# Monetary Policy and Asset Prices when Credit Markets are Imperfect

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I. Introduction.

A fundamental result in the theory of corporate finance is the Modigliani-Miller theorem. The theorem states that in a world with perfect capital markets a firm's financial position (debt vs. equity level) is irrelevant to its decisions on production and investment activities. This separation occurs because perfect capital markets allow information to flow easily: if the entrepreneur has a good idea for a new product, then the product will be produced irregardless of her personal financial position because outside investors will see through her to the profit opportunity in the good project, and provide any needed financing.

The Modigliani-Miller irrelevance result on financial position has important implications for monetary policy. Since worthy production activities will be funded regardless of the financial position of the underlying entrepreneur, there is no reason for monetary policy to respond to asset prices.[1] The Modiglani-Miller theorem, however, is not necessarily meant to be a statement of reality. In fact, there is a voluminous empirical literature that provides evidence that financial position does affect a firm's ability to operate. The question is whether these departures from Modigliani-Miller will provide a rationale for monetary policy to depend on equity prices. As it stands the theorem provides an important benchmark and forces one to think carefully about the workings of financial markets, and what imperfections would create a world in which a firm's financial position (and hence equity prices) does affect its ability to engage in production.

There are many possible imperfections that could generate such a world. In this Review we focus on an informational story. Suppose that only the entrepreneur knows the intricate details of his/her proposed project. If outside investors provide financing to the entrepreneur they have no way of knowing for sure what she will do with their funds. Furthermore, suppose that the outside investors have limited ability to punish the entrepreneur after the fact if he/she runs off with their money, or squanders the funds on misguided production activity. In such a scenario external investors will likely provide financing only if they are sure they can recoup their investment if things turn sour. One way of ensuring this is to limit the size of their financing to the entrepreneur's financial position. That is, external financing will be limited to the value of the entrepreneur's collateral that can be seized after the fact.

The previous paragraph outlines a story in which financial position, or what we will henceforth call "collateral" or "net worth", has a fundamental affect on a firm's

[1] A response might be warranted if equity prices aid in forecasting macro variables of interest such as output and inflation.

ability to engage in production. Increases in equity prices will increase this collateral and thus a firm's ability to produce. This is not a Modigliani-Miller world. What is the role of monetary policy in such a world? Can monetary policy help the economy respond to fundamental shocks buffeting the system? Should monetary policy respond to asset prices in such a world?

This paper addresses these questions in a theoretical model. To keep the analysis tractable the model is highly stylized, but the essential point will survive more complicated modeling environments.[2] A key conclusion is that there is a role for activist monetary policy. The informational restrictions impose a collateral constraint on this economy, and monetary policy can be usefully employed to alleviate this constraint in response to shocks. These shocks may emanate from changes in the production possibilities of a firm (ie., productivity shocks) or from exogenous changes in equity prices.

## II. The Model

The theoretical model consists of households and entrepreneurs. We will discuss the decision problems of each in turn.

*Households:*

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[2] For example, there is empirical evidence that small firms are more affected by collateral constraints than are large firms (see Gerlter and Gilcrhist (1999)). We abstract from this heterogeneity and simply posit a single representative firm. In future work that attempts to quantify the size of these collateral effects, this heterogeneity should be modeled more explicitly.

Households are infinitely lived, discounting the future at rate β. Their period-by-period utility function is given by

$$U(c_t, L_t) \equiv c_t - \frac{L_t^{1+\frac{1}{\tau}}}{1+\frac{1}{\tau}} \qquad (1)$$

where $c_t$ denotes consumption and $L_t$ denotes work effort. We choose this particular functional form for convenience. Each period the household chooses how much to work at a real wage of $w_t$. The resulting labor supply relationship is given by

$$L_t = \left(\frac{w_t}{R_t}\right)^{\tau}. \qquad (2)$$

Notice that labor supply responds positively to the real wage with elasticity τ. $R_t$ denotes the gross nominal interest rate. Labor supply is negatively related to the nominal rate because we assume that households must use cash to facilitate their consumption purchases. That is, there is a "cash-in-advance constraint" on consumption purchases.[3] The opportunity cost of holding cash is given by the gross nominal rate. Hence, higher nominal rates make it more difficult to turn labor income into consumption, and thus higher nominal rates discourage labor supply. Another way of thinking about it is that the gross nominal interest rate acts like a wage tax where $\frac{1}{R_t} = (1 - t_w)$. The basis of the celebrated "Friedman rule" that the net nominal interest rate should be zero (or R=1)

[3] See the appendix for a precise statement of the household's problem and the resulting first order conditions.

comes directly from this observation: a zero interest rate eliminates this implicit wage tax.[4]

The other choice a household must make is its consumption vs. savings decision. The only means of savings by households is in the form of acquiring shares to a real asset that pays out (real) dividends of $D_t$ consumption goods at the end of time-t. It is helpful to think of this as an apple tree that produces $D_t$ apples in time-t. The tree trades at share price $q_t$ at the beginning of the period (before the time-t dividend is paid). Under our assumption on household preferences, the equilibrium real share price is given by the present discounted value of dividends (the assumption of linear utility implies that the discount rate on dividends is the constant β):

$$\bar{q}_t = E_t \sum_{j=0}^{\infty} \beta^j D_{t+j} \tag{3}$$

If the share price were below this level ($q_t < \bar{q}_t$), then household demand for shares would be infinite; if the share price were above this level ($q_t > \bar{q}_t$), then household demand for shares would be zero. Hence, households will hold a finite and positive level of tree shares only if $\bar{q}_t$ is the equilibrium price. The dividend process is given by

$$D_{t+1} = (1-\rho_D)D_{ss} + \rho_D D_t + \varepsilon_{t+1}^D .$$

The symbol $E_t$ denotes the rational forecast of future dividends, and recall that β is the rate of household time preference. Notice that the asset price depends only upon the exogenous dividend process, and the share price is increasing in the current and future

[4] In our model the first best policy will be the Friedman rule. In our policy section we analyze a second-best problem where for some unspecified reason the monetary authority desires to keep the long-run average interest rate above zero, R > 1.

dividend levels. The exogenous discount process is an AR1 which simply means that next period's dividend is a weighted average of today's dividend ($D_t$) and the long-run average of divideds ($D_{ss}$) plus a random i.i.d. shock $\varepsilon_{t+1}^{D}$.

*Entrepreneurs:*

Entrepreneurs are also infinitely-lived with linear preferences over consumption. They are distinct from households in that they operate a constant returns to scale production technology that uses labor to produce consumption goods:

$$y_t = A_t H_t \tag{4}$$

where $A_t$ is the current level of productivity, and $H_t$ denotes the number of workers employed at real wage $w_t$. Like dividends productivity ($A_t$) is an exogenous AR1 random process given by

$$A_{t+1} = (1-\rho_A)A_{ss} + \rho_A A_t + \varepsilon_{t+1}^{A}.$$

The entrepreneur is constrained by a borrowing limit. In particular, the entrepreneur must be able to cover her entire wage bill with collateral accumulated in advance. We will denote this collateral as $n_t$ for "net worth". The loan constraint is thus

$$w_t H_t \le n_t. \tag{5}$$

(Notice that all variables are in real terms.)

Why is the firm so constrained? There are many possible informational stories that would motivate such a constraint. We will assume the classic hold-up problem. Suppose that the hired workers first supply their labor input, but that output is subsequently produced if and only if the entrepreneur provides his unique human capital to the process. This sequence of production implies that the entrepreneur could force workers to accept lower wages ex post for otherwise nothing would be produced. Workers will anticipate this hold-up possibility, and thus will take steps in advance to mitigate them. This is not as easy as it sounds. For example, an equity-type arrangement in which the worker and entrepreneur agree ex ante to split the production ex post will not work. After the worker has supplied his labor the entrepreneur can refuse to provide her unique human capital unless the worker share is made arbitrarily small. The worker's only choice is to accept this small share or take nothing. The worker could seize the existing assets of the entrepreneur, but then we are back to our collateral constraint. In fact, as demonstrated by Hart and Moore (1994) and Kiyotaki and Moore (1997), these hold-up problems can be entirely avoided if the wage bill is entirely covered by existing collateral that the workers could simply seize in case of default.[5]

We can easily enrich this story by assuming that there exist financial institutions that intermediate between workers and entrepreneurs. For example, suppose that these intermediaries provide within-period financing to entrepreneurs, and that this financing is used by firms to pay workers. The intermediary, however, is concerned about the hold-up problem, and thus limits its lending to the firm's net worth. Hence we once again have the collateral constraint (5).[6]

Below we will assume that the loan constraint binds so that labor demand is given by

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[5] This implicitly assumes a one-period problem so that there is no way to punish an entreprenuer for not supplying his labor by taking away future income.

[6] Kiyotaki and Moore (1997) use a similar constraint. See Hart and Moore (1994) for more discussion of the hold-up problem.

$$H_t = \left(\frac{n_t}{w_t}\right). \tag{6}$$

Notice that labor demand varies inversely (with a unit elasticity) to the real wage, but is positively affected by the level of net worth. Firms that have more collateral are able to employ more workers because hold-up problems are less severe. The binding collateral constraint implies that $A_t > w_t$, ie., the firm would like to hire more workers but is collateral-constrained.

Entrepreneurs' sole source of net worth is previously acquired ownership of apple trees. If we let $e_{t-1}$ denote the number of tree shares acquired at the beginning of time t-1, then time-t net worth is given by

$$n_t = e_{t-1}q_t \tag{7}$$

so that the loan constraint is given by

$$w_t H_t \leq e_{t-1}q_t. \tag{8}$$

As noted above, the assumption that the loan constraint is binding implies that the firm's marginal profits per worker employed is ($A_t$-$w_t$). These profits motivate the entrepreneur to acquire more net worth. We will need to limit this accumulation tendency so that collateral remains relevant. The entrepreneur's budget constraint is given by

$$c_t^e + e_t q_t = e_{t-1}q_t + e_t D_t + H_t(A_t - w_t) \tag{9}$$

The right hand side of the budget constraint is the income of the entrepreneur in period t: revenue from the entrepreneur selling his existing trees ($e_{t-1}q_t$), dividends from new tree purchases ($e_t D_t$) and profits ($H_t(A_t - w_t)$). The left hand side represents her potential purchases in period t. She either buys consumption with this revenue ( $c_t^e$ ) or purchases new trees shares ( $e_t q_t$ ). Using the binding loan constraint, we can rewrite this as

$$c_t^e + e_t(q_t - D_t) = e_{t-1} q_t \frac{A_t}{w_t} \tag{10}$$

Because of the profit opportunities from net worth ($A_t > w_t$), the entrepreneur would like to accumulate trees until the constraint no longer binds (trees are more valuable to collateral-constrained entrepreneurs than they are to households). To prevent this from happening we will assume that the entrepreneurs must consume a fraction of their net income each period:

$$c_t^e = e_t D_t + (1-\gamma) e_{t-1} q_t \frac{A_t}{w_t}. \tag{11}$$

For simplicity we also assume that they consume all of their current dividends. Hence, entrepreneurial tree holdings evolve as

$$e_t = \gamma e_{t-1} \frac{A_t}{w_t} \tag{12}$$

Below we will choose $\gamma < 1$ to offset the high return to internal funds and thus keep the entrepreneur collateral constrained in equilibrium. This forced consumption-savings decision implies that trees will be priced by households so that the equilibrium price of trees will be $q_t = \overline{q}_t$.

*Equilibrium*

There are two active markets in this theoretical model, the market for apple trees and the labor market (the money market and bond market are discussed in the appendix).

We normalize the supply of tree shares to unity so that the asset market clears with $e_t + s_t = 1$. The equilibrium tree price is given above by (3). As for the labor market, equating labor supply to labor demand ($L_t = H_t$) and solving for the real wage yields

$$w_t = n_t^{\frac{1}{1+\tau}} R_t^{\frac{\tau}{\tau+1}} \tag{13}$$

The equilibrium real wage is increasing in net worth because higher net worth increases labor demand. The wage is also increasing in the nominal interest rate because a higher nominal rate decreases labor supply. Equilibrium employment is given by

$$L_t = \left(\frac{n_t}{R_t}\right)^{\frac{\tau}{1+\tau}}. \tag{14}$$

Employment responds positively to net worth, and negatively to the nominal rate for the reasons noted above.

*Log-Linearizing the Model.*

Because the model is relatively simple, it is convenient to express the equilibrium in terms of log-deviations. Below the ~'s represent percent deviations from steady-state.

$$\tilde{L}_t = \frac{\tau}{1+\tau}\left(\tilde{n}_t - \tilde{R}_t\right) \tag{15}$$

$$\tilde{n}_t = \tilde{q}_t + \tilde{e}_{t-1} \tag{16}$$

$$\tilde{e}_t = \frac{\tau}{1+\tau}\tilde{e}_{t-1} + \tilde{A}_t - \frac{1}{1+\tau}\tilde{q}_t - \frac{\tau}{1+\tau}\tilde{R}_t \tag{17}$$

where (17) comes from (12) and the asset-price (3). Using (16) to eliminate $n_t$ we can write (15) as:

$$\tilde{L}_t = \frac{\tau}{1+\tau}\left(\tilde{q}_t + \tilde{e}_{t-1} - \tilde{R}_t\right) \tag{18}$$

In (17) we will use the fact that the share price (3) can be expressed as

$$\tilde{q}_t = \tilde{D}_t\left(\frac{1-\beta}{1-\beta\rho_D}\right) \tag{19}$$

where $\rho_D$ is the autocorrelation in the dividend process. In summary, the model consists of equations (17)-(19). There is one predetermined variable, $e_{t-1}$, and three exogenous shocks: $A_t$, $D_t$, and $R_t$.

Before turning to the question of monetary policy, it is useful to sharpen one's economic intuition about the model by considering several experiments.

*Experiment 1: A Shock to Productivity ($A_t$).*

Suppose that we hold all other variables constant, and only consider shocks to productivity. Then we have:

$$\tilde{L}_t = \frac{\tau}{1+\tau}\tilde{e}_{t-1} \tag{20}$$

$$\tilde{e}_t = \frac{\tau}{1+\tau}\tilde{e}_{t-1} + \tilde{A}_t \tag{21}$$

Combining we have:

$$\tilde{L}_{t+1} = \frac{\tau}{1+\tau}\left(\tilde{L}_t + \tilde{A}_t\right). \tag{22}$$

Notice that contemporaneous employment does not respond to shocks to productivity, $A_t$ (see (20)). This is a manifestation of the collateral constraint. When productivity is high, the firm would like to expand employment but is unable to do so because of the need to finance current activity with current collateral. Thus, the collateral constraint limits the ability of the firm to respond to shocks.

There is, however, a delayed response. A positive shock to $A_t$ has no effect on current employment, but raises $e_t$ and thus tomorrow's net worth (see (21)). Hence, employment responds with a lag to shocks to productivity.

This lagged response generates persistence to a temporary a shock. That is, even if there is only a temporary one period shock to $A_t$, the effect on employment $L_t$ and thus output is much longer and only dies out at the rate given by $\tau/(1+\tau)$. If the shock to productivity is serially correlated, this effect remains so that the collateral constraint causes a productivity shock to have a more persistent effect

*Experiment 2: A Shock to Dividends.*

Proceeding as before we have:

$$\tilde{L}_t = \frac{\tau}{1+\tau}\tilde{e}_{t-1} + \left(\frac{\tau}{1+\tau}\right)\left(\frac{1-\beta}{1-\beta\rho_D}\right)\tilde{D}_t \qquad (23)$$

$$\tilde{e}_t = \frac{\tau}{1+\tau}\tilde{e}_{t-1} - \left(\frac{1}{1+\tau}\right)\left(\frac{1-\beta}{1-\beta\rho_D}\right)\tilde{D}_t \qquad (24)$$

Combining we have:

$$\tilde{L}_t = \frac{\tau}{1+\tau}\left(\tilde{L}_{t-1} + \left(\frac{1-\beta}{1-\beta\rho_D}\right)(D_t - D_{t-1})\right)$$

The most remarkable observation is that employment responds positively to dividend shocks even though these shocks have no effect on worker productivity nor on labor supply. Instead, the effect of dividends on employment comes entirely through the collateral constraint.  Because trees are used as collateral, and a dividend shock drives up the price of trees, the collateral constraint is relaxed and the firm is able to expand employment.  Once again these effects are highly persistent.

*Experiment 3: A Monetary Policy Shock.*

We will assume that monetary policy is given by directives for the gross nominal interest rate $R_t$.  The implied path for the money supply can be backed out of the money demand relationship (please see the appendix).

Proceeding as before we have:

$$\tilde{L}_t = \frac{\tau}{1+\tau}(\tilde{e}_{t-1} - \tilde{R}_t) \tag{25}$$

$$\tilde{e}_t = \frac{\tau}{1+\tau}(\tilde{e}_{t-1} - \tilde{R}_t) \tag{26}$$

Combining we have:

$$\tilde{L}_t = \frac{\tau}{1+\tau}\left(\tilde{L}_{t-1} - \tilde{R}_t\right). \tag{27}$$

There are two differences between the interest rate shock and the productivity shock. First, the interest rate shock has an immediate effect on employment as it alters labor supply contemporaneously.  Second, the effect is negative as the higher interest rate lowers the desire of households to work.  As in the previous cases, the shock has a persistent effect via the collateral constraint.

*Optimal Monetary Policy*

What is the optimal response of the nominal interest rate to productivity and dividend shocks? To answer such a question we need a welfare criterion. The most natural choice in the present context is the sum of household and entrepreneurial utility. This is given by

$$V_t \equiv c_t + c_t^e - \frac{L_t^{1+\frac{1}{\tau}}}{1+\frac{1}{\tau}} = A_t L_t + D_t - \frac{L_t^{1+\frac{1}{\tau}}}{1+\frac{1}{\tau}}, \tag{28}$$

where the equality follows from the fact that total time-t consumption must equal the total supply of time-t consumption goods. This supply comes from those goods produced using the entrepreneur’s production technology, and the dividends that are produced by the apple tree. The only choice variable in $V_t$ is employment. Maximizing $V_t$ with respect to $L_t$ yields the following optimality condition

$$L_t = A_t^{\tau}. \tag{29}$$

We will call this solution the “first best” outcome because the welfare criterion cannot be made any higher. Notice two natural features of the first best. First, employment responds positively to productivity shocks. When productivity is high, it is efficient for employment to respond positively. Second, the first best employment does not respond to dividend or share prices. The welfare criterion $V_t$ is increasing in $D_t$, but these shocks have no effect on labor productivity, and thus it is efficient for employment to not respond to these shocks.

Is the first-best achievable? If there was no collateral constraint, then we would have $w_t = A_t$ and the first-best could be achieved by setting $R_t = 1$, ie., setting the net nominal rate to zero. This is the celebrated Friedman rule. It is optimal in this model because of the cash-in-advance constraint on consumption which distorts the labor margin.

But in a world with agency costs, this first-best is not possible because employment is given by (14), which, as noted above, is too low ($A_t > w_t$) because of the collateral constraint, Furthermore, according to (14), employment fluctuates with net worth and not with the level of productivity. Compared to the first-best outcome, these employment responses are dreadful: contemporaneous employment does not respond to productivity even though it is efficient to do so, but employment does respond to share prices which, in an efficient world, should have no effect on employment. In short, the collateral constraint causes the economy to under respond to productivity shocks, and to over respond to dividend shocks.

The advantage of following Friedman's rule is that it minimizes the distortion on labor from the cash-in-advance-constraint.[7] The disadvantage is that a pegged zero nominal interest rate precludes the monetary authority from responding to shocks to get employment to respond efficiently. It turns out that the benefit of a lower nominal interest rate always wins out in this environment –the first best policy is to simply set the nominal interest rate to zero (i.e., R=1) and leave it there. But what happens if the monetary authority does not set the long-run interest rate to zero but keeps it positive for some unspecified reason?[8] Can monetary policy improve on this economy's ability to

[7] Recall that because cash must be held to facilitate transactions, higher nominal rates discouraged labor supply in (2).

[8] For example, a positive nominal interest rate may be set so that the government receives inflation-tax revenues.

respond to shocks in this world? Yes. To illustrate this ability, let us consider a second best exercise.

*Optimal Policy in Log-Deviations.*

We take the steady state of the economy as given and simply use monetary policy so that the economy responds to shocks efficiently. Optimal employment (in log deviations) is given by

$$\tilde{L}_t = \tau \tilde{A}_t . \qquad (34)$$

To find the optimal (second-best) interest rate policy, we can impose (34) in the system (18)-(19), and back out the implied interest rate. This exercise yields the following:

$$\tilde{R}_t = \tilde{q}_t + \tilde{e}_{t-1} - (1+\tau)\tilde{A}_t \qquad (35)$$

$$\tilde{e}_t = (1+\tau)\tilde{A}_t - \tilde{q}_t \qquad (36)$$

Combining we have

$$\tilde{R}_t = [\tilde{q}_t - \tilde{q}_{t-1}] - (1+\tau)\left[\varepsilon_t^A + (\rho_A - 1)\tilde{A}_{t-1}\right]$$

There are several observations of interest.

What are the properties of this (second-best) optimal monetary policy?[9] When there is a positive shock to productivity $A_t$, the central bank should lower the nominal interest rate so that employment can expand in an efficient manner. A constant interest rate policy does not allow this because of the collateral constraint. This procyclical

[9] Optimal monetary policy refers to how the central bank should change the interest rate to shocks to technology shocks and share prices. Money growth is endogenous and as discussed in the appendix can be backed out of the money demand relationship, that is, the cash-in-advance constraint.

interest rate policy overcomes the collateral constraint and allows the economy to respond appropriately.

Suppose that shocks to productivity are autocorrelated with coefficient $\rho_A$. A positive technology shock of 1% calls for an immediate interest rate decline of $(1+\tau)$%, but then an increase to $(1+\tau)(1-\rho_A)$. The increase is needed to prevent an overexpansion of employment arising from the fact that net worth will rise with the initial interest rate decline.

In contrast, if there is a shock to share prices that drives up $n_t$, the central bank should increase the interest rate by enough to keep employment constant. It is inefficient for employment to respond to these dividend shocks, and the central bank can ensure no response by raising the nominal rate in response.

*Conclusion*

This paper addresses the question of how monetary policy should be conducted in a world in which in which asset prices have a direct effect on real activity because of binding collateral constraints, that is a world in which the Modigliani-Miller theorem does not hold. How should monetary policy be conducted in such a world? Should policy respond to asset prices? How should policy respond to productivity movements? In this environment there is a welfare-improving role for a monetary policy that will actively respond to asset price and productivity shocks. This activist interest rate policy allows the economy to respond to shocks in a Pareto efficient manner. By assumption, monetary policy cannot eliminate the long run impact of the informational constraint, but it can smooth the fluctuations in this constraint. This smoothing is welfare-improving.

Our results are quite stark since all firms in the economy are subject to this hold-up problem. One can imagine an environment in which mostly smaller firms are subject to agency costs. This will change the quantitative predictions of the model but not the qualitative predictions.

This Review uses a monetary model with flexible nominal prices. In contrast, Bernanke and Gertler (1999) analyze a similar question in a model with sticky prices. They conclude that as long as monetary policy responds aggressively to inflation then there is no rationale for a direct response to asset prices. This conclusion arises because in their model asset price shocks directly increase aggregate demand and thus the price level. Hence, a policy that responds aggressively to inflation is automatically responding to asset prices. In the model of this Review, there is no direct link between inflation and asset prices so that the central bank must respond directly to the latter. This Review suggests that to the extent that asset prices do not immediately lead to price inflation, then there may be a role for a monetary policy response to asset price movements.

**Appendix 1**

The household's maximization problem is given by

$$\text{Max} \qquad E\sum_{t=0}^{\infty} \beta^{t}\left\{c_t - \frac{L_t^{1+\frac{1}{\tau}}}{1+\frac{1}{\tau}}\right\}$$

s.t.

$$\frac{M_{t-1}+X_t}{P_t} + s_{t-1}q_t + s_t D_t + \frac{R_{t-1}B_{t-1} - B_t}{P_t} - s_t q_t - c_t \geq 0$$

$$\frac{M_{t-1}+X_t}{P_t} + s_{t-1}q_t + s_t D_t + w_t L_t + \frac{R_{t-1}B_{t-1} - B_t}{P_t} - s_t q_t - c_t - \frac{M_t}{P_t} \geq 0$$

where $B_t$ denotes bond holdings (in zero net supply), and lump-sum monetary injections, $X_t = \frac{M_t^s}{M_{t-1}^s} - 1$, are assumed to be given to the households at the beginning of the period ($M_t^s$ denotes the time-t per capita money supply). Notice that the bond and tree markets open either simultaneous to or before the consumption market. The first constraint is the cash-in-advance constraint: the cash remaining after leaving the bond and tree markets is the cash that can be used to purchase consumption. The second constraint is the intertemporal budget constraint.

After minor simplification household optimization is defined by the binding cash constraint and the following Euler equations:

$$1 = \beta R_t E_t(P_t / P_{t+1}) \qquad (A1)$$

$$L^{1/\tau} = w_t \beta E_t\left(\frac{P_t}{P_{t+1}}\right) \qquad (A2)$$

$s_t = \infty$ if $q_t < \overline{q}_t$

$s_t$ indeterminate if $q_t = \overline{q}_t$

$s_t = 0$ if $q_t > \overline{q}_t$, where

$$\overline{q}_t = D_t + E_t \beta \overline{q}_{t+1}$$

Substituting (A1) into (A2), we have

$$L_t = \left(\frac{w_t}{R_t}\right)^{\tau}$$

which is equation (2) in the text. Along with the equilibrium conditions given in the text, we also have $B_t = 0$ and $M_t^s = M_t$. Since we are following an interest rate policy, the implied inflation behavior is given by (A1). The supporting money growth process can then be found by backing it out of the binding cash-in-advance constraint.

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