelation coefficient, is equal to $\frac{\eta(\tau+1)}{\tau+\eta+\sigma}$. Using the baseline calibration, this is equal to 0.17. Asset prices and aggregate wealth respond with the same proportional magnitudes as output. For the flexible price model with credit frictions, the initial output response is the same as the efficient response, because all determinants of output other than labour (ie, last period's borrowing decision, the share of capital held by productive agents, and investment in inventories) are predetermined. But note that the asset price falls more than twice as much. This amplification is due to the following mechanism. In period one, producers and investors experience an unanticipated loss of output, as well as an unanticipated reduction in the value of producers' collateral. This means that in period one, producers cannot maintain their share of the capital stock: they can now afford less than the steady-state share, because they buy capital with the reinvested share of output and with collateralised borrowing. This means that capital will be less efficiently used for production from period two onwards. Because today's capital price is the present discounted value of all future marginal returns to capital, the price of capital falls by more than in the efficient model, and this fall further exacerbates the reduction in producers' net worth. Output in period two, rather than rising back towards the steady state, falls further due to the shift in capital from highly productive to less productive entrepreneurs. After period two, it takes time for the most productive agents to rebuild their share of wealth, and it therefore takes time for asset prices and output to return to their steady-state values.

Under flexible prices, the degree of amplification that results from credit frictions is around three (the peak output fall is three times larger than the output fall that would prevail without credit frictions). The high degree of amplification is achieved with a plausible parameter value for the capital share and a plausible parameter value for the intertemporal elasticity of substitution (log utility implies a value of one).

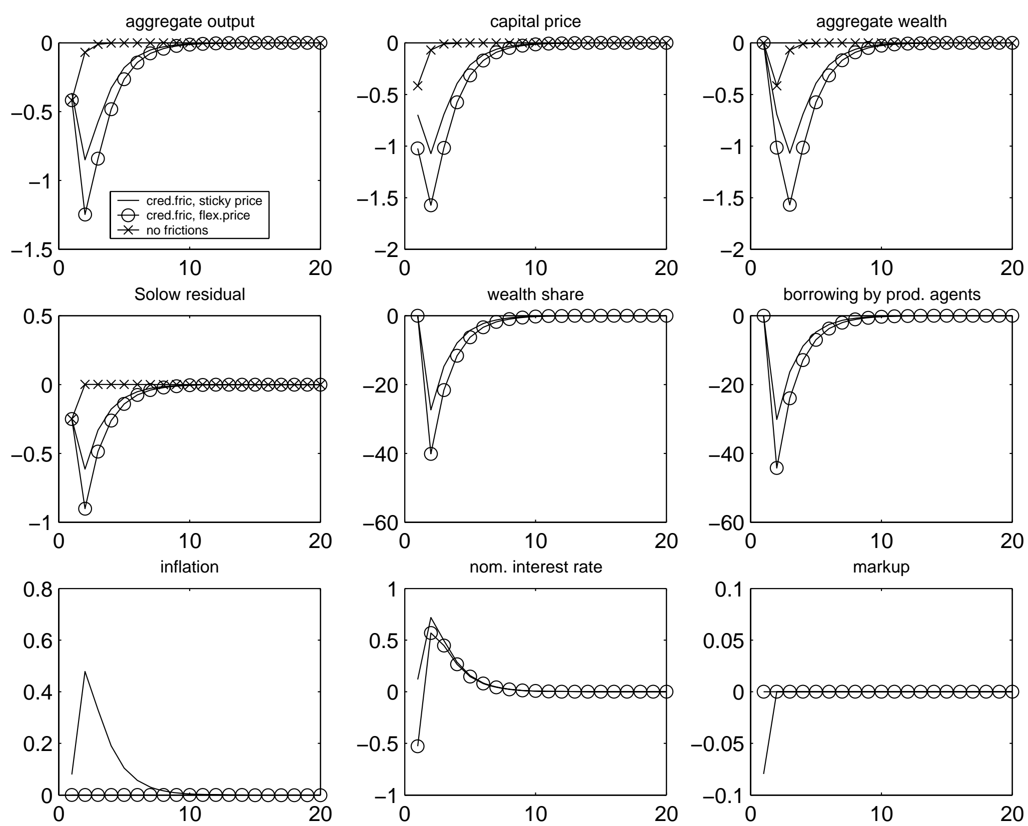
It is useful to compare these results with those of Cordoba and Ripoll (2004), who find that the quantitative importance of credit frictions is not necessarily a robust result. They make four points. First, for their basic model specification, substantial amplification from credit frictions is not plausible, because it requires an implausibly high capital share in production, or an

implausibly low elasticity of substitution. Second, even if their model is extended, amplification only occurs in limited regions of the parameter space. Third, even when amplification is important, the total impact of credit frictions on output can never be very large, because it is the product of four terms that are less than one (share of capital held by productive agents, the importance of capital in production, the magnitude of the reallocation of capital, and the productivity gap between unproductive and productive agents). This third finding is all the more important due to its generality, it does not depend on particular modelling choices.

We address these points in turn. First, the result that very high capital shares are needed to generate amplification hinges on Cordoba and Ripoll's modelling choice that each agent has the same technology, so that a high relative level of productivity can only exist for an agent that also has a low relative share of capital. Our model features heterogeneous technology across productive and unproductive agents, which is closer to Cordoba and Ripoll's extended model, which in turn also allows bigger amplification for still plausible parameters. Second, the finding that credit frictions only have an important impact in very specific ranges of the parameter space (ie are a knife-edge result) is not necessarily a weakness. Rather, it corresponds well to the casual observation that highly leveraged economies can function for long periods of time without any apparent instability, but then suddenly respond in a disproportionate way to disturbances as the structure of the economy has changed gradually. The effect of the recent credit crunch on leveraged economies such as the United States, United Kingdom, Ireland and Spain is an example of this phenomenon. Third, we fully acknowledge that the direct effect of credit frictions on output via redistribution of capital cannot be very large. But one should include in the evaluation of credit effects the interaction with other propagation channels. In our stylised model, one such interaction is with labour supply: output falls more with credit frictions, which then reduces wages, lowers the quantity of labour supplied which magnifies the output effect. A key area for future research is the exploration of other such interactions.

In the full model, with sticky prices as well, the initial fall in aggregate output is slightly muted relative to the efficient and flexible price models. As output falls, the nominal price level needs to rise for any given monetary policy stance that does not fully accommodate the output fall. But prices are sticky, so they do not rise enough. This causes the real marginal cost of the retail sector to rise, as not all retailers are able to charge their desired mark-up. For the entrepreneurs, however, paying a lower mark-up is beneficial: it increases the value of their output in

Chart 1: Response to productivity shock (baseline model)



consumption terms, which in turn increases the amount of labour they want to hire, relative to the amount of labour they would want to hire with constant mark-ups. This mechanism, while appearing perhaps non-standard when described this way, is simply the New Keynesian channel whereby those who cannot change prices change output to meet demand. Ouput is therefore higher than it would have been under flexible prices. So aggregate output falls by less in the period of the shock. This has important consequences for output dynamics in future periods. Because output falls by less, there is a smaller redistribution of wealth from producers to investors. There is therefore a smaller response of asset prices and aggregate wealth, because less of the capital stock shifts from producers to investors during the transmission of the shock. The entire credit - asset price effect has been dampened by the stickiness of prices. The response of inflation, nominal interest rates and the mark-up in the sticky price model are also shown in Chart 1.

The key difference, relative to standard sticky-price monetary models, is that under flexible prices the output fall from period two onwards is no longer fully efficient. This can be seen from the fact that the no-frictions level of output, which also corresponds to a social planner solution in the absence of all frictions, lies strictly above the flexible-price level of output from period two onwards.[11] In standard sticky-price monetary models, it is considered desirable for monetary policy to respond aggressively to inflation following a productivity shock, as this will simultaneously reduce inflation and ensure that output follows the same path as a model without price stickiness. In those models, as soon as productivity has returned to its steady-state level, so does the flexible price level of output. But in the credit frictions model considered in this paper, only the initial fall in output is an efficient response to a change in aggregate productivity. The subsequent further fall, and the slow return to steady state are the result of inefficiencies in the credit market.

How large the dampening effect of sticky prices will be depends on how aggressively monetary policy responds to inflation. As the adverse productivity shock puts upward pressure on inflation, the monetary policy reaction function dictates that the nominal interest rate should rise. The more aggressive the rise in interest rates, the smaller the resulting increase in inflation, and the smaller the reduction in mark-ups. As monetary policy becomes sufficiently aggressive in its

[11] It is important to emphasise that to achieve the first best it is necessary for the path of all variables to match the social planner path, not just output. I am using output deviations here as an indication of whether we are moving further from or closer to an optimal path. A full welfare analysis is carried out in the next section.

response to inflation, the economy's response to productivity shocks approaches that of the flexible price economy, where mark-ups are constant. As monetary policy becomes less aggressive, by responding less strongly to inflation, output fluctuations become smaller. However, in order to ensure determinacy of the equilibrium, monetary policy must react to inflation with a coefficient of at least one, so aggressiveness cannot be toned down too far. Ensuring determinacy of the equilibrium is one interpretation of what central banks refer to as anchoring inflation expectations.

One further aspect of the model that is worth mentioning is that, even though the level of productivity of each firm is only perturbed for a single period, the measured aggregate level of productivity falls persistently. Panel 4 of Chart 1 shows the response of the Solow residual, A_t. This is calculated as the total factor productivity in the economy under the assumption that there is no heterogeneity in productivity. When log-linearised, it is equal to

$$\hat{A}_t = \frac{y}{y+y'}\hat{y}_t + \frac{y'}{y+y'}\hat{y'}_t - \eta\hat{X}_{t-1} - (1-\sigma-\eta)\hat{l}_t \quad \textbf{(56)}$$

The shift in capital from producers to investors causes measured aggregate productivity to fall further in the period following the shock, and given that the shift in capital is persistent, the fall in aggregate productivity is persistent too. Furthermore, the extent of the fall depends on how monetary policy reacts to the shock. If monetary policy keeps inflation strictly constant, aggregate productivity falls further, relative to the case where monetary policy allows inflation to rise temporarily. The model therefore gives an interesting perspective on the interaction between aggregate productivity, heterogeneity and monetary policy. This is discussed in more detail in the next section.

5.6 Response to monetary policy shock

Chart 2 shows the model economy's response to a temporary white noise shock to the monetary policy rule, where the model now features price adjustment costs and the monetary policy rule **(55)**.[12] The shock is calibrated to cause a 0.25% rise in the annualised nominal interest rate. The discussion here is brief, because most of the mechanism is similar to that in the case of a productivity shock. Only the initial phase of the transmission of the disturbance differs. Nominal

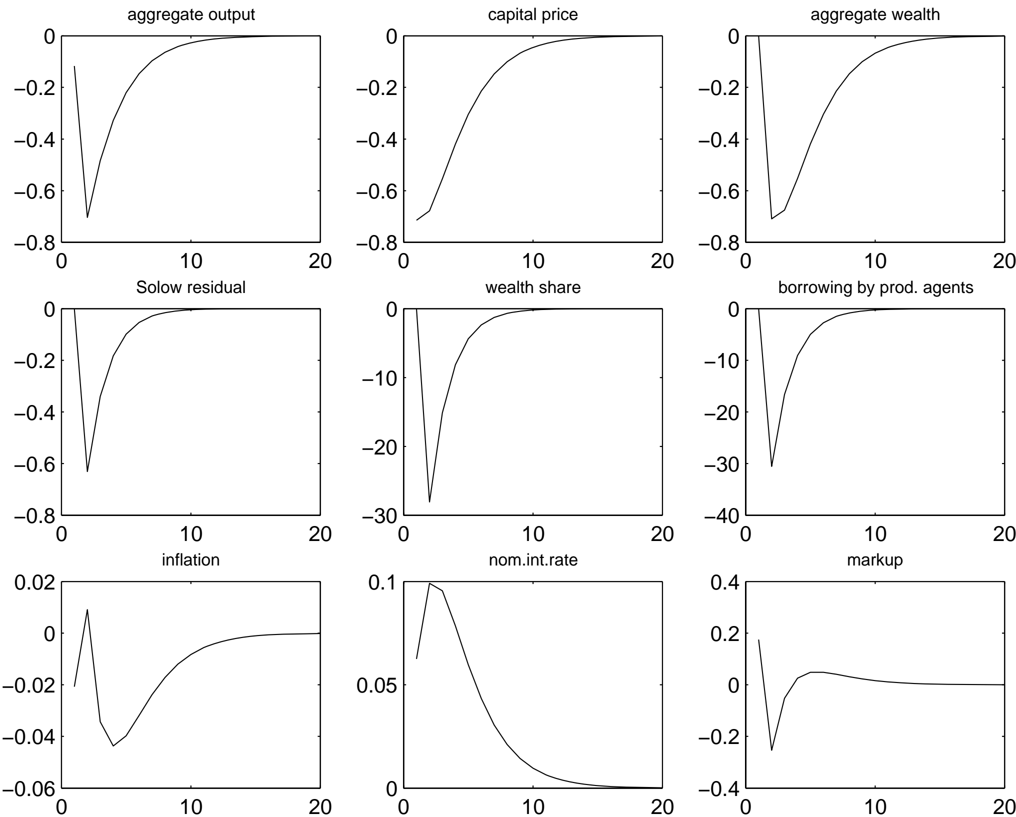
[12]The response of this price adjustment cost version of the model to productivity shocks is omitted, but is quantitatively and qualitatively very close to the baseline model.

interest rates rise in response to the shock. Because retailers are unable to lower their prices sufficiently in response to the monetary contraction, their mark-ups rise. Entrepreneurs therefore face a fall in the consumption value of their output, which reduces net worth both via a direct effect of the mark-up and via the consequent reduction in labour inputs. The fall in output is only 10 basis points, but total wealth is around 70 basis points. Because of the leverage effect, producers suffer a larger fall in net worth than investors. Their share of total wealth falls by nearly 30%, so the wealth distribution is shifted from those with high productivity to those with low productivity. This lowers return on capital in future periods, which causes a fall in the price of capital today, resulting in a reduction of net worth that is much larger than the reduction of the initial period's output alone. Output in the following period is lower still, because capital is now being used less efficiently. The return to the steady-state happens gradually, as producers rebuild their share of wealth, so that the wealth distribution returns to its stationary distribution. Note that in this case the efficient path of output, as well as the path of output under flexible prices, remains constant, because monetary policy would have no effect in this model absent sticky prices.

It is also interesting to note that aggregate productivity, as measured by the Solow residual, falls in response to a monetary contraction, as capital shifts from high to low productivity agents, and is therefore less efficiently used even for a given level of inputs. This puts an interesting perspective on the real business cycle (RBC) and monetary policy literature. The RBC tradition is to claim that monetary policy does not explain much of the variation in output, because a large share of the fluctuation can be explained as an endogenous response to exogenous productivity or technology shocks (see eg, Prescott (1986) and Plosser (1989). But if measured aggregate productivity is not exogenous, but instead is affected by monetary policy shocks, as well as by the systematic response of monetary policy to other shocks, this conclusion in unwarranted. More recently, several authors of the real business cycle tradition have questioned the interpretation of aggregate productivity as strictly determined by technology alone (see eg, Prescott (1998) and Kehoe and Prescott (2002)). Chari, Kehoe and McGrattan (2004) have suggested that aggregate productivity, rather than being taken as given, is something that needs to be formally explained by a model.[13] They call it the 'efficiency wedge'. The model I present here is one possible formalisation of a process that makes the efficiency wedge endogenous, and sensitive to monetary policy.

[13] In the vintage capital version of RBC models, aggregate productivity is largely endogenous, as technology shocks only affect the newest vintage of capital, and the remaining dynamics of aggregate productivity are driven by the optimal switch to new capital.

Chart 2: Response to monetary policy shock (price adjustment cost model)



6 The optimal policy problem

Having analysed the model properties under a simple *ad hoc* monetary policy rule and with monetary policy that stabilises inflation instantly and perfectly, I now turn to the question of what optimal monetary policy is.

6.1 Objective of the policymaker

The policymaker maximises the weighted sum of the welfare of entrepreneurs and of workers. The one-period welfare function is therefore the sum of the utility of all the agents. There is no unique way to sum utilities, but one candidate is

$$U_t = \ln\left(c_t + c_t'\right) + \mu \ln\left(c_t^w - \frac{\chi l_t^{\tau+1}}{\tau+1}\right) \quad \textbf{(57)}$$

This formulation uses total consumption across entrepreneurs, who are *ex-ante* identical. Workers are not identical to entrepreneurs: they face different constraints and have a different utility function, so they are treated separately, and added to the aggregate welfare function using μ, the Pareto weight on workers.[14]

The policymaker then solves the dynamic problem of maximising welfare, conditional on being in some given initial state, subject to the private sector model equations outlined in the appendix. This problem takes the form

$$\max \sum_{t=0}^{\infty} \beta^t \left\{U_t - \lambda_t f(x_{1,t-1}, x_{1,t}, x_{2,t}, x_{2,t+1})\right\} \quad \textbf{(58)}$$

where $f(.)$ is a vector of the equations describing the behaviour of the private sector, x_1 is a vector of the natural state variables of the private sector model, $x_{2,t}$ is a vector of non-predetermined private sector variables and λ_t is a vector of Lagrange multipliers. The maximisation is subject to initial conditions $x_{1,-1}$, which are the initial conditions of the natural state variables. The natural state variables of the private sector model are the level of borrowing b_{t-1}, the lagged user cost u_{t-1}, and the level of capital held by productive agents k_{t-1}.[15] As discussed in, eg, Ljungqvist and Sargent (2004), we must be careful how to treat the Lagrange

[14] This particular welfare function does not give any importance to the distribution of consumption across entrepreneurs, as only total entrepreneurial consumption matters. The distribution of consumption across entrepreneurs matters indirectly, of course, because a reallocation of resources away from highly productive producers lowers total output, and hence total consumption. Using a welfare function that takes into account the distribution of consumption among entrepreneurs explicitly would make credit-driven fluctuations more costly in welfare terms, and therefore likely lead to higher optimal inflation variability.

[15] There is no unique way to choose state variables. One could also work with wealth and the share of wealth held by producers as states.

multipliers on the various constraints. The multipliers on equations with a forward-looking element must be treated as additional state variables. This is because these Lagrange multipliers capture the policymaker's earlier promises upon which private sector expectations were formed. It is this particular treatment of past promises that makes the policy a 'commitment' policy. It is assumed that the policymaker acts as a Stackelberg leader, and does not re-optimise after the private sector has formed expectations. The remaining Lagrange multipliers are treated as non-predetermined, ie, they can jump freely at period t. The predetermined Lagrange multipliers in this particular system are the multipliers on the borrowing constraint, the Phillips curve, the expected return on investment and the asset-pricing condition for capital, which are the equations of the private sector model that involve expectations of future variables.

The system of first-order conditions is solved by log-linearising it around its steady state, and then solving the resulting system of linear difference equations using the Schur decomposition as described in Soderlind (1999).

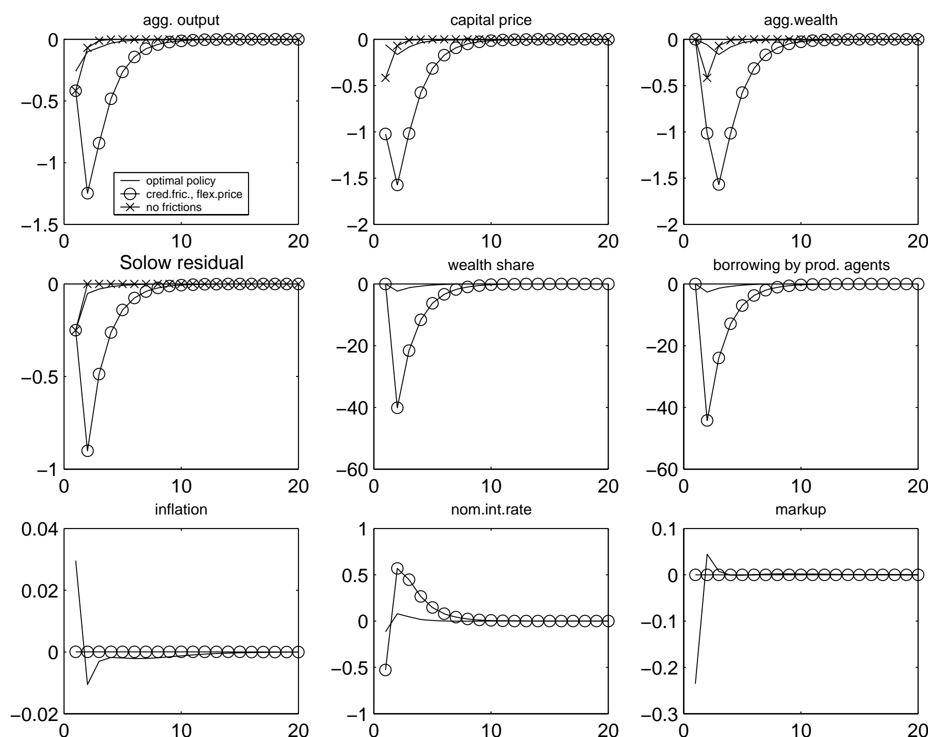
6.2 Optimal response to productivity shock

To understand what optimal monetary policy is trying to achieve, it is useful to consider, in addition to the optimal policy solution, two other solutions for the model, also considered in Section 5.5. First, I consider the solution of the model when there are no credit frictions and prices are fully flexible. Recall from Section 5.3 that his implies that output dynamics are entirely driven by the exogenous process for aggregate productivity and lagged output. There is no feedback from any net worth or asset price variable in the model. And asset prices and entrepreneurial wealth are simply proportional to output.

A second version of the model that is useful for comparison is the model with credit frictions but flexible prices. This can be interpreted either as an economy where there are no impediments or costs to changing prices, or as an economy where the monetary policy maker is concerned only with stabilising inflation, which can be achieved perfectly in this model.

Let us now consider the optimal monetary policy or Ramsey solution. This is the model economy with credit frictions and sticky prices, and with a monetary policy maker who maximises the welfare of the private sector agents as outlined in detail in Section 6.1. As shown in Chart 3, the

Chart 3: Response to adverse productivity shock



initial output fall is smaller than in the frictionless model and the flex-price credit model, and inflation is allowed to rise initially. The formal solution to a full optimisation problem confirms the intuition gained in the previous section: it is optimal for the policymaker to dampen the initial output fall, because of the consequences it has in future periods. The policymaker is therefore trading off the efficiency loss of dampening the initial output and asset price fall (and the temporary rise in inflation) against the efficiency gain from limiting the damaging effect of the credit propagation mechanism in subsequent periods.

In effect, the combination of both credit frictions and sticky prices has resulted in a traditional short-run trade-off between the deviation of output from its efficient level and inflation. A trade-off between the output gap and inflation in the short run is largely absent from the New Keynesian literature unless one considers shocks that hit the price level directly.[16] This absence

[16]In models such as those discussed by Clarida, Gali and Gertler (1999) and Woodford (2003), the level of output that prevails under flexible prices is the appropriate target for monetary policy, and this level can theoretically be achieved as long as there are no direct shocks to the price level. For the case of productivity shocks, there is therefore no trade-off between output fluctuations from their flex-price level and inflation deviations from target. This is not the case if other frictions are added. For example, Erceg, Henderson and Levin (2000) show that a trade-off also exists if both wages and prices are sticky.

of a fundamental trade-off has been dubbed the ‘divine coincidence’ by Blanchard (2005), in reference to the fact that closing the welfare-relevant measure of the output gap coincides with stabilising inflation. Angeletos (2003) also discussed this problem with the New Keynesian models. In my approach, there is no longer any divine coincidence, because stabilising prices does not stabilise output around its efficient level, or even its constrained efficient level. And as shown in Chart 3, the optimal policy involves allowing inflation to rise briefly following an adverse productivity shock. The nature of the propagation mechanism due to credit frictions implies that in this model the trade-off is not between current inflation and the *current* gap between output and its efficient level. Instead, there is a dynamic trade-off between current inflation and the *future* gap between output and its efficient level. This dynamic nature of the trade-off has important consequences for the concept of the output gap. It means that, even if we could measure it accurately, the distance between output and its efficient level at any point in time is not a useful summary of the objective of monetary policy, in the way that the New Keynesian gap between output and its flexible price level summarises the monetary policy objective.

Table B: Theoretical moments of selected variables

	Ramsey	Frictionless	Flex-price credit
$s.d.(y + y')$	1.157	2.000	6.658
$s.d.(q)$	0.798	2.000	8.974
$s.d.(\pi)$	0.128	0	0
$a.r.(y + y')$	0.431	0.167	0.779
$a.r.(q)$	0.698	0.167	0.806
$a.r.(\pi)$	-0.246	0	0
$s.d.(\varepsilon_{P,t})$	1.000	1.000	1.000

Notes: $s.d.$ denotes standard deviation, expressed in per cent, and $a.r$ denotes first-order autocorrelation. Moments were calculated for log-linear deviations of aggregate output $(y + y')$, the price of capital (q), and inflation(π).
Each column represents a different version of the model.

Table B illustrates the trade-off and the desirability of smoothing output and asset price fluctuations. Under optimal or Ramsey policy, inflation variability[17] is non-zero. It is of the same order of magnitude as the variability of actual inflation in low-inflation industrialised countries such as the United States.[18] Output variability under optimal policy is much smaller than in the

[17] The theoretical standard deviations and autocorrelations of the model variables were calculated using the method described in Hamilton (1994), pages 265-66.

[18] The standard deviation of US quarterly inflation, on the GDP deflator measure, is 0.25% for the sample period 1983:1-2005:1. (Source: US BEA). The standard deviation of US quarterly output, measured as deviations from a Hodrick-Prescott filtered trend, was 1.11% over the same period.

flex-price credit model. The reduction in output variability also implies a reduction in asset price variability. Quantitatively, the ability of the monetary policy maker to affect the real economy in the short run allows most of the adverse effects of credit frictions to be offset. In the illustrative calibration used here, the standard deviation of output under optimal policy is around one sixth of the standard deviation of output under price stability. In other words, a little inflation variability buys a large reduction in output variability.

Comparing the Ramsey outcome with the frictionless model, we see that aggregate output is more persistent, but less variable, under the Ramsey policy than in the frictionless model. The increased persistence of Ramsey output arises because it is not efficient to offset the initial output fall entirely, so there is still some persistence from the credit mechanism that prevents output from rising back to its steady-state level as quickly as the frictionless model. This is illustrated in Chart 3 by the fact that the wealth share of producers still falls under optimal policy.

7 Robustness checks

In this section I want to explore the extent to which the quantitative conclusions are sensitive to the particular choice of parameters. I will vary four key parameters. I explore the consequences of (a) putting a smaller Pareto weight on workers ($\mu = 0.1$), (b) making labour supply less elastic ($\tau = 1$), (c) making goods prices less sticky ($\psi = 2$), and (d) weakening the credit channel by lowering the productivity gap between producers and investors ($\frac{a}{\gamma} = 1.01$).

Table C: Robustness of optimal policy results to parameter changes

	Baseline	Workers	Lab.elast.	Nom.rigid.	Prod.gap
$s.d.(y + y')$	1.157	1.1337	1.105	1.270	1.427
$s.d.(q)$	0.798	0.597	0.764	1.133	1.139
$s.d.(\pi)$	0.128	0.196	0.160	0.313	0.094
$a.r.(y + y')$	0.431	0.373	0.359	0.558	0.300
$a.r.(q)$	0.698	0.665	0.660	0.676	0.371
$a.r.(\pi)$	-0.246	0.245	-0.347	-0.372	0.220
$s.d.(\varepsilon_{P,t})$	1.000	1.000	1.000	1.000	1.000

Notes: $s.d.$ denotes standard deviation, expressed in per cent, and $a.r.$ denotes first-order autocorrelation. Moments were calculated for log-linear deviations of aggregate output ($y + y'$), the price of capital (q), and inflation(π).
Each column represents a different version of the model.

The results appear to be robust to even these large parameter changes, with the crucial parameters being the strength of the credit channel and the extent of nominal rigidities, as can be expected, since these are the two frictions the policymaker is trading off against each other. The changes in the model properties help to firm up the underlying intuition, so I will describe them case by case.

Lowering the welfare weight on workers makes output less variable, but inflation more so. That is because, in order to dampen the effect of the shock on initial output, the expansionary monetary policy dampens output partly by its effect on labour. Since only workers supply labour, if policy is less concerned with worker welfare, it can tolerate greater deviations from the optimal path of labour, meaning it will dampen the output fall more strongly and tolerate higher inflation variability.

Less elastic labour supply implies that output falls by less following an adverse productivity shock, even in the frictionless model. That automatically weakens the credit channel, leading to less output variability. But it also means that monetary policy has to generate more inflation to dampen output by a given amount. In other words, the slope of the short-run Phillips curve has become steeper. So inflation variability is higher.

Lowering price stickiness gives monetary policy less traction, but leaves the strength of the credit channel unchanged. Monetary policy is therefore less able to dampen output responses, and a stronger burst of inflation is needed to dampen output by a given amount. The result is that both output variability and inflation variability under optimal policy are larger.

Finally, weakening the credit channel brings the model closer to the frictionless model. Higher variability of output can be tolerated, because it no longer has strong effects on the efficiency with which capital is used. And inflation variability is smaller, because there is no longer the need to use inflation to dampen the output response to a productivity shock as strongly.

8 Conclusion

I have shown that the presence of both nominal rigidities and credit frictions can lead to a trade-off between inflation variability and output variability. In particular, because an output fall leads to a reallocation of resources toward less productive agents, it will result in large *future*

deviations of output from its efficient level. So there is a trade-off between the rise in inflation immediately following the shock, and the fall in *future* output relative to its efficient level. Allowing a small temporary rise in inflation following an adverse productivity shock is optimal, because it results in output being much closer to its efficient level in future periods, ie, it avoids unnecessarily large fluctuations in future output. A large reduction in output variability can be achieved by allowing only a small amount of inflation variability. Conversely, the cost of stabilising inflation too aggressively can be large.

This trade-off between inflation variability and output variability is consistent with the remit of the Monetary Policy Committee, which aims for price stability partly as a precondition for the wider economic goal of economic stability. Thus in this paper we are able to provide a new aspect of the transmission mechanism that supports that remit.

Appendix A: Model equations

The full model is described by the following equations. The timing convention is that all variables that are decided at date t after the realisation of the period t shock will have the subscript t. Predetermined variables therefore have a subscript $t-1$. The wage of workers is denoted z_t.

Total wealth of entrepreneurs (W_t)

$$W_t = (\eta + \sigma)\frac{y_t + y_t'}{\varphi_t} + q_t \tag{A-1}$$

the share of wealth held by producers (s_t)

$$\begin{aligned} s_t W_t = {} & (1-\delta)\left[(\eta+\sigma)\frac{y_t}{\varphi_t} + q_t k_{t-1} - b_{t-1}\right] \\ & + n\delta\left[(\eta+\sigma)\frac{y_t'}{\varphi_t} + q_t(1-k_{t-1}) + b_{t-1}\right] \end{aligned} \tag{A-2}$$

the user cost of capital (u_t)

$$u_t = \frac{\sigma}{\eta}(\beta W_t - q_t) \tag{A-3}$$

capital held by producers (k_t)

$$k_t = \beta\frac{\sigma}{\eta+\sigma}\frac{s_t W_t}{u_t} \tag{A-4}$$

borrowing constraint (b_t)

$$b_t = E_t q_{t+1} k_t \tag{A-5}$$

Phillips curve (π_t)

$$\begin{aligned} \pi_t(\pi_t - 1) = {} & \beta E_t\left[\frac{u_{w,t+1}}{u_{w,t}}\pi_{t+1}(\pi_{t+1}-1)\right] \\ & + \frac{\theta-1}{\psi}\left(y_t + y_t'\right)\left(\frac{\theta}{\theta-1}\frac{1}{\varphi_t} - 1\right) \end{aligned} \tag{A-6}$$

return on investment (r_t)

$$r_t = E_t\left(\varepsilon_{P,t+1}^{\frac{1}{\eta+\sigma}}\gamma^{\frac{1}{\eta+\sigma}}\varphi_{t+1}^{-\frac{1}{\eta+\sigma}} z_{t+1}^{-\frac{1-\eta-\sigma}{\eta+\sigma}} u_t^{-\frac{\sigma}{\eta+\sigma}}\right) \tag{A-7}$$

pricing equation for capital (q_t)

$$u_t = q_t - E_t\frac{q_{t+1}}{r_t} \tag{A-8}$$

labour market equilibrium in terms of workers' wage (z_t)

$$z_t^{\frac{1+\tau}{\tau}}\left(\frac{1}{\chi}\right)^{1/\tau}=\frac{1-\eta-\sigma}{\eta+\sigma}\left(W_t-q_t\right) \quad \textbf{(A-9)}$$

Fisher equation [19] determining the nominal interest rate (R_t)

$$E_t\frac{R_t}{\pi_{t+1}}\frac{1}{(\eta+\sigma)\frac{y'_{t+1}}{\varphi_{t+1}}\varphi+q_{t+1}}=E_t r_t\frac{1}{(\eta+\sigma)\frac{y'_{t+1}}{\varphi_{t+1}}\varphi+q_{t+1}} \quad \textbf{(A-11)}$$

producers' output (y_t)

$$y_t=\alpha^{\frac{1}{\eta+\sigma}}\varepsilon_{P,t}^{\frac{1}{\eta+\sigma}}u_{t-1}^{\frac{\eta}{\eta+\sigma}}\left(z_t\varphi_t\right)^{-\frac{1-\eta-\sigma}{\eta+\sigma}}\frac{k_{t-1}}{\sigma} \quad \textbf{(A-12)}$$

investors' output (y'_t)

$$y'_t=\gamma^{\frac{1}{\eta+\sigma}}\varepsilon_{P,t}^{\frac{1}{\eta+\sigma}}u_{t-1}^{\frac{\eta}{\eta+\sigma}}\left(z_t\varphi_t\right)^{-\frac{1-\eta-\sigma}{\eta+\sigma}}\frac{(1-k_{t-1})}{\sigma} \quad \textbf{(A-13)}$$

definition of u_w, which is the marginal utility of consumption of workers

$$\frac{1}{u_{w,t}}=\frac{\tau}{\tau+1}\left(\frac{1}{\chi}\right)^{\frac{1}{\tau}}z_t^{\frac{1+\tau}{\tau}}+\left(y_t+y'_t\right)\left(1-\frac{1}{\varphi_t}\right)-\frac{\psi}{2}\left(\pi_t-1\right)^2 \quad \textbf{(A-14)}$$

the aggregate productivity process ($\varepsilon_{P,t}$)

$$\log\varepsilon_{P,t}=\rho\log\varepsilon_{P,t-1}+\upsilon_t \quad \textbf{(A-15)}$$

When the model is solved for an *ad hoc* monetary policy, as opposed to optimal monetary policy, the final equation to close the model is the monetary policy rule.

[19] This is the standard asset pricing arbitrage condition, based on the marginal utility of consumption of the investors. I have made the following substitution:

$$E_t c'_{t+1}=(1-\beta)\left[(\eta+\sigma)\frac{y'_{t+1}}{\varphi_{t+1}}+q_{t+1}\right]E_t c'_{t+1}=(1-\beta)\left[(\eta+\sigma)\frac{y'_{t+1}}{\varphi_{t+1}}+q_{t+1}\right] \quad \textbf{(A-10)}$$

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