Anticipated Inflation in a Neoclassical Growth Model with a Cash-in-advance Constraint*

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Abstract: Sufficient conditions for the long run non-superneutrality of money are established in a neoclassical growth model with a labor-leisure choice. Money is held to satisfy a cash-in-advance constraint on consumption purchases. Production requires capital and labor while period utility depends on consumption and leisure. Sufficient conditions for increased money growth to reduce output in the long run are: (1) the crosspartial derivative of the production function is non-negative (capital and labor are complements in production), and (2) the crosspartial derivative of the period utility function is non-negative (consumption and leisure are complements in utility).

Keywords: anticipated inflation, superneutrality of money, cash-in-advance

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1. Introduction

Empirical evidence points to a negative correlation between money growth and economic performance; see, among others, Kormendi and Meguire (1985), De Gregorio (1993) and Gomme (1993). An early effort to reconcile this result with economic theory is Stockman (1981) who analyzed a neoclassical growth model with inelastic labor supply. In his model, money is held to satisfy a cash-in-advance constraint. Increased money growth has negative long run effects if the cash-in-advance constraint applies to consumption and investment; money is superneutral in the long run if only consumption is subject to the cash-in-advance constraint. More recently, Cooley and Hansen (1989) analyzed a similar environment except that there is a labor-leisure choice and the cash-in-advance constraint applies to consumption alone. Their numerical results again point to negative long run effects of money growth.

The model analyzed below is similar to that of Cooley and Hansen (1989): there is an infinitely lived representative household which values consumption and leisure; production requires capital and labor; and money is held to satisfy a cash-in-advance constraint on consumption. The model is described in more detail in Section 2. A number of standard assumption are made there. Sufficient conditions for increased money growth to reduce output in the long run are presented in Section 3; they are: (1) the crosspartial derivative of the production function is non-negative (labor and capital are complements in production), and (2) the crosspartial of the period utility function is non-negative (consumption and leisure are complements in utility). The functional forms used by Cooley and Hansen (1989) satisfy these conditions: the production function is Cobb-Douglas and so its crosspartial is strictly positive, and the period utility function is additively separable which implies that its crosspartial derivative is zero. The case in which the cash-in-advance constraint applies to both consumption and investment is also analyzed. Most of the results for the basic model continue to hold, again provided that the crosspartial derivative restrictions hold.

This paper differs from work in the literature in that both capital and labor supply are endogenous, and the results are analytical. Stockman (1981) and Abel (1985) imposed inelastic labor supply while Cooley and Hansen (1989) do not develop analytical results. Aschauer and Greenwood (1983), Kimbrough (1986) and Carmichael (1989) have endogenous labor supply but no capital. In Greenwood and Huffman (1987), labor supply is endogenous but capital is exogenous.

Analyzing the role of money growth on economic activity has a long history. However, this earlier work is inconsistent with the empirical regularity that money growth is negatively correlated with output (growth). For example, Sidrauski (1967) shows that money is superneutral when real money balances enter the utility function. In Tobin (1965), money and capital compete for a place in investors' portfolios. The 'Tobin effect' refers to the result that an increase in money growth, and hence inflation, lowers the return to money, causing investors to switch into capital.

Section 2 presents the model. Both preferences and technology are assumed to be well behaved. Analytical results for the long run effects of money growth are presented in Section 3. Section 4 extends the analysis to a situation in which both consumption and investment are subject to the cash-in-advance constraint, and section 5 concludes.

2. The Economic Environment

2.1. Households

The representative household ranks alternative streams of consumption, c_t, and leisure, ℓ_t, according to

$$\sum_{t=0}^{\infty} \beta^t U(c_t, \ell_t), \qquad \beta \in [0, 1). \tag{2.1}$$

The period utility function, U, is assumed to be at least twice continuously differentiable. In addition, marginal utility is strictly positive ($U_1, U_2 > 0$) and diminishing ($U_{11}, U_{22} < 0$).

The household faces a cash-in-advance constraint on its purchases of consumption:

$$P_t c_t \leq m_t + \tau_t \tag{2.2}$$

where P_t is the price level, m_t the household's start of period cash balances, and τ_t is a lump-sum transfer of money from the government.

In addition, the household faces the budget constraint,

$$c_t + i_t + \frac{m_{t+1}}{P_t} = r_t k_t + w_t n_t + \frac{m_t + \tau_t}{P_t} + \pi_t \tag{2.3}$$

where i_t is investment, k_t is capital, r_t is the real rental price of capital, n_t is hours worked, w_t is the real wage, and π_t is profits received from firms.[1] The right-hand side of (2.3) represents sources of funds while the left-hand side is uses.

The capital stock evolves according to

$$k_{t+1} = (1 - \delta) k_t + i_t, \qquad \delta \in [0, 1]. \tag{2.4}$$

Finally, the household faces a constraint on its time,

$$\ell_t + n_t = 1 \tag{2.5}$$

where the time endowment is normalized to one.

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[1] A more serious treatment of firm ownership would complicate the algebra without affecting the results of the paper. If the technology is constant-returns-to-scale, then profits are zero in equilibrium and such institutional details would be irrelevant.

2.2. Firms

The typical firm maximizes period-by-period profits,

$$\Pi_t = Y_t - r_t K_t - w_t N_t \tag{2.6}$$

where output is given by

$$Y_t = F(K_t, N_t). \tag{2.7}$$

Assume that F is at least twice continuously differentiable, that it has positive marginal products ($F_1, F_2 > 0$), diminishing marginal products ($F_{11}, F_{22} < 0$) and that the firm's second-order condition holds ($F_{11}F_{22} - F_{12}^2 \geq 0$). The second-order condition will hold as a strict inequality if F is decreasing-returns-to-scale, and as an equality if F is constant-returns-to-scale.

2.3. Government

The government simply satisfies its budget constraint,

$$\tau_t = (\mu - 1)M_t \tag{2.8}$$

where M_t is per capita money balances and μ is the gross growth rate of money.

2.4. Equilibrium

A competitive equilibrium consists of prices, $\{P_t, r_t, w_t\}_{t=0}^{\infty}$, actions of the household, $\{c_t, i_t, k_{t+1}, n_t, \ell_t, m_{t+1}\}_{t=0}^{\infty}$, actions of the firm, $\{K_t, N_t, Y_t, \Pi_t\}_{t=0}^{\infty}$, and actions of the government, $\{M_t, \tau_t\}_{t=0}^{\infty}$, such that:

(1) taking as given prices and actions by firms and the government, the actions by the household maximize its lifetime utility, (2.1), subject to the constraints (2.2) through (2.5),
(2) taking as given prices, the actions by the firm maximize its profits, (2.6), subject to the technology (2.7),
(3) the government budget constraint, (2.8), is satisfied, and
(4) markets clear:

$$k_t = K_t, \tag{2.9}$$

$$n_t = N_t, \tag{2.10}$$

$$m_{t+1} = M_{t+1}, \text{ and} \tag{2.11}$$

$$c_t + k_{t+1} = F(k_t, n_t) + (1 - \delta)k_t. \tag{2.12}$$

3. Analysis

As in Stockman (1981), attention will be focused on the steady state. Provided money growth is sufficiently rapid ($\mu > \beta$), the cash-in-advance constraint will hold with equality in steady state.

The household's problem can more succinctly be written:

$$\max_{\{c_t, k_{t+1}, m_{t+1}, n_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t U(c_t, 1-n_t) \tag{3.1}$$

subject to

$$c_t + k_{t+1} + \frac{m_{t+1}}{P_t} = (1-\delta+r_t)k_t + w_t n_t + \frac{m_t+\tau_t}{P_t} \tag{3.2}$$

and

$$P_t c_t = m_t + \tau_t. \tag{3.3}$$

The associated first-order conditions are:

$$\frac{U_2(c_t, 1-n_t)}{w_t} = \beta \frac{U_2(c_{t+1}, 1-n_{t+1})}{w_{t+1}}[r_{t+1}+1-\delta] \tag{3.4}$$

and

$$\frac{U_2(c_t, 1-n_t)}{P_t w_t} = \beta \frac{U_1(c_{t+1}, 1-n_{t+1})}{P_{t+1}}. \tag{3.5}$$

Equation (3.4) governs the household's capital accumulation. U_{2t}/w_t represents the utility cost of acquiring the marginal unit of capital at t: the household must sacrifice leisure, earning the real wage rate. The term in brackets on the right-hand side is the return to capital while the remaining terms convert this return into date t units of utility.

Equation (3.5) illustrates how inflation distorts economic activity in this model. Working more at date t has a utility cost, at the margin, of U_{2t} and generates extra cash balances, $P_t w_t$. This cash can be spent next period at which times its value has fallen by the rate of inflation, P_{t+1}/P_t. On the margin, these money balances yield utility U_{1t+1} which is discounted back to date t at the rate β.

From the firm's problem,

$$r_t = F_1(K_t, N_t) \tag{3.6}$$

and

$$w_t = F_2(K_t, N_t). \tag{3.7}$$

That is, factors are paid their marginal products.

In steady state, real money balances, M_t/P_t, are constant. This implies that the gross rate of inflation, P_{t+1}/P_t, will equal the growth rate of money, μ. Imposing equilibrium conditions and substituting (3.6) and (3.7) into the (3.4) and (3.5), the steady state solutions for consumption, capital and labor must satisfy:

$$1 = \beta[F_1(k,n)+1-\delta] \tag{3.8}$$

$$\mu U_2(c, 1-n) = \beta U_1(c, 1-n) F_2(k,n) \tag{3.9}$$

and

$$c + \delta k = F(k, n). \tag{3.10}$$

It is easiest to obtain (3.10) from the goods market clearing condition, (2.12). The cash-in-advance constraint, (3.3), can then be used to determine end-of-period real money balances. Notice that real money balances do not enter into (3.8)–(3.10).

Totally differentiating (3.8)–(3.10) yields:

$$\begin{bmatrix} \beta F_{11} & \beta F_{12} & 0 \\ \beta U_1 F_{12} & \beta U_1 F_{22} - \beta F_2 U_{12} + \mu U_{22} & \beta F_2 U_{11} - \mu U_{12} \\ F_1 - \delta & F_2 & -1 \end{bmatrix} \begin{bmatrix} dk \\ dn \\ dc \end{bmatrix} = \begin{bmatrix} 0 \\ U_2 d\mu \\ 0 \end{bmatrix} \tag{3.11}$$

or,

$$A \begin{bmatrix} \partial k/\partial \mu \\ \partial n/\partial \mu \\ \partial c/\partial \mu \end{bmatrix} = \begin{bmatrix} 0 \\ U_2 \\ 0 \end{bmatrix} \tag{3.12}$$

where all partial derivatives are evaluated at their steady state values.

The determinant of A is given by:

$$\begin{aligned} |A| = {} & \beta^2 F_2 F_{11} U_{12} - \beta\mu F_{11} U_{22} + \beta^2 F_{12} F_2 U_{11}(F_1 - \delta) - \beta\mu F_{12} U_{12}(F_1 - \delta) \\ & - \beta^2 F_2^2 U_{11} F_{11} + \beta\mu U_{12} F_2 F_{11} - \beta^2 U_1 [F_{11} F_{22} - F_{12}^2]. \end{aligned} \tag{3.13}$$

Earlier, it was assumed that marginal products are positive ($F_1, F_2 > 0$) and diminishing ($F_{11}, F_{22} < 0$); the firm's second-order condition holds ($F_{11}F_{22} - F_{12}^2 \geq 0$); and marginal utility is positive ($U_1, U_2 > 0$) and diminishing ($U_{11}, U_{22} < 0$). Next, notice that $F_1 - \delta > 0$ as a consequence of (3.8) and the assumption that the discount rate, β, lies strictly between zero and one. A sufficient condition for $|A| < 0$ is $F_{12} \geq 0$ and $U_{12} \geq 0$; that is, if the crosspartial derivatives of the production and utility functions are non-negative.

These conditions on the crosspartials will certainly be satisfied if the aggregate production function is Cobb-Douglas ($F_{12} > 0$) and the utility function is additively separable in consumption and leisure ($U_{12} = 0$) as in Cooley and Hansen (1989). Clearly the restrictions on the crosspartials will hold for more general technologies and preferences.

Imposing the non-negativity condition on the crosspartial derivatives of the production and utility functions, it can be shown that

$$\frac{\partial k}{\partial \mu} = \frac{\beta U_2 F_{12}}{|A|} \leq 0 \qquad (< 0 \text{ if } F_{12} > 0) \tag{3.14a}$$

$$\frac{\partial n}{\partial \mu} = \frac{-\beta U_2 F_{11}}{|A|} < 0 \tag{3.14b}$$

$$\frac{\partial c}{\partial \mu} = \frac{\beta U_2 [F_{12}(F_1 - \delta) - F_2 F_{11}]}{|A|} < 0 \tag{3.14c}$$

(3.14) show that increased money growth (inflation) has a non-positive effect on capital and a negative effect on employment and consumption.

The intuition is as follows. An increase in money growth (inflation) reduces the effective return to work since a dollar earned in the current period cannot be spent until next period as a consequence of the cash-in-advance constraint. The restriction on the crosspartial derivative of the utility function implies that the household will want to reduce both consumption and labor in the long run. Non-negativity of the crosspartial of the production function then ensures—via (3.8)—that capital will not rise in response to the fall in employment.

From (2.7), it can be confirmed that

$$\frac{\partial y}{\partial \mu} = F_1 \frac{\partial k}{\partial \mu} + F_2 \frac{\partial n}{\partial \mu} < 0. \tag{3.15}$$

That output falls in the long run in response to an increase in money growth follows from the negative effect on employment, and the non-positive effect on capital.

The cash-in-advance constraint, (2.2), implies that real money balances fall with money growth. This follows directly from the fact that consumption falls with money growth.

Turning now to the effect on factor prices,

$$\frac{\partial r}{\partial \mu} = F_{11} \frac{\partial k}{\partial \mu} + F_{12} \frac{\partial n}{\partial \mu} = 0. \tag{3.16}$$

where the equality follows from direct substitution using (3.14). In the long run, the real interest rate is pinned down by (3.8) which depends only on preferences and the production technology. The effect on the real wage is given by

$$\begin{aligned} \frac{\partial w}{\partial \mu} &= F_{12} \frac{\partial k}{\partial \mu} + F_{22} \frac{\partial n}{\partial \mu} \\ &= \frac{-\beta U_2 [F_{11} F_{22} - F_{12}^2]}{|A|} \\ &\geq 0. \end{aligned} \tag{3.17}$$

Notice that the long run response of the real wage rate is zero if the technology is constant-returns-to-scale ($F_{11}F_{22} - F_{12}^2 = 0$), and is positive if decreasing-returns-to-scale.

4. Cash-in-advance on Consumption and Investment

Nonsuperneutrality of money arises above because inflation distorts the labor–leisure choice. In Stockman (1981), nonsuperneutrality arises because inflation distorts, instead, the capital accumulation decision since both consumption and investment are subject to the cash-in-advance constraint. What happens in Stockman's model when there is a labor–leisure choice?

The earlier cash-in-advance constraint, (2.2), is replaced by

$$P_t(c_t + i_t) \leq m_t + \tau_t \tag{4.1}$$

The household's problem is to maximize (3.1) subject to (4.1) and (2.3)–(2.5), taking as given prices and government behavior. The first-order condition (3.4), which governed capital accumulation, is replaced by

$$U_1(c_t, 1 - n_t) = \beta \left[r_{t+1} \frac{U_2(c_{t+1}, 1 - n_{t+1})}{w_{t+1}} + (1 - \delta) U_1(c_{t+1}, 1 - n_{t+1}) \right]. \tag{4.2}$$

The key equations describing the steady state are now (3.9), (3.10) and

$$\mu[1-\beta(1-\delta)] = \beta^2 F_1(k,n) \tag{4.3}$$

where (3.9) has been substituted into the steady state version of (4.2). Differentiating these steady state equations yields

$$\underbrace{\begin{bmatrix} \beta^2 F_{11} & \beta^2 F_{12} & 0 \\ \beta U_1 F_{12} & \beta U_1 F_{22} - \beta F_2 U_{12} + \mu U_{22} & \beta F_2 U_{11} - \mu U_{12} \\ F_1 - \delta & F_2 & -1 \end{bmatrix}}_{B} \begin{bmatrix} \partial k/\partial\mu \\ \partial n/\partial\mu \\ \partial c/\partial\mu \end{bmatrix} = \begin{bmatrix} 1-\beta(1-\delta) \\ U_2 d\mu \\ 0 \end{bmatrix} \tag{4.4}$$

where, again, all partial derivatives are evaluated at steady state values. The determinant of B is

$$\begin{aligned} |B| = {} & \beta^2 F_{11}[\beta F_2 U_{12} - \mu U_{22}] + \beta^2 f_{12}[\beta F_2 U_{11} - \mu U_{12}](F_1 - \delta) \\ & + \beta^2 F_2 F_{11}[\mu U_{12} - \beta F_2 U_{11}] - \beta^3 U_1 [F_{11} F_{22} - F_{12}^2]. \end{aligned} \tag{4.5}$$

As in the earlier analysis, a sufficient condition for $|B| < 0$ is $U_{12} \geq 0$ and $F_2 \geq 0$. Imposing this condition, it follows that

$$\frac{\partial k}{\partial \mu} = \frac{[1-\beta(1-\delta)][\beta F_2 U_{12} - \beta U_1 F_{22} - \mu U_{22}](1+F_2) + \beta^2 U_2 F_{12}}{|B|} < 0 \tag{4.6a}$$

$$\frac{\partial n}{\partial \mu} = \frac{[1-\beta(1-\delta)][\beta U_1 F_{12} + (F_1-\delta)(\beta F_2 U_{11} - \mu U_{12})] - \beta^2 U_2 F_{11}}{|B|} \tag{4.6b}$$

$$\frac{\partial c}{\partial \mu} = \frac{|B_3|}{|B|} \tag{4.6c}$$

where

$$\begin{aligned} |B_3| = {} & [1-\beta(1-\delta)][\beta U_1 F_2 F_{12} + (F_1-\delta)(\beta F_2 U_{12} - \beta U_1 F_{22} - \mu U_{22})] \\ & + (F_1 - \delta)\beta^2 U_2 F_{12} - \beta^2 F_2 U_2 F_{11}. \end{aligned}$$

Relative to the previous analysis (i.e., when the cash-in-advance constraint applied to only consumption), first notice that the effect of money growth on the steady state capital stock is now unambiguously negative (previously, this sign depended on the sign on F_{12}). This result probably is not too surprising since Stockman (1981) found a negative long run effect of money growth on the capital stock.

Second, the effect of money growth on steady state employment can no longer be signed. While the direct effect of the inflation tax on labor supply is still present, there is now, in addition, an effect of the capital stock. In general, changes in the capital stock also change the real wage which will have income and substitution effects on employment which operate in opposite directions. The net effect of money growth on employment is ambiguous.

As before, higher money growth reduces steady state consumption.

Next, from

$$y = c + \delta k$$

it follows that

$$\frac{\partial y}{\partial \mu} = \frac{\partial c}{\partial \mu} + \delta \frac{\partial k}{\partial \mu} < 0.$$

That is, higher money growth leads to lower output in the longer run.

The effect of money growth on the real interest rate is given by

$$\begin{aligned}\frac{\partial r}{\partial \mu} &= \frac{\partial k}{\partial \mu} F_{11} + \frac{\partial n}{\partial \mu} F_{12} \\ &= \frac{|B_1|F_{11} + |B_2|F_{12}}{|B|}\end{aligned}$$

where

$$\begin{aligned}|B_1|F_{11} + |B_2|F_{12} = [1 - \beta(1-\delta)]\{&[\beta F_2 U_{12} - \mu U_{22}](1+F_2)F_{11} - \beta U_1 F_2 F_{11} F_{22} \\ &- \beta U_1 [F_{11}F_{22} - F_{12}^2] + (F_1 - \delta)[\beta F_2 U_{11} - \mu U_{12}] \\ < 0 &\end{aligned}$$

Notice that even though the sign of the effect of money growth on employment cannot be signed, the interest rate effect *can* be signed. Intuitively, the return on investment needs to be higher to compensate for the fact that the inflation tax lowers the return to investment.

Finally,

$$\begin{aligned}\frac{\partial w}{\partial \mu} &= \frac{\partial k}{\partial \mu} F_{11} + \frac{\partial n}{\partial \mu} F_{12} \\ &= \frac{|B_1|F_{12} + |B_2|F_{22}}{|B|}\end{aligned}$$

where

$$\begin{aligned}|B_1|F_{12} + |B_2|F_{22} = [1 - \beta(1-\delta)]\{&[\beta F_2 U_{12} - \mu U_{22}](1+F_2)F_{12} \\ &- \beta U_1 F_2 F_{12} F_{22} + (F_1 - \delta)[\beta F_2 U_{11} - \mu U_{12}]F_{22} \\ &- \beta^2 U_2 [F_{11}F_{22} - F_{12}^2]\}.\end{aligned}$$

In general, this effect cannot be signed. However, when the production function is constant-returns-to-scale, $(F_{11}F_{22} - F_{12}^2) = 0$ and increased money growth has a negative effect on the steady state real wage.

5. Conclusion

In the neoclassical growth model analyzed above, money is held to satisfy a cash-in-advance constraint on consumption purchases. Sufficient conditions for money growth to have negative long run economic effects are: (1) the crosspartial derivative of the production function is non-negative (capital and labor are complements in production), and (2) the crosspartial of the period utility function is non-negative (consumption and leisure are complements in utility). These conditions are satisfied for the class of preferences (constant relative risk aversion with a Cobb-Douglas aggregator over consumption and leisure) and technologies (Cobb-Douglas) typically employed in the real business cycle literature. Given these sufficient conditions, it was shown that in the long run, an increase in money growth: (1) has a non-positive effect on capital (negative if $F_{12} > 0$), (2) a negative effect on consumption, output, real balances and employment, (3) no effect on the real interest rate, and (4) a non-negative effect on the real wage (positive if the production technology is decreasing-returns-to-scale).

It was also shown that most of the analytical results continue to hold when both consumption and investment are subject to the cash-in-advance constraint, provided the sufficient conditions above are satisfied. In particular, the long run effect of an increase in money growth: (1) reduces the capital stock, consumption and output, (2) raises the real interest rate, (3) unambiguously lowers the real wage only when the technology is constant-returns-to-scale, and (4) has an indeterminant effect on employment.

These results extend and generalize analytical results in a number of papers, including Stockman (1981), Aschauer and Greenwood (1983), Kimbrough (1986), Carmichael (1989) and Greenwood and Huffman (1987). In the analysis above, both capital accumulation and labor supply are endogenous while the aforementioned papers restrict one or the other of these decision to be exogenous.

The results in this paper also complement the numerical work of Cooley and Hansen (1989). They restrict attention to a Cobb-Douglas production technology and preferences which are additively separable in consumption and leisure. Their choice satisfies the sufficient conditions derived above for increased money growth to have negative real effects. An important contribution of Cooley and Hansen is to quantify the welfare costs of inflation. For example, they find that a 10% inflation has a welfare cost of about 0.4% of income relative to an optimal policy.

Finally, it is fairly straightforward to show that the *same* sufficient conditions hold for the 'liquidity effects' model of Lucas (1990) and Fuerst (1992).

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