Quantity Rationing of Credit and the Phillips Curve

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Abstract

Quantity rationing of credit, when some firms are denied loans, has macroeconomics effects not fully captured by measures of borrowing costs. This paper develops a monetary DSGE model with quantity rationing and derives a Phillips Curve relation where inflation dynamics depend on cyclical unemployment, a risk premium and the fraction of firms receiving financing. Unemployment arising from disruptions in credit flows is defined to be cyclical. GMM estimates using data from a survey of bank managers confirms the importance of these variables for inflation dynamics.

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1 Introduction

The idea that financial factors affect the supply sector of the macroeconomy is not controversial. Ravenna and Walsh (2006) derive and give supporting empirical evidence for a Phillips curve where an interest rate contributes to firm costs. However, a recurrent theme in discussions about the role of credit markets[1] is that borrowing costs do not give a complete picture, and changes in quantity rationing, when some firms are denied loans, plays an important role.

The present work derives a Phillips Curve from a monetary DSGE model with quantity rationing of credit. Cyclical[2] unemployment is defined to be unemployment that arises due to disruptions in credit flows. The resulting Phillips Curve has the standard New Keynesian form where marginal cost is a function of cyclical unemployment, a risk premium, and the fraction of firms that are not quantity rationed.

Firms have heterogeneous needs for financing their wage bills and must take collateralized loans to meet them. If the collateral requirement is sufficiently strict, some firms do not get financing. The parameter representing firm's ability to provide collateral represents credit market conditions and has a natural empirical proxy in the survey of bank managers from the Federal Reserve Bank of New York. Using this data, estimations show a significant role for all the variables in the theoretical specification of the Phillips Curve and demonstrate that ignoring quantity rationing of credit constitutes a serious mis-specification. Removing the survey data eliminates the role of cyclical unemployment and makes forward looking inflation expectations appear to be more important.

There are similarities with the present approach and that of Blanchard and Gali (2007), where involuntary unemployment arises due to real wage stickiness. They provide empirical evidence for a Phillips Curve where unemployment and producer price inflation represent marginal cost. However, real wage rigidities are temporary and cannot explain persistent unemployment. Credit market flaws are a leading candidate for the underlying cause of persistent unemployment of a type that policymakers might want to minimize.

There are a number of other models of unemployment based on labor market imperfections that can explain sustained unemployment, search models such as Mortenson and Pissarides (1994) being the dominant approach. Alternatively, the cost of monitoring workers (Shapiro and Stiglitz, 1984) or implicit contracts (Azariadis, 1975) can increase the marginal cost of labor and lower the equilibrium level of labor, which have been interpreted as involuntary unemployment. While these may all be important factors in the level of unemployment, whether changes in these frictions are closely connected to changes in cyclical (involuntary) unemployment is questionable. Recessions are not caused by an increase in monitoring costs, for example.

The importance of quantity rationing has been emphasized in the literature from a number of different

[1] Lown and Morgan (2006) is one example, and they give a number of references including Blanchard and Fisher (1981).
[2] The somewhat normative phrase "involuntary unemployment" is also used in this context.

perspectives. There is little empirical evidence for borrowing costs being important determinants of fluctuations in inventories and output (Kayshap, Stein and Wilcox 1994). Lown and Morgan (2006) provide evidence, using the loan officer survey data, that lending standards are significantly correlated with aggregate lending and real output. Boissay (2001) shows that quantity rationing acts as a significant financial accelerator of fluctuations in a real business cycle model. The framework presented here borrows some of the modeling language from this approach.

A number of papers develop DSGE models that include financial intermediaries whose lending is constrained by frictions arising from agency restrictions such as net worth (Carlstrom and Fuerst 1997, Bernanke, Gertler and Gilchrist 1996), monitoring costs (Bernanke and Gertler 1989) or collateral constraints (Monacelli 2009). Faia and Monacelli (2008) is related in that firms borrowing is affected by idiosyncratic shocks. In their approach, the monitoring costs vary across firms and only a fraction of intermediaries participate, while in the present work there is a representative intermediary and a fraction of firms receives financing. Recently, Gertler and Kiyotaki (2011) and Gertler and Karadi (2009) have developed sophisticated models based on the net worth approach that allow for analysis of monetary policy when the zero lower bound on interest rates might bind to model financial crises.

As noted above, the financial frictions in the work referenced here all take the form of price rationing. A notable exception is Kiyotaki and Moore (1997), which has a collateral constraint that varies endogenously with economic conditions, giving rise to multiple steady states. While the approach in the present work is much simpler, it allows for easy comparison with other policy related models and empirical work.

2 The model

Following standard New Keynesian approaches, there is nominal stickiness in that monopolistic competitors do not all set prices at the same time. The primary departure of this model from standard approaches is the introduction of a working capital requirement for firms.

2.1 Demand for intermediate goods

Intermediate goods producers are monopolistic competitors and produce differentiated goods $y_t(i)$ and set prices $p_t(i)$ in time t. Final goods Y_t are produced from intermediate goods according to

$$Y_t = \left(\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di \right)^{\frac{\theta}{\theta-1}},$$

and consumers maximize over the aggregate consumption C_t given by

$$C_t = \left(\int_0^1 c_t(i)^{\frac{\theta-1}{\theta}} \, di \right)^{\dfrac{\theta}{\theta-1}} .$$

The parameter $\theta > 1$ represents the degree of complementarity for inputs in production and goods for consumption. Final goods producers maximize profits $P_t Y_t - \int_0^1 p_t(i) \, y_t(i) \, di$ where P_t is the final goods price. Optimizing (see Chari, Kehoe and McGrattan (1996) or Walsh (2003)) yields the following condition on the demand for intermediate goods.

$$y_t^d(i) = Y_t \left(\frac{P_t}{p_t(i)} \right)^{-\theta} \tag{1}$$

Final good producers are competitive and make zero profits, which determines the following condition on prices.

$$P_t = \int_0^1 p_t(i)^{\theta-1} \, di$$

2.2 Working capital requirement

The formulation of the model focuses on the role of quantity rationing of credit. The primary innovation of the model is the heterogeneity of firms in the need for financing a portion of their wage bill, embodied in the variable v_t which has distribution $F(v_t)$ over $[0, 1]$. This variable could represent differences in firms internal financial resources or the timing of their cash flows. If a firm is unable to get financing, it does not produce that period[3]. An individual firm with draw v_t, producing good i, has financing need $\xi(v_t, i) = W_t l(v_t, i) \, v_t$ where W_t is the nominal wage, and $l(v_t)$ is the labor demand for a producing firm. Firms are wage takers so W_t is the wage for all firms. If the firm gets financing, it produces output $y_t(v_t, i) = a_t l_t(v_t, i)^{\alpha}$ where a_t is the level of productivity and α is the usual Cobb-Douglas production parameter with values between zero and one.

Firms cannot commit to repayment of loans and so must provide collateral in the form of period t output. The collateral condition is $\mu_t p_t(i) \, y_t(v_t, i) \geq (1 + r_t) \, \xi(v_t, i)$ where the interest rate is r_t and the μ_t is the fraction of cash flow the intermediary accepts as collateral. The productivity shock a_t and need for financing v_t are both realized at the beginning of period t, so the intermediary does not face any uncertainty in the lending decision. Substituting for $y_t(v_t, i)$ and $\xi(v_t, i)$ yields the following form for the collateral

[3] A more natural assumption would be that some firms or portions of firms are able to produce without financing each period. The present approach is chosen to simplify the exposition.

requirement.

$$\mu_t a_t l_t (v_t, i)^{\alpha} \geq (1 + r_t) \frac{W_t}{p_t(i)} l_t (v_t, i) v_t \tag{2}$$

The exogenous process μ_t represents the aggregate credit market conditions embodied in the collateral requirements made by banks and firms' ability to meet them. A sudden fall in confidence, such as the collapse of the commercial paper market in the Fall of 2008, could be represented by an exogenous drop[4] in μ.

Profit for an individual firm with realization v_t producing good i for its financing need is the following.

$$\Pi_t (v_t, i) = p_t(i) a_t l_t (v_t, i)^{\alpha} - W_t l_t (v_t, i) - r_t W_t l_t (v_t, i) v_t$$

Hence, labor demand for the firm is

$$\alpha a_t l_t (v_t, i)^{\alpha - 1} = \frac{W_t}{p_t(i)} (1 + r_t v_t). \tag{3}$$

Using the labor demand relation, the collateral constraint (2) becomes $\mu_t (1 + r_t v_t) \geq \alpha (1 + r_t) v_t$. From this condition, we can define $\overline{v}_t$, the maximum v_t above which firms cannot produce. For firms to produce in period t, they must have a v_t such that

$$v_t \leq \overline{v}_t = \min \left\{ 1, \left[\frac{\alpha}{\mu_t} (1 + r_t) - r_t \right]^{-1} \right\}. \tag{4}$$

Note that the fraction of firms producing $\overline{v}_t$ is increasing in the credit market confidence parameter μ_t. At an interior value for $\overline{v}_t < 1$, it must be the case that $\mu < \alpha$, which implies that the fraction of firms producing is decreasing in the interest rate.

For the present specification, changes in the fraction of firms receiving financing $\overline{v}_t$ are driven primarily by fluctuations in exogenous credit market conditions. While this is not necessarily unrealistic, there are many potential extensions of the model where the variable $\overline{v}_t$ would depend on other endogenous quantities. For example, financing could be required for investment goods and capital used as collateral, so fluctuations in capital levels would affect the fraction of firms receiving financing. One advantage of the form of equation (4) is the fraction $\overline{v}_t$ depends on real factors, so we can isolate the impact of quantity rationing on inflation dynamics.

In its present form, the collateral requirement does not act as an accelerator of other shocks such as productivity. Productivity is included here primarily for comparison with related models.

[4] Gertler and Kiyotaki (2011) model the start of the crisis as a deterioration of the value of assets held by financial intermediaries.

2.3 Households

The household optimization problem is closely related to standard approaches such as Ravenna and Walsh (2006), but the fraction of non-rationed firms affects firm profits received by the household and the aggregate quantity lent by intermediaries. The household chooses optimal levels of consumption C_t, labor supplied L_t and deposits (savings) D_t.

$$\max_{C_t,L_t,D_t} E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma_1}}{1-\sigma_1} + \chi_M \frac{\left(M_{t-1}/P_t\right)^{1-\sigma_2}}{1-\sigma_2} - \chi_L \frac{L_t^{1+\eta}}{1+\eta} \right] \quad \text{subject to} \tag{5}$$

$$P_t C_t + D_t + M_t \leq (1+r_t) D_t + M_{t-1} + W_t L_t + \int_0^{\overline{v}_t} \Pi_t dF(v_t) + G_t$$

The household is assumed to insure against labor market fluctuations internally, as in Gertler and Karadi (2009), for one example. Households hold shares in all firms and receive profits from producing firms $\int_0^{\overline{v}_t} \Pi_t dF(v_t)$. They also receive profits G_t from the intermediary where $G_t = D_t - D_t(1+r_t) + r_t \xi_t^e + \overline{M}_t$, where $\overline{M}_t$ is the monetary injection made by the central bank each period. Households borrow D_t at the beginning of period t and repay $(1+r_t) D_t$ at the end. The timing is typical of models that formally include a financial sector, Christiano and Eichenbaum (1992) for example. The amount of lending to firms in industry i is

$$\xi_t^e(i) = \int_0^{\overline{v}_t} W_t l(v_t, i) v_t dF(v_t). \tag{6}$$

Household deposits are used for loans to the firms so $D_t = \xi_t^e$, where ξ_t^e is the aggregate quantity of loans such that $\xi_t^e = \int_0^1 \xi_t^e(i) di$.

First order conditions from the household optimization problem yield standard consumption Euler and labor-leisure relations.

$$1 = \beta(1+r_t) E_t \left[\left(\frac{C_t}{C_{t+1}} \right)^{\sigma} \right] \tag{7}$$

$$W_t = \chi L_t^{\eta} C_t^{\sigma} \tag{8}$$

2.4 Aggregate output, labor and financing cost

Finding an expression for marginal cost at both the industry and aggregate levels is a primary goal, which requires aggregating firm level variables in the profit function. The level of output and labor for firms producing good i are specified naturally, given that some firms may not be producing due to quantity rationing.

$$y_t(i) = a_t \int_0^{\overline{v}_t} l_t(v_t, i)^{\alpha} \, dF(v_t) \tag{9}$$

$$l_t(i) = \int_0^{\overline{v}_t} l_t(v_t, i) \, dF(v_t) \tag{10}$$

Using labor demand (3) to substitute for $l_t(v_t, i)$ in the aggregate labor equation (10) and integrating determines the following aggregate labor demand equation assuming that v_t is distributed uniformly over $[0, 1]$ so $F(v_t) = v_t$.

$$l_t(i) = \left(\frac{W_t}{p_t(i)}\right)^{\dfrac{-1}{1-\alpha}} \Upsilon(a_t, r_t, \overline{v}_t) \tag{11}$$

$$\text{for} \quad \Upsilon(a_t, r_t, \overline{v}_t) = \left(\frac{1-\alpha}{\alpha}\right) (\alpha a_t)^{\frac{1}{1-\alpha}} r_t^{-1} \left[1 - (1 + r_t \overline{v}_t)^{\dfrac{-\alpha}{1-\alpha}}\right]$$

Similarly, combining labor demand (3) with aggregate output (9) yields

$$y_t(i) = \left(\frac{W_t}{p_t(i)}\right)^{\dfrac{-\alpha}{1-\alpha}} \vartheta(a_t, r_t, \overline{v}_t) \tag{12}$$

$$\text{for} \quad \vartheta(a_t, r_t, \overline{v}_t) = \left(\frac{1-\alpha}{2\alpha-1}\right) \alpha^{\dfrac{\alpha}{1-\alpha}} a_t^{\dfrac{1}{1-\alpha}} r_t^{-1} \left[1 - (1 + r_t \overline{v}_t)^{\dfrac{1-2\alpha}{1-\alpha}}\right].$$

When the production function parameter α is such that $\alpha > \frac{1}{2}$, aggregate labor and output are both increasing in $\overline{v}_t$ for a given wage. Using the above two equations, aggregate output and labor can be related as follows.

$$y_t(i) = l_t(i)^{\alpha} \frac{\vartheta(a_t, r_t, \overline{v}_t)}{\Upsilon(a_t, r_t, \overline{v}_t)^{\alpha}} \tag{13}$$

The cost for the representative firm depends on the wage bill and the aggregate quantity of financing $\xi_t^e(i)$, which is derived using labor demand (3) to substitute for $l_t(v_t, i)$ in the aggregate lending relation

(6) and integrating (see Appendix).

$$\xi_t^e(i) = \frac{W_t}{r_t}\left(\frac{W_t}{p_t(i)}\right)^{\frac{-1}{1-\alpha}} \Phi(a_t, r_t, \overline{v}_t) \tag{14}$$

$$\text{for } \Phi(a_t, r_t, \overline{v}_t) = \left(\frac{1-\alpha}{\alpha}\right)(\alpha a_t)^{\frac{1}{1-\alpha}} r_t^{-1}\left[\left(\frac{1-\alpha}{2\alpha-1}\right)\left(1-(1+r_t\overline{v}_t)^{\frac{1-2\alpha}{1-\alpha}}\right) - r_t\overline{v}_t(1+r_t\overline{v}_t)^{\frac{-\alpha}{1-\alpha}}\right]$$

3 Phillps Curve derivation

3.1 Marginal cost

The standard derivation for a Phillips Curve relation focuses on marginal cost. Firms that make the same good i have the price and wage, so there is a representative cost minimization problems for those firms. The real cost for the representative firm producing good i is the sum of the wage bill and the financing cost, using equation (14), $\frac{W_t}{P_t}l_t(i) + \frac{r_t}{P_t}\xi_t^e(i)$, which is minimized subject to the production constraint (13) for a given level of output $y_t(i)$. The Lagrangian for this problem, where the Lagrange multiplier $\varphi_t(i)$ represents marginal cost, is

$$\mathcal{L} = \frac{W_t}{P_t}l_t(i)\left(1+\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right) + \varphi_t(i)\left(y_t(i) - l_t(i)^\alpha \frac{\vartheta(\cdot)}{\Upsilon(\cdot)^\alpha}\right),$$

and the resulting first order condition with respect to $l_t(i)$ determines

$$\varphi_t(i) = \frac{W_t}{P_t}l_t(i)^{1-\alpha}\frac{\Upsilon(\cdot)^\alpha}{\vartheta(\cdot)}\left(1+\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right).$$

Production decisions are made independently of firms' ability to update prices, so in equilibrium $y_t(i) = Y_t$ and $l_t(i) = L_t$ so average marginal cost across all firms is

$$\varphi_t = \frac{W_t}{P_t}L_t^{1-\alpha}\left\{\frac{\Upsilon(\cdot)^\alpha}{\vartheta(\cdot)}\left(1+\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right)\right\}. \tag{15}$$

In models without financial factors, the term $\{\cdot\}$ in (15) is simply a_t^{-1}. The qualitative impact of productivity is the same here, but marginal cost depends on price and quantity rationing of credit as well.

Using the labor supply equation (8) and the aggregate output equation (9), marginal cost in (15) can be expressed as follows.

$$\varphi_t = L_t^{1+\eta-\alpha(1-\sigma)} J\left(a_t, r_t, \overline{v}_t\right) \tag{16}$$

$$\text{where } J\left(a_t, r_t, \overline{v}_t\right) = \chi \left(\frac{\vartheta\left(a_t, r_t, \overline{v}_t\right)}{\Upsilon\left(a_t, r_t, \overline{v}_t\right)^{\alpha}} \right)^{\sigma-1} \left(1 + \frac{\Phi\left(a_t, r_t, \overline{v}_t\right)}{\Upsilon\left(a_t, r_t, \overline{v}_t\right)}\right)$$

This equation defines a steady state relationship for $\left(\widetilde{L}, \widetilde{a}, \widetilde{r}, \widetilde{\overline{v}}\right)$, recalling that the steady state and flexible price level of marginal cost depends solely on the pricing power of the monopolistically competitive firms such that $\widetilde{\varphi} = \dfrac{\theta - 1}{\theta}$. The fraction of non-rationed firms and the interest rate have intuitive roles.

Proposition 1 *The function $J\left(a_t, r_t, \overline{v}_t\right)$ in (16) is increasing in $\overline{v}_t$ for $\alpha > \frac{1}{2}$ and $\sigma > 1$.*

Proof. See appendix. ■

Proposition 1 and the aggregate labor relation (11) imply that an easing of credit standards that allows more firms to enter leads to higher aggregate marginal cost. In addition to the usual increasing marginal cost intuition, an increase in $\overline{v}_t$ allows higher marginal cost firms to produce.

The relationship between the interest rate and marginal cost is more complicated. Whether the function $J\left(a_t, r_t, \overline{v}_t\right)$ and aggregate labor demand $l_t\left(i\right)$ from (11) are increasing in r_t is sensitive to parameter choices, but for natural selections marginal cost rises with borrowing costs as in Ravenna and Walsh (2006).

3.2 Price stickiness

To study inflation dynamics, we assume prices are sticky in that only a fraction of firms can update their prices in a given period. The convention in Christiano, Eichenbaum and Evans (2005) produces a Phillips curve where inflation depends on both expected and lagged inflation, which is more empirically realistic[5], than the relation without lagged inflation that results from Calvo (1983) updating. In the former "dynamic optimization" approach, a fraction 1-ω of firms are able to re-optimize their prices each period, while the firms that cannot re-optimize set

$$p_t\left(j\right) = \pi_{t-1}^{\varrho} p_{t-1}\left(j\right),$$

where inflation is $\pi_t = P_t/P_{t-1}$ and $\varrho \in [0,1]$ represents the degree of price indexation. Re-optimizing firms maximize discounted expected future profits taking into account the possibility of future price revisions. Cogley and Sbordone (2006) derive the following form for the Phillips curve where $\widehat{\pi}_t$ and $\widehat{\varphi}_t$ are percentage (log difference) deviations from the steady state values. The following form is standard in the literature,

[5] Inclucing lagged inflation has empirical support unless one allows for a time varying trend in inflation as in.Cogley and Sbordone (2006), which is discussed at the end of the next section.

though it is a special case of their derivation where steady state inflation is constant at zero. In the theoretical model, steady state inflation is zero as long as the steady state injection of money is zero as well.

$$\begin{aligned}
\widehat{\pi}_t &= \frac{\varrho}{1+\beta\varrho}\widehat{\pi}_{t-1} + \frac{\omega\beta}{1+\omega\beta\varrho}E_t\widehat{\pi}_{t+1} + \kappa\widehat{\varphi}_t \\
\text{for } \kappa &= \frac{(1-\beta\omega)(1-\omega)}{(1+\beta\varrho)(1+\theta\omega)\omega}
\end{aligned} \tag{17}$$

One strategy for estimating the Phillips Curve (19) is to use labor cost data as a proxy for marginal cost $\widehat{\varphi}_t$ as in Sbordone (2002), Gali and Gertler (1999) and Gali, Gertler and Lopez-Salido (2001), which has had success in explaining inflation dynamics. Ravenna and Walsh (2006) develop a New Keynesian model with borrowing to pay the wage bill and derive a Phillips Curve that includes an interest rate. They demonstrate the empirical relevance of financial factors by estimating a Phillips Curve with unit labor costs and the interest rate representing marginal cost.

3.3 Unemployment

The analysis here focuses on the labor market and its relation to financial factors. Cyclical unemployment is defined here as unemployment that arises due to disruptions in credit markets. To this end, we define the natural levels of endogenous variables separately from flexible price levels.

Definition 2 *For the vector of aggregate, endogenous variables* $X_t = \left(Y_t, L_t, C_t, D_t, r_t, \overline{v}_t, \frac{W_t}{P_t}, \frac{M_t}{P_{t-1}}, p_t(i), P_t\right)$,

- *the* ***flexible price levels*** X_t^f *are such that* $X_t^f = X_t | \{p_t(i) = P_t = 1, \forall t\}$,
- *the* ***natural levels*** X_t^n *are such that* $X_t^n = X_t | \left\{\overline{v}_t = \widetilde{\overline{v}}, p_t(i) = P_t = 1, \forall t\right\}$,
- ***cyclical unemployment*** U_t^c *is such that* $U_t^c = L_t^n - L_t$, *and*
- ***natural unemployment*** U_t^n *is such that* $U_t^n = \widetilde{L} - L_t^n$.

Hence, cyclical unemployment arises due to quantity rationing, the failure of some firms to receive credit compared to the steady state, and the failure of prices to adjust. Natural unemployment arises due to deviations in productivity a_t from its steady state value $\widetilde{a}$. In related models without quantity rationing such as Ravenna and Walsh (2006), there is no distinction between natural and flexible price levels.

So far, there is nothing to prevent cyclical unemployment from falling below zero. While negative cyclical unemployment might seem counter-intuitive to some, it could model a situation where unemployment falls below normal levels due to excess credit flows. With the additional assumption that all firms receive financing in the steady state, $\widetilde{\overline{v}} = 1$, cyclical unemployment would be positive always. Such an assumption is not necessary for the succeeding analysis but is left as a possible option in future work.

Marginal cost depends on cyclical unemployment. Linearizing the marginal cost equation (16) gives the following.

$$\begin{aligned} \widehat{\varphi}_t &= \Theta \widehat{L}_t + \delta_a \widehat{a}_t + \delta_r \widehat{r}_t + \delta_v \widehat{\overline{v}}_t \\ \text{for } \Theta &= 1 + \eta - \alpha (1 - \sigma) \end{aligned}$$

One can also use equation (16) to express a relation between natural levels and linearize to find

$$0 = \Theta \widehat{L}_t^n + \delta_a \widehat{a}_t + \delta_r \widehat{r}_t^n$$

The fraction of unrationed firms does not appear, since credit market fluctuations do not affect natural levels. The zero on the left hand side arises, since the marginal cost is constant under flexible prices, and for natural levels as well as a consequence. Subtracting the equation linearizing around the natural levels from the previous linearization yields

$$\widehat{\varphi}_t = -\Theta \widehat{U}_t^c + \delta_r \left(\widehat{r}_t - \widehat{r}_t^n \right) + \delta_v \widehat{\overline{v}}_t. \tag{18}$$

The parameters Θ, δ_r and δ_v are all positive for reasonable parameter choices, see the proof and discussion of Proposition 1. The spread $\widehat{r}_t - \widehat{r}_t^n$ represents the difference the interest rate that assumes normal credit flows and one that does not. Therefore, the spread is a risk premium due to the possible disruption of credit flows to firms.

Combining this representation of marginal cost with equation (17), gives the Phillips Curve relation that is the focus of the empirical analysis.

$$\begin{aligned} \widehat{\pi}_t &= \delta_{-1} \widehat{\pi}_{t-1} + \delta_1 E_t \widehat{\pi}_{t+1} - \delta_U \widehat{U}_t^c + \delta_r' \left(\widehat{r}_t - \widehat{r}_t^n \right) - \delta_v' \widehat{\overline{v}}_t \qquad (19) \\ \delta_{-1} &= \frac{\varrho}{1 + \beta \varrho}, \qquad \delta_1 = \frac{\omega \beta}{1 + \omega \beta \varrho} \\ \delta_U &= \kappa \Theta, \qquad \delta_r' = \kappa \delta_r, \qquad \delta_v' = \kappa \delta_v \end{aligned}$$

Inflation dynamics are specified as usual in the New Keynesian approach, but marginal cost is replaced by cyclical unemployment and financial factors.

The roles of all the variables are intuitive. Unemployment and inflation have an inverse relationship as in the original Phillips Curve. The cost of borrowing impacts marginal cost and inflation, as in Ravenna and Walsh (2006). An easing of credit standards, meaning a rise in μ_t, leads to an increase in $\widehat{\overline{v}}_t$, which also pushes up marginal cost, since production rises and firms with higher marginal costs are able to enter. The importance of these factors independently or in combination are issues to be addressed empirically.

4 Empirical Evidence

Estimation of the Phillips Curve (19) verifies that cyclical unemployment, borrowing costs and credit market standards are important factors in inflation dynamics. Cyclical unemployment and the interest rate spread representing borrowing costs have economically significant impacts on inflation in the way specified by the model. Credit market standards, as measured by the N.Y. Fed survey of bank managers, also plays a significant role, and omitting this variable can seriously bias the estimates of the other parameters. In particular, ignoring credit market standards makes inflation appear to be more dependent on forward looking behavior.

For the estimation of the Phillips Curve (19), the data on inflation is the standard log difference of the GDP deflator, but the specification of the other variables requires a few details. The empirical analysis focuses on U.S. Data for the sample 1990Q2 to 2010Q4 coinciding with the most recent continuous reporting of the N.Y. Fed survey of bank managers. This measure of confidence is a proxy for the credit market conditions parameter μ_t, the primary determinant of the fraction of firms with financing $\overline{v}_t$. The survey data is the fraction of bank managers who report an easing of lending standards over the previous quarter[6].

Definition 2 suggests that the data series for natural unemployment should be constructed by removing the fluctuations in employment caused by productivity. However, the empirical relationship between aggregate labor market quantities such as hours worked and productivity is an unsettled issue in the literature, see Christiano, Eichenbaum and Vigfusson (2003) and Francis and Ramey (2009) for example. Furthermore, Canova, Lopez-Salido and Michelacci (2010) report that neutral technology shocks, such as the ones in the present model, have little impact on labor when long cycle fluctuations are removed from the data.

For this work, we sidestep these issues and follow Gali's (2011) development of a wage Phillips Curve by assuming a constant natural rate. Two alternative specifications using the natural rate estimate of the Congressional Budget Office (CBO) and a natural rate obtained by detrending are also examined. There are more sophisticated methods for measuring the natural rate using other data, but dealing with the potential

[6] See Lown and Morgan (2006) for a detailed description of the survey data. They present standards as the percentage of manager reporting a tightening. Strictly speaking, the data in the present work is the percentage that do not report tighter standards.

interaction of the that data with the variables used to estimate (19) is a large econometric problem beyond the scope of the present work.

The risk premium in the Phillips Curve specification (19) is represented by spread between the yields on corporate BAA bonds and the 10 year Treasury, both bonds of similar maturity. In their VAR analysis using the bank manager survey data, Lown and Morgan (2006) use a short term spread between commercial paper and T-bill rates, and we check our results for this spread at a maturity of six months. Ravenna and Walsh (2006) use the spread between the ten year and three month bond yields, but such a term premium, as opposed to a risk premium, is inappropriate for the model developed here.

Estimates are obtained with the GMM[7] using lags of the independent variables as instruments. The choice of instruments, four lags of inflation, cyclical unemployment, credit market conditions and the interest rate spread, is similar in approach to Blanchard and Gali (2007). The informativeness of the instruments is verified by inspecting the F-statistics for the OLS regression of the instruments on the independent variables. The smallest value for the F-statistic is 24.1 exceeding the minimum of 10, recommended by Stock, Wright and Yogo (2002).

The central empirical results are the estimates of the Phillips Curve (19) parameters in Table 1. The J-statistic is the measure of fit, and the associated p-value tests the null that the over-identifying restrictions are satisfied.

Table 1

δ_{-1}	δ_1	δ_U	δ'_r	δ'_v	cons	J-stat
0.63160	0.26909	-0.06316	0.35342	0.02074	-2.28309	4.9318
(0.0000)	(0.0060)	(0.0313)	(0.0014)	(0.0000)	(0.0000)	(0.8936)
0.45781	0.40008	0.00787	0.095904		0.06235	6.76317
(0.0000)	(0.0000)	(0.6925)	(0.0000)		(0.7013)	(0.8179)

GMM estimates for (19) where the natural rate of unemployment is constant.

The first line reports estimates of (19) with all variables included. The fit is good, and all the coefficients are significant. The estimate on cyclical unemployment $\widehat{\delta}_U = -0.06$ is lower than the estimate of -0.20 from Blanchard and Gali (2007), who use a different specification and sample[8], but is still economically relevant. The sign on $\widehat{\delta'}_v$ is correct according to the theoretical model. An easing of credit market standards is associated with an increase in the confidence parameter μ_t and the fraction of firms receiving financing $\overline{v}_t$.

[7] The covariance matrices are generated by the variable bandwith method of Newey and West.

[8] In particlar, their sample is for 1960-2004 and includes the value of a non-produced input.

While the economic content of the magnitude of $\widehat{\delta'}_v$ is difficult to interpret directly, it is highly statistically significant. When the credit market conditions series is removed in the second estimation, the estimates of the coefficient on unemployment is no longer statistically significant, the coefficient on the spread is much smaller and the forward looking component of inflation is larger. Comparison of these two estimations give strong evidence for the connection between quantity rationing of credit and cyclical unemployment. A reason for the failure of some estimations of Phillips Curves with unemployment may have been the omission of financial factors. Furthermore, forward looking behavior plays a smaller role when the financial market factors are included.

Table 2 shows estimates similar to those in Table 1 with an alternative definition of cyclical unemployment. Here, the variable $\widehat{U}_t^c$ is represented by the difference between the unemployment rate and the natural rate of unemployment published by the Congressional Budget Office. According to Definition 2, the natural rate of unemployment should be uncorrelated with credit market conditions. Granger causality test reject any correlation between this measure of natural unemployment and credit market conditions with p-values 0.4277 and 0.1925 for each direction of causality.

Table 2

δ_{-1}	δ_1	δ_U	δ'_r	δ'_v	cons	J-stat
0.61580	0.28340	-0.07472	0.34050	0.01744	-2.23891	5.81802
(0.0000)	(0.0036)	(0.0151)	(0.0004)	(0.0000)	(0.0000)	(0.8303)
0.37552	0.43505	-0.02416	-0.06984		0.20911	6.54728
(0.0000)	(0.0000)	(0.3429)	(0.0006)		(0.0352)	(0.8345)

GMM estimates for (19) where the natural rate of unemployment taken from the CBO.

The results are very similar to those using a constant natural rate of unemployment (Table 1). When the credit market conditions variable is removed, $\widehat{\delta}_U$ is no longer significant, and, in this case, neither is $\widehat{\delta'_r}$. The change in the importance of inflation expectations with the removal of the survey data is even more dramatic. In all the estimations, if the data on credit market conditions is removed as instruments and as an independent variable, the estimates of $\widehat{\delta'_r}$ become statistically insignificant.

A third specification of the natural rate of unemployment is obtained through detrending. Cyclical unemployment is the difference between the unemployment rate[9] and the trend created with the Hodrick-Prescott filter with a high smoothing parameter ($\lambda = 10,000$), as in Shimer (2005), since lower values create

[9] Besides the survey data from the N.Y. Fed, all other data come from the St. Louis Fed database.

excess variation in the natural rate represented by the trend. For example, with the value $\lambda = 1600$, there is no cyclical unemployment by 2010Q4, when other studies (Weidner and Williams 2011) with different methodology estimate it to be 2% at minimum. The results for this specification are in Table 3.

Table 3

δ_{-1}	δ_1	δ_U	δ_r'	δ_v'	cons	J-stat
0.68444	0.343929	-0.08506	0.32884	-0.01683	-2.16500	6.59383
(0.0000)	(0.1237)	(0.0289)	(0.0044)	(0.0001)	(0.0002)	(0.7722)
0.31822	0.50255	0.04261	0.06042		0.23350	6.06353
(0.0000)	(0.0000)	(0.0830)	(0.0033)		(0.0047)	(0.8691)

GMM estimates for (19) where the natural rate of unemployment is obtained by detrending.

The results are similar to those in Tables 1 and 2, though the estimate of $\widehat{\delta}_U$ is larger and quite close to the estimate in Blanchard and Gali (2007). These estimates must be treated with caution; however, since the detrended specification for natural unemployment is correlated with the credit market conditions data.

The results indicate that expectations are not as important to inflation dynamics as previously thought. While the coefficient on expected inflation in other GMM estimates of the a Phillips curve (Gali, Gertler, Lopez-Salido (2001), Blanchard and Gali (2007) are typically above 0.6, the estimates of δ_1 are below 0.4 when credit market conditions are taken into account. These results suggest that ignoring financial factors gives an upward bias to the coefficients on forward looking variables, but more evidence is needed before this conjecture is accepted over alternative explanations.

There are two major alternative approaches to modeling and estimating the Phillips Curve. Blanchard and Gali (2007) impose real wage rigidity, which allows them to define involuntary unemployment and generate inflation persistence without price indexation. Their estimation results concerning the importance of unemployment are similar to the findings in the present work. Their estimates also show significant persistence, though expectations play a more important role in their estimations. The connection between real wage rigidity and unemployment is intuitive though the persistence of the effect is questionable. Developing a model with both wage rigidity and financial frictions is a promising avenue for future work.

Cogley and Sbordone (2008) estimate a Phillips curve with time varying trend inflation, using unit labor cost as a proxy for marginal cost. With a time varying trend, inflation is much less persistent.. Linearizing around a constant trend is defensible for the sample 1990-2010, when the credibility of the Federal Reserve was high. In contrast, trend inflation shows large variations in the results of Cogley and Sbordone (2008).

An additional issue is their assumption of a constant trend for marginal cost, which may be less appropriate than a constant trend for inflation. Estimating a model with both financial factors and time varying variables is another import area for research to reconcile these results.

5 Conclusion

Inflation dynamics depend on financial factors including both borrowing costs and quantity rationing of credit, as demonstrated by the theoretical model based on heterogeneous firm need for financing and estimation of the resulting Phillips curve using data for a risk premium and credit market conditions. Cyclical unemployment is defined as the unemployment arising due to a disruption in credit flows, and it has an intuitive relationship with inflation.

The approach presented here has implications for future theoretical and policy work. The heterogeneity in the need for financing could apply to financing of investment purchases or consumption. The distinction of cyclical unemployment from natural unemployment based on quantity rationing of credit has important implications for the proper unemployment target for policymakers. Furthermore, the connection between the credit and labor markets demonstrates the potential use of non-traditional policy interventions in financial markets to stabilize aggregate variables.

Appendix

The expression for the aggregate financing cost (14) is obtained by substituting for $l_t(v_t, i)$ in the aggregate lending relation (6), using the labor demand equation (3), where $F(v_t) = v_t$.

$$\xi_t^e(i) = (\alpha a_t)^{\frac{1}{1-\alpha}} W_t \left(\frac{W_t}{p_t(i)}\right)^{\frac{1}{\alpha-1}} \int_0^{\overline{v}_t} v_t (1 + r_t v_t)^{\frac{1}{\alpha-1}} dv_t$$

Integration by parts is used to obtain a solution for the integral expression above.

$$\begin{aligned}
\int_0^{\overline{v}_t} v_t (1 + r_t v_t)^{\frac{1}{\alpha-1}} dv_t &= v_t \left(\frac{\alpha-1}{\alpha}\right) r_t^{-1} (1 + r_t v_t)^{\frac{\alpha}{\alpha-1}} |_0^{\overline{v}_t} - \int_0^{\overline{v}_t} \left(\frac{\alpha-1}{\alpha}\right) r_t^{-1} (1 + r_t v_t)^{\frac{\alpha}{\alpha-1}} dv_t \\
&= \overline{v}_t \left(\frac{\alpha-1}{\alpha}\right) r_t^{-1} (1 + r_t \overline{v}_t)^{\frac{\alpha}{\alpha-1}} - \frac{(\alpha-1)^2}{\alpha(2\alpha-1)} r_t^{-2} \left[1 - (1 + r_t \overline{v}_t)^{\frac{2\alpha-1}{\alpha-1}}\right]
\end{aligned}$$

Substituting the expression for the integral back into the above expression for $\xi_t^e(i)$ yields the relation (14).

The proof of Proposition 1 follows.

Proof. From equation (16), the derivative of $J(\cdot)$ with respect to $\overline{v}_t$ is

$$\frac{d}{d\overline{v}_t}J(\cdot)=\chi\left\{(\sigma-1)\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]^{\sigma-2}\frac{d}{d\overline{v}_t}\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]\left(1+\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right)+\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]^{\sigma-1}\frac{d}{d\overline{v}_t}\left[\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right]\right\}.$$

The functions $\Upsilon(\cdot)$, $\vartheta(\cdot)$, and $\Phi(\cdot)$ are all positive by construction, so the above ratios of these functions must be positive as well. Given the assumption in proposition 1 that $\sigma>1$, if the signs of the derivatives inside $\{\cdot\}$ are both positive, then the sign of $\frac{d}{d\overline{v}_t}J(\cdot)$ is positive.

The sign of $\frac{dJ(\cdot)}{d\overline{v}_t}$ depends on the signs of the derivatives inside $\{\cdot\}$. To show that $\frac{d}{d\overline{v}_t}\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]>0$, and $\frac{d}{d\overline{v}_t}\left[\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right]>0$, note that

$$\frac{d}{d\overline{v}_t}\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]=\Upsilon(\cdot)^{-\alpha-1}\left[\frac{d\vartheta(\cdot)}{d\overline{v}_t}\Upsilon(\cdot)-\alpha\frac{d\Upsilon(\cdot)}{d\overline{v}_t}\vartheta(\cdot)\right],$$

and

$$\frac{d}{d\overline{v}_t}\left[\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right]=\Upsilon(\cdot)^{-2}\left[\frac{d\Phi(\cdot)}{d\overline{v}_t}\Upsilon(\cdot)-\frac{d\Upsilon(\cdot)}{d\overline{v}_t}\Phi(\cdot)\right].$$

Using the specifications in equations (11), (12), and (14), we can compute the following derivatives.

$$\begin{aligned}\frac{d\Upsilon(\cdot)}{d\overline{v}_t}&=(\alpha a_t)^{\frac{1}{1-\alpha}}(1+r_t\overline{v}_t)^{\frac{1}{\alpha-1}}\\ \frac{d\vartheta(\cdot)}{d\overline{v}_t}&=\alpha^{-1}(\alpha a_t)^{\frac{1}{1-\alpha}}(1+r_t\overline{v}_t)^{\frac{\alpha}{\alpha-1}}\\ \frac{d\Phi(\cdot)}{d\overline{v}_t}&=(\alpha a_t)^{\frac{1}{1-\alpha}}r_tv_t(1+r_t\overline{v}_t)^{\frac{1}{\alpha-1}}\end{aligned}$$

The $[\cdot]$ term in $\frac{d}{d\overline{v}_t}\left[\frac{\vartheta(\cdot)}{\Upsilon(\cdot)^{\alpha}}\right]$ can be written as

$$\begin{aligned}&\frac{d\vartheta(\cdot)}{d\overline{v}_t}\Upsilon(\cdot)-\alpha\frac{d\Upsilon(\cdot)}{d\overline{v}_t}\vartheta(\cdot)\\ =\;&(\alpha a_t)^{\frac{2}{1-\alpha}}\alpha^{-2}(1-\alpha)r_t^{-1}(1+r_t\overline{v}_t)^{\frac{\alpha}{\alpha-1}}\left[1-\alpha^2(1+r_t\overline{v}_t)^{-1}-\left(1-\alpha^2\right)(1+r_t\overline{v}_t)^{\frac{\alpha}{\alpha-1}}\right]\end{aligned}$$

For $\alpha>\frac{1}{2}$, $(1+r_t\overline{v}_t)^{\frac{\alpha}{\alpha-1}}<1$. Furthermore, the term $(1+r_t\overline{v}_t)^{-1}$ is also less than one so the $[\cdot]$ term above must be positive. Therefore, it is also the case that $\frac{d\vartheta(\cdot)}{d\overline{v}_t}\Upsilon(\cdot)-\alpha\frac{d\Upsilon(\cdot)}{d\overline{v}_t}\vartheta(\cdot)>0$.

The $[\cdot]$ term in $\frac{d}{d\overline{v}_t}\left[\frac{\Phi(\cdot)}{\Upsilon(\cdot)}\right]$ can be written as

$$\begin{aligned}&\frac{d\Phi(\cdot)}{d\overline{v}_t}\Upsilon(\cdot)-\frac{d\Upsilon(\cdot)}{d\overline{v}_t}\Phi(\cdot)\\ =\;&(\alpha a_t)^{\frac{2}{1-\alpha}}\alpha^{-1}(1-\alpha)r_t^{-1}(1+r_t\overline{v}_t)^{\frac{1}{\alpha-1}}\left\{r_t\overline{v}_t-\left(\frac{1-\alpha}{2\alpha-1}\right)\left[1-(1+r_t\overline{v}_t)^{\frac{2\alpha-1}{\alpha-1}}\right]\right\}\end{aligned}$$

For any strictly convex function $f(x)$, it must be the case that $f(x) - f(y) > f'(y)(x-y)$. Since, for $\alpha > \frac{1}{2}$, $(1+x)^{\frac{2\alpha-1}{\alpha-1}}$ is convex, then setting $x = r_t \overline{v}_t$ and $y = 0$, it must be true that $(1+r_t\overline{v}_t)^{\frac{2\alpha-1}{\alpha-1}} - 1 > \left(\frac{2\alpha-1}{\alpha-1}\right) r_t \overline{v}_t$ or equivalently $r_t \overline{v}_t > \left(\frac{1-\alpha}{2\alpha-1}\right)\left[1-(1+r_t\overline{v}_t)^{\frac{2\alpha-1}{\alpha-1}}\right]$, noting that $\frac{1-\alpha}{2\alpha-1} < 0$. Hence, the $\{\cdot\}$ term in the above equation must be positive, and so $\frac{d\Phi(\cdot)}{d\overline{v}_t}\Upsilon(\cdot) - \frac{d\Upsilon(\cdot)}{d\overline{v}_t}\Phi(\cdot) > 0$ as well.

Therefore, both derivatives in the expression for $\frac{d}{d\overline{v}_t}J(\cdot)$ above are positive, which implies that $J(\cdot)$ is increasing in $\overline{v}_t$, as required. ■

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