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The Growth Effects of Monetary Policy*

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For years, scholars have recognized the key role government policies play in the process of development. The recent availability of quality data has led to quantitative analyses of the effect such policies have on development. Most of the renewed research effort on this front, both theoretical and empirical, has emphasized the relationship between fiscal policy and the paths of development of countries. (See Jones and Manuelli 1990, Barro 1991, and Rebelo 1991, for example.) In contrast, although there have been several empirical studies on the relationship between monetary policy and growth (Fischer 1991), there has been very little theoretical work in this area. (Jones and Manuelli 1990 and Gomme 1991 are exceptions.) We have two goals in this article. One is to summarize the recent empirical work on the growth effects of monetary policy instruments. The other is to compare the empirical findings with the implications of quantitative models in which monetary policy can affect growth rates. We ask, in particular, What is the relationship in the data between monetary policy instruments and the rate of growth of output? Are the predicted quantitative relationships from theoretical models consistent with the data?

Monetary policy plays a key role in determining inflation rates. In the next section, we summarize the empirical evidence on the relationship between inflation and growth in a cross section of countries. This evidence suggests a systematic, quantitatively significant negative association between inflation and growth. While the precise estimates vary from one study to another, the evidence suggests that a 10 percentage point increase in the average inflation rate is associated with a decrease in the average growth rate of somewhere between 0.2 and 0.7 percentage points.

Then we explore the ability of various models with transactions demand for money to account for this association. We use the growth rate of the money supply as our measure of the differences in monetary policies across countries. Although many models predict qualitatively that an increase in the long-run growth rate of the money supply decreases the long-run growth rate of output in the economy, we find that in these models, a change in the growth rate of the money supply has a quantitatively trivial effect on the growth rate of output. The reason is that in endogenous growth models, changes in output growth rates require changes in real rates of return to savings, and it turns out that changes in inflation rates have trivial effects on real rates of return and thus on output growth rates.

We go on, then, to broaden our notion of monetary policy to include financial regulations. We study environments in which a banking sector holds money to meet reserve requirements. We model banks as providing intermediated capital, which is an imperfect substitute for other

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forms of capital, and we consider two kinds of experiments. In the first, we hold reserve requirements fixed and examine the effects of changes in inflation rates on growth rates. Even though higher inflation rates distort the composition of capital between bank-intermediated capital and other forms of capital and thus reduce growth rates, the quantitative effects turn out to be small. In the second kind of experiment, we simultaneously change money growth rates and reserve requirements in a way that is consistent with the association between these variables in the data. This avenue is promising because these variables are positively correlated, and changes in each of them have the desired effect on output growth rates. We find that monetary policy changes of this kind have a quantitative effect on growth rates that is consistent with the lower end of the estimates of the relationship between inflation rates and growth rates. We conclude by arguing that models that focus on the transactions demand for money cannot account for the sizable negative association between inflation and growth, while models that focus on the distortions caused by financial regulations can.

The Evidence on Inflation and Growth

Numerous empirical studies analyze the relationship between the behavior of inflation and the rate of growth of economies around the world. Most of these studies are based on (some subset of) the Summers and Heston 1991 data sets and concentrate on the cross-sectional aspects of the data that look at the relationship between the average rate of growth of an economy over a long horizon (typically from 1960 to the date of the study) to the corresponding average rate of inflation over the same period and other variables. Some of the more recent empirical studies undertake similar investigations using the panel aspects of the data more fully. (See Fischer 1993, for example.)

To summarize this literature, we begin with some simple facts about the data. According to Levine and Renelt (1992), those countries that grew faster than average had an average inflation rate of 12.34 percent per year over the period, while those countries that grew more slowly than average had an average inflation rate of 31.13 percent per year.[1] Similar results are reported in Easterly et al. 1994. Here *fast growers* are defined as those countries having a growth rate more than one standard deviation above the average (and averaging about 4 percent per year) and are found to have had an average inflation rate of 8.42 percent per year. In contrast, *slow growers*, defined as those countries having a growth rate less than one standard deviation below the average (and averaging about –0.2 percent per year), had an average inflation rate of 16.51 percent per year. Using the numbers from either Levine and Renelt 1992 or Easterly et al. 1994 to estimate an unconditional slope (which those studies do not do), we see that a 10 percentage point rise in the inflation rate is associated with a 5.2 percentage point fall in the growth rate. These groups of countries also differ in other systematic ways; for example, fast growers spent less on government consumption, had higher investment shares in gross domestic product (GDP), and had lower black market premiums. However, this association between inflation and growth suggests that monetary policy differences are important determinants in the differential growth performances present in the data.[2]

In two recent studies, Fischer (1991, 1993) analyzes the Summers and Heston 1991 data using both cross-sectional and panel regression approaches to control for the other systematic ways in which countries differ from one another. Fischer (1991) controls for the effects of variables such as initial income level, secondary school enrollment rate, and budget deficit size and finds that on average, an increase in a country's inflation rate of 10 percentage points is associated with a decrease in its growth rate of between 0.3 and 0.4 percentage points per year. Moreover, the evidence in Fischer 1991 seems to suggest that the relationship between growth and inflation may be nonlinear, with the growth effect of inflation decreasing as the level of the inflation rate is increased. When countries are split into three groups based on their average inflation rates over the period (below 15 percent, from 15 to 40 percent, and above 40 percent), Fischer (1991) finds that a 10 percentage point increase in the inflation rate is associated with a 1.3 percentage point decrease in the growth rate in those countries in the low inflation range, a 0.75 percentage point decrease in those countries in the middle inflation range, and a 0.2 percentage point decrease in those countries in the high inflation range. These effects are quantitatively similar to the earlier results reported in Fischer 1991, where a 10 percentage point increase in the inflation rate is associated with a decrease in the growth rate of between 0.4 and 0.7 percentage points.

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[1]The cross-sectional average of the time series average rates of per capita income growth in the Summers and Heston 1991 data is around 1.92 percent per year.

[2]Some studies do not arrive at this conclusion. McCandless and Weber (1995) find no correlation between inflation and the growth rate of output.

Similar results are reported by Roubini and Sala-i-Martin (1992), who find that a 10 percentage point increase in the inflation rate is associated with a decrease in the growth rate of between 0.5 and 0.7 percentage points. (See also Grier and Tullock 1989.) Barro (1995), using a slightly different framework to control for the effect of initial conditions and other institutional factors, also finds a negative effect of inflation on growth that he estimates to be between 0.2 and 0.3 percentage points per 10 percentage point increase in inflation. He also finds the relationship to be nonlinear, although—contrary to the other studies—he estimates that the greater effect of inflation on growth comes from the experiences of countries in which inflation exceeds a rate of between 10 and 20 percent per year.

In summary, the standard regression model seems to suggest a nonlinear relationship between inflation and growth with a mean decrease in the growth rate of between 0.3 and 0.7 percentage points for each 10 percentage point increase in the inflation rate.[3] Are these growth effects of higher inflation significant? As an illustration of the importance of these effects, note the difference in growth rates between two countries that are otherwise similar but which have a 10 percentage point difference in annual inflation rates. Although these countries start in 1950 with the same levels of income, their growth rates would differ by a factor of between 16 and 41 percentage points by the year 2000 (starting with the average growth rate of 1.92 percent per year as the base).[4]

Models of Growth and Money Demand

Two theoretical arguments in the literature concern the effect on output of changing the average level of inflation. One argument is based on what has become known as the *Mundell-Tobin effect*, in which more inflationary monetary policy enhances growth as investors move out of money and into growth-improving capital investment. The evidence we have summarized seems to be sharply in contrast to this argument, at least as a quantitatively important alternative. The other argument is based on the study of exogenous growth models. In an early paper in this area, Sidrauski (1967) constructs a model in which a higher inflation rate has no effect on either the growth rate or the steady-state rate of output. Other authors construct variants in which higher inflation rates affect steady-state capital/output ratios but not growth rates. (See Stockman 1981 and Cooley and Hansen 1989.)

In this section, we analyze a class of endogenous growth models in an attempt to better understand the empirical results presented in the previous section. The regression results presented there implicitly ask what the growth response will be to a change in long-run monetary policy that results in a given percentage point change in the long-run rate of inflation. Thus our goal here is to describe models in which monetary policy has the potential for affecting long-run growth. Three elements are obviously necessary in a candidate model: It must generate long-run growth endogenously, it must have a well-defined role for money, and it must be explicit about the fiscal consequences of different monetary policies.

The feature necessary for a model to generate long-run growth endogenously is that, in contrast to the neoclassical family of exogenous growth models, the rate of return on capital inputs does not go to zero as the level of inputs is increased, when the quantities of any factors that are necessarily bounded are held fixed. Stated another way, the marginal product of the reproducible factors in the model must be bounded away from zero. (See Jones and Manuelli 1990 and Rebelo 1991 for a detailed development of the key issues.)

We report results for four types of endogenous growth models:[5]

- A simple, one-sector model with a linear production function (*Ak*).
- A generalization of the linear model that endogenizes the relative price of capital (*two-sector*).
- A model which emphasizes human capital accumulation (*Lucas*).
- A model with spillover effects in the accumulation of physical capital (*Romer*).

To generate a role for money in these models, a variety of alternatives is available. We report results for three models of money demand:

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[3] Although we do not study the relationship between inflation volatility and growth here (as does Gomme 1991 theoretically), empirical studies have found that more volatile monetary policies also have depressing effects on growth rates. (See Kormendi and Meguire 1985, Fischer 1993, and Easterly et al. 1994.) One must be careful interpreting this relationship, however, since there is a high correlation between the average inflation rate experienced over the period in a country and the volatility of the inflation rate. This correlation is reported to be 0.97 in Levine and Renelt 1992.

[4] Although these are important differences, one must be careful in interpreting this evidence. As discussed in Levine and Renelt 1992, there is a high degree of multicollinearity between many of the regressors that authors include in these studies; hence, most of the empirical findings are nonrobust in the Leamer sense.

[5] See the Appendix for a description of the technologies and preferences.

- A cash/credit goods model in which a subset of goods must be purchased with currency (*cash in advance,* or *CIA, in consumption*).
- A shopping time model in which time and cash are substitute inputs for generating transactions (*shopping time*).
- A CIA model in which all purchases must be made with currency, but in which cash has a differential productivity between consumption and investment purchases (*CIA in everything*).

Although these models are only a subset of the available models, we think that the combinations of the various growth and money demand models represent a reasonable cross section.

Finally, we must specify how the government expands the money supply. We restrict attention to policy regimes in which households are given lump-sum transfers of money. In all the models we examine, the growth effects of inflation that occur when money is distributed lump-sum are identical to those that occur when the growth of the money supply is used to finance government consumption, as long as the increased money supply is not used to fund directly growth-enhancing policies. Alternative assumptions about the uses of growth of the money supply may lead to different conclusions about the relationship between inflation and growth. For example, using the growth of the money supply to subsidize the rate of capital formation or to reduce other taxes may stimulate growth. Since the evidence suggests that inflation reduces growth, we restrict attention to lump-sum transfers.

The growth and money demand models just listed give us 12 possible models in all. Rather than give detailed expositions of each of the 12 models, we will discuss the Lucas model with CIA in consumption. Full details of the balanced growth equations for each of the 12 models are presented in Chari, Jones, and Manuelli, forthcoming.

A Representative Model of Growth and Money Demand

We consider a representative agent model with no uncertainty and complete markets. In this model, there are two types of consumption goods in each period called *cash goods* and *credit goods*. Cash goods must be paid for with currency. Both of these consumption goods, as well as the investment good, are produced using the same technology. The resource constraint in this economy is given by

$$(1) \qquad c_{1t} + c_{2t} + x_{kt} + x_{ht} + g_t \le F(k_t,n_t h_t)$$

where c_{1t} is the consumption of cash goods; c_{2t} is the consumption of credit goods; x_{kt} and x_{ht} are investment purchases in physical capital and human capital, respectively; k_t is the stock of physical capital; n_t is the number of hours worked; h_t is the stock of human capital; g_t is government consumption; and F is the production function. Physical capital follows $k_{t+1} \le (1-\delta_k)k_t + x_{kt}$, where δ_k is the depreciation rate, while human capital follows $h_{t+1} \le (1-\delta_h)h_t + x_{ht}$, where δ_h is the depreciation rate on human capital.

Trading in this economy occurs as follows: At the beginning of each period, a securities market opens. In this market, households receive capital and labor income from the previous period, the proceeds from government bonds, and any lump-sum transfers from the government. At this time, households pay for credit goods purchased in the previous period. Finally, households must choose how much cash they will hold for the purchase of cash goods in the next period.

The consumer's problem is to

$$(2) \qquad \max \textstyle\sum_{t=0}^{\infty} \beta^t u(c_{1t}, c_{2t}, 1-n_t)$$

subject to

$$(3) \qquad m_{t-1} + b_{t-1} \le v_t$$

$$(4) \qquad p_t c_{1t} \le m_{t-1}$$

$$(5) \qquad \begin{aligned} v_{t+1} \le\ & (v_t - b_{t-1} - m_{t-1}) + (m_{t-1} - p_t c_{1t}) - p_t c_{2t} - p_t x_{kt} \\ & - p_t x_{ht} + p_t r_t k_t (1-\tau) + p_t w_t n_t h_t (1-\tau) \\ & + [1 + (1-\tau)R_t]b_{t-1} + T_t \end{aligned}$$

$$(6) \qquad k_{t+1} \le (1-\delta_k)k_t + x_{kt}$$

$$(7) \qquad h_{t+1} \le (1-\delta_h)h_t + x_{ht}$$

where β is the discount factor, u is the consumer's utility, v_t is wealth at the beginning of period t, m_{t-1} is money holdings at the beginning of period t, b_{t-1} is bond holdings at the beginning of period t, R_t is the nominal interest rate paid on bonds during period t, r_t is the rental price of capital during the period, τ is the tax rate on income (assumed constant), T_t is the size of the transfer to the household delivered at the end of period t, and w_t is the real wage rate. Note that we have adopted the standard assumption from the human capital literature that firms hire effective labor $n_t h_t$ from workers and pay a wage of w_t per unit of time.

(See Rosen 1976.) Since all four goods available in a period (c_1, c_2, x_k, and x_h) are perfect substitutes on the production side, they all sell for the same nominal price p_t.

On the production side, we assume that there is a representative firm solving the static maximization problem

$$(8) \qquad \max p_t[F(k_t,n_th_t) - r_tk_t - w_tn_th_t].$$

Let M_t be the aggregate stock of money and μ be the (assumed constant) rate of growth of the money supply.

Equilibrium for the model requires maximization by both the household and the firms, along with the following conditions:

$$(9) \qquad c_{1t} + c_{2t} + x_{kt} + x_{ht} + g_t \leq F(k_t,n_th_t)$$

$$(10) \qquad m_t = M_t$$

$$(11) \qquad T_{t+1} = M_{t+1} - M_t = (\mu-1)M_t$$

$$(12) \qquad g_t = \tau F(k_t,n_th_t).$$

The first two of these conditions are market-clearing in the goods market and the money market, respectively. Conditions (11) and (12) describe the characteristics of policy in the model. Condition (11) says that the increase in the money supply enters the system through a direct lump-sum transfer to the household. Finally, condition (12) says that government purchases are financed by a flat-rate tax on income. An implication of conditions (11) and (12) is that the government's budget is balanced on a period-by-period basis.

To study the long-run behavior of the model, we use the solutions to the maximization problems of the household and the firm together with equilibrium conditions (9) through (12) to calculate what are known as the *balanced growth equations*. Along a balanced growth path, output grows at a constant rate. In general, for the economy to follow such a path, both the production function and the preferences must take on special forms. On the production side, a sufficient condition is that $F(k,nh)$ is a Cobb-Douglas production function of the form $Ak^{\alpha}(nh)^{1-\alpha}$, where A and α are parameters. On the preference side, the consumer, when faced with a stationary path of interest rates, must generate a demand for constant growth in consumption. This requirement is satisfied by preferences of the form

$$(13) \qquad U(c_{1t},c_{2t}) = [(c_{1t}^{-\lambda}+\eta c_{2t}^{-\lambda})^{-1/\lambda}]^{(1-\sigma)}(1-n_t)^{\psi(1-\sigma)}/(1-\sigma)$$

where η, λ, σ, and ψ are preference parameters. With these assumptions, we can show that the dynamics of the system converge to a balanced growth path. (See Benhabib and Perli 1994 and Ladron-de-Guevara, Ortigueira, and Santos 1994.)

For this model, the balanced growth equations of the system are

$$(14) \qquad c_2/c_1 = \{\eta[1 + (1-\tau)R]\}^{1/(1+\lambda)}$$

$$(15) \qquad \gamma^{\sigma} = \beta[1 - \delta_k + \alpha An^{1-\alpha}(h/k)^{1-\alpha}(1-\tau)]$$

$$(16) \qquad \gamma^{\sigma} = \beta[1 - \delta_h + (1-\alpha)An^{1-\alpha}(h/k)^{-\alpha}(1-\tau)]$$

$$(17) \qquad \gamma^{\sigma}\pi = \beta[1 + (1-\tau)R]$$

$$(18) \qquad [(1-n)/n^{\alpha}](h/k)^{1-\alpha}(1-\alpha)A = (c_1/k)\psi[1 + \eta(c_2/c_1)^{-\lambda}][1 + (1-\tau)R]$$

$$(19) \qquad \pi\gamma = \mu$$

$$(20) \qquad \lambda = 1 - \delta_k + (x_k/k)$$

$$(21) \qquad \lambda = 1 - \delta_h + (x_h/k)(k/h)$$

$$(22) \qquad (c_1/k) + (c_2/k) + (x_h/k) + (x_k/k) + (g/k) = An^{1-\alpha}(h/k)^{1-\alpha}$$

where $\pi = p_{t+1}/p_t$ is the steady-state level of inflation; $\gamma = c_{1t+1}/c_{1t} = c_{2t+1}/c_{2t} = x_{kt+1}/x_{kt} = x_{ht+1}/x_{ht} = k_{t+1}/k_t$ is the growth rate of output; $c_2/c_1 = c_{2t}/c_{1t}$ is the steady-state ratio of credit consumption to cash consumption; c_1/k, c_2/k, x_k/k, x_h/k, and h/k are the long-run ratios of the respective parts of output relative to the size of the capital stock; and n is the balanced growth level of the labor supply. This system of nine equations in nine variables (π, γ, R, c_1/k, c_2/k, x_k/k, x_h/k, h/k, and n) can be solved given values of the parameters and the policy variables (μ and τ) to trace the long-run reaction of the system to a change in policy.

Consider the effect of an increase in the growth rate of money μ. Note that the right side of equation (15) [or equation (16)] can be interpreted as the after-tax rate of return on savings. Thus (15) relates the long-run rate of growth to the equilibrium after-tax rate of return r on capital. If either time spent working n or the human capital-to-physical capital ratio h/k is affected by changes in μ, then the growth rate of the economy depends on μ. As a special case, consider what happens when $\delta_k = \delta_h$. Here, equations (15) and (16) can be used to solve for h/k and to show that it is given by $(1-\alpha)/\alpha$, independently of the rate of inflation. In this case, it follows that the growth rate γ is affected by changes in μ if and only if n is affected. In this model, inflation acts as a tax that distorts the consumption of cash goods relative to credit goods. This distortion can in turn distort the labor/leisure choice and thus affect time allocated to work n. [See equation (18).]

Given that h/k is constant (since we have assumed that $\delta_k = \delta_h$), the steady-state after-tax real rate of return on capital is affected by changes in the steady-state value of n. This is true here because n represents the rate of usage of the productive capital good h. A higher n corresponds to a more intensive use of the stock and hence a higher marginal product of capital (when h/k is held fixed). In this case, if n decreases in response to an increase in μ, then the equilibrium long-run rate of growth in the economy will decrease as μ is increased.

Although one would expect an increase in μ to decrease n and hence decrease γ, this is not always true. In fact, the exact behavior of this system of equations depends critically on the substitutability between cash goods and credit goods. For example, in the special case where the depreciation rates on the two types of capital δ_h and δ_k are equal to, say, δ, we can show that if the two types of consumption goods are complements (that is, $\lambda > 0$), then the growth rate falls monotonically in μ and approaches the lowest feasible rate in this economy: $1 - \delta$. However, if the two goods are substitutes (that is, $\lambda < 0$), then we can show that the relationship between the steady-state values of γ and μ is not monotone. At low levels of μ, γ is a decreasing function of μ, but eventually γ becomes an increasing function of μ as the system is demonetized. That is, if μ is high enough, c_1/c_2 goes to zero, and the growth rate converges to that of the system when monetary expansion is at its optimal rate. (See Jones and Manuelli 1990 for details.)

Computations

Next, we provide estimates of the quantitative magnitudes of the growth effects of inflation for our 12 models.

To provide these estimates, we must have parameter values for each of these 12 models. We select parameter values for each of the models using a combination of figures from previous studies and facts about the growth experience of the U.S. economy between 1960 and 1987. Throughout the calibrations, we assume that a period is 1.5 months, that is, the length of time it takes one dollar to produce one transaction for the cash good. (See Chari, Christiano, and Eichenbaum 1995.) We assume that the discount factor $\beta = 0.98$ at an annual rate. (See Chari, Christiano, and Kehoe 1994.) We also assume that the intertemporal elasticity of substitution $\sigma = 2.0$, that the preference parameter $\lambda = -0.83$ (Chari, Christiano, and Kehoe 1991), that the fraction of time spent working $n = 0.17$ (Jones, Manuelli, and Rossi 1993), that the capital share parameter $\alpha = 0.36$ (Chari, Christiano, and Kehoe 1994), that the depreciation rate on human capital $\delta_h = 0.008$ at an annual rate (Jones, Manuelli, and Rossi 1993), and that the tax rate on income $\tau = 0.22$.[6] The rest of the parameters are estimated using the steady-state equations of the models so as to make them hold exactly. We use the following auxiliary relationships based on the U.S. economy's experience during 1960–87:

- The average annual growth rate in per capita gross national product (GNP) is 2.06 percent.
- The average annual rate of inflation is 5.08 percent.
- If we ignore the fraction of cash held in banks and outside the country, cash in the hands of the public averages 2.04 percent of annual GNP.
- Investment in physical capital as a fraction of GNP averages 16.69 percent.

All but the third of these facts are obtained from U.S. President 1994. The third is from Porter 1993. These facts, along with the parameter values given, are used in conjunction with the balanced growth equations to obtain values for the other (nonspecified) parameters of the models and for the balanced growth endogenous variables of the system.

For example, in the Lucas model with CIA in consumption, the parameter values obtained are $A = 0.08$, $\delta_k = 0.04$, $\eta = 1.03$, and $\psi = 8.22$, and the values for the endogenous variables are $\mu = 1.07$, $R = 15$ percent, $c_1/k =$

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[6]We run several experiments to test the robustness of our results to our choice of parameters. For these experiments, we use the Lucas model of growth along with the CIA in everything model of money demand. First, we estimate the length of a period using the *Nilson Report*'s (1992) numbers on the fraction of transactions that are completed using cash. The *Nilson Report* (1992) does not say exactly what transactions are included in its measure of all transactions. We calibrate the model two different ways: one assuming that transactions on x_h are included in the calculations and one assuming that they are not. These calibrations produce estimates of the period length of 1.63 months and 1.02 months, respectively. In addition, we try lowering our parameter that determines the elasticity of the labor supply ψ to the level 2 used in the real business cycle literature (Chari, Christiano, and Kehoe 1994), while allowing the potential workday to vary. Finally, we try reducing the elasticity of substitution between cash goods and credit goods from –0.83 to –0.2. None of these experiments results in a significant change in the growth effect of inflation. Details of these experiments are available from the authors upon request.

0.007, c_2/k = 0.01, x_k/k = 0.007, x_h/k = 0.01, and h/k = 2.31. All variables are in annualized terms. To get some feel for these numbers, note that the fitted growth rate of money μ (1.07) is higher than the observed value of the growth rate of the monetary base in the period (1.0684), but only slightly. [That is, equation (19) does not hold exactly at the true μ, π, and γ combination because velocity is not constant in the data.] These numbers also imply a capital/output ratio in this model of 2.8, which is close to that used in the literature (Chari, Christiano, and Kehoe 1994). The implied value of 0.43 for $c_1/(c_1+c_2)$ is roughly the same as the *Nilson Report*'s estimate of 0.41 for the ratio of cash purchases to other purchases in the U.S. economy (*Nilson Report* 1992). Finally, the value of 23.54 percent for x_h as a fraction of GNP is close to the sum of the values of health care expenditures and education expenditures in the United States. (See 1992 issues of the U.S. Department of Commerce's *Survey of Current Business*.)

Thus the model does well mimicking the U.S. economy along a variety of dimensions (some by design). Note that the implied pretax nominal rate of return is 15 percent, which is probably high by most standards. This is a common feature of the endogenous growth models without uncertainty (given our assumptions that $\sigma = 2.0$ and $\beta = 0.98$). A detailed description of the calibration method for each model is contained in Chari, Jones, and Manuelli, forthcoming.

We compute solutions to the balanced growth equations assuming that $\pi = 1.1$ and $\pi = 1.2$. This increase of 10 percentage points in the inflation rate allows us to easily compare the changes in the growth rates predicted by the models with those found in the data, as discussed. We choose a baseline of $\pi = 1.1$ because this is close to the average rate of inflation in the cross-country samples analyzed by empirical researchers. Note that from a purely formal point of view, the balanced growth equations describe the relationship between the growth rate and the rate of monetary expansion μ. However, since this is not the regression that empirical researchers have run, we did the experiment by changing μ by however much is necessary in order to guarantee that the inflation rate is increased by 10 percentage points per year. The findings of this experiment are displayed in Table 1.[7]

Table 1 gives the percentage change in the growth rates when the inflation rate is increased 10 percentage points.[8] There are several notable features of the results of this experiment. The most important of these features is that the predicted change in the growth rate is an order of magnitude smaller than that of around 0.5 found in the empirical literature. Another notable feature is that there is no guarantee, in general, that an increase in the inflation rate will necessarily decrease the growth rate, although this is generally true. [Jones and Manuelli (1990) show that in the Lucas model with CIA in consumption, the relationship between inflation and growth is not monotone.] Note, however, that just because the growth rate increases as μ increases (in some regions of the parameter space), this increase does not mean that welfare increases. On the contrary, this is not true in general: increasing levels of inflation induce welfare-decreasing substitutions from c_1 to c_2. A third notable feature is that in the *Ak* and two-sector models of growth in combination with the CIA in consumption and shopping time models of money demand, one can show theoretically that the growth effect of inflation is exactly zero. In these models, inflation has no effect on the after-tax real return to savings. (In this sense, these models are Fisherian.) It follows, therefore, from the analogs of (15) and (16), that γ is unaffected by μ.

Table 1

A Small Inflation Effect on Growth

Percentage Point Change in Growth Rate
When Inflation Increases 10 Percentage Points

	Money Demand Models		
Growth Models	CIA in Consumption	Shopping Time	CIA in Everything
Ak	0	0	−.011
Two-Sector	0	0	−.009
Lucas	−.009	−.005	−.027
Romer	−.007	.128	−.024

[7]For the purposes of calibration, our *Ak* model is a version of the Lucas model in which the labor supply is inelastic. This model has all the important qualitative features of the *Ak* model, but it allows labor share and investment rates to be chosen so as to be close to those seen in the U.S. time series. See Chari, Jones, and Manuelli, forthcoming, for details.

[8]For the CIA in everything versions of the models, we assume that all of c_1 and a fraction ε of the c_2 and x_k expenditures used are subject to the CIA constraint. For the results presented in Table 1, we use $\varepsilon = 0.2$, since most investment transactions do not use cash directly. We experiment with increasing ε over an appreciable range, and although the growth effects are larger with larger ε, they still fall short of the effect seen in the data. In the next section, we discuss a model in which cash is used indirectly for these transactions through the banking system.

In summary, the results of this section show that constructing models in which inflation affects growth is fairly straightforward. However, in general, these models predict a very small effect of inflation on growth.

Models With Banks, Growth, and Inflation

In this section, we study an alternative way of introducing money into the model. The 12 models already analyzed have the feature that all money is held in the hands of the public for carrying out transactions in consumption of one form or another. In fact, a significant fraction of the monetary base in the United States and other countries is held by banks. Here we construct a simple model of financial intermediation in which banks are subject to reserve requirements. The equilibrium portfolio of a typical depositor is thus necessarily part capital and part money. Therefore, changes in the real rate of return on money (through inflation) reduce the real after-tax return on savings and thus affect growth. In this model, we repeat the previous computations and again find that the quantitative effect of changes in μ is much smaller than that seen in the data.

Given these conclusions, we turn to the possibility that our notion of monetary policy is too narrow. A broader and more realistic description of monetary policy allows for changes both in the growth rate of the money supply and in banking regulations. To the extent that increases in inflation rates are driven by needs for seigniorage, one would expect these increases to be accompanied by measures designed to increase the demand for the monetary base. In our model of financial intermediation, these measures are increases in reserve requirements.

We find that, in the data, inflation and the fraction of the monetary base held by banks are positively correlated. This correlation opens the possibility that a measure of monetary policy such as reserve requirements could be an important variable missing in the existing empirical work. To explore this possibility, we consider monetary policy experiments that consist of simultaneously changing the reserve requirements and the growth rate of the money supply in a way consistent with the empirical evidence. We find that when this change is made, existing models of growth and money demand can approximately reproduce the quantitative effects of inflation on growth found by empirical researchers.

A Simple Model With Banks

We study a model in which the banking system plays an essential role in facilitating production and capital accumulation. (See Greenwood and Smith, forthcoming, for a survey of the theoretical work in this area and Roubini and Sala-i-Martin 1992, King and Levine 1993, and Ireland 1994 for recent empirical work.) In our model, two types of capital are used in the production of final output, both of which are essential. One of these two types of capital must be intermediated as loans through the banking system, while the other is financed through conventional equity and debt markets. Finally, we assume that there is smooth substitution between the two, so that the amount of this banking type of capital can be altered across different policy regimes. In order to make loans, banks are required to hold reserves.[9]

We denote the two types of physical capital by k_1 and k_2. The first type of capital k_1 is intermediated through capital markets. The second type of capital k_2 must be intermediated through banks. That is, for k_2 to be used in production, consumers must place deposits in the banking system and firms must borrow these deposits in the form of bank loans to finance purchases of k_2. Banks are required to hold reserves against their deposits. We assume that no resources are used to operate the banking system. Here, then, an intermediary is simply a constraint, the reserve requirement relating the amount of base money that must be held in the banking system to the amount of capital of type 2 that is to be financed. We consider only two kinds of growth models here, the *Ak* and the Lucas versions. For the Lucas model, the production function is

$$(23) \quad k_{1t}^{\alpha_1} k_{2t}^{\alpha_2} (n_t h_t)^{1-\alpha_1-\alpha_2}.$$

Reserve Requirements

For this version of the model, the consumer's problem is to

$$(24) \quad \max \sum_{t=0}^{\infty} \beta^t u(c_{1t}, c_{2t}, 1-n_t)$$

subject to

$$(25) \quad p_t c_{1t} \leq m_{1t-1}$$

[9]Our model is similar to the one analyzed by Haslag (1994), but ours is more realistic along two dimensions. First, he assumes that all capital must be intermediated through banks, while we allow the share of bank assets to be endogenous. Second, he uses money only to meet reserve requirements, while we use money to facilitate consumption transactions as well. See also Valentinyi 1994.

$$(26) \quad d_t + m_{1t} + b_t \leq (m_{1t-1} - p_t c_{1t}) - p_t c_{2t} - p_t x_{k1t} - p_t x_{ht} + p_t r_t k_t (1-\tau) + p_t w_t n_t h_t (1-\tau) + [1 + (1-\tau) R_{dt}] d_{t-1} + [1 + (1-\tau) R_t] b_{t-1} + T_{t+1}$$

$$(27) \quad k_{1t+1} \leq (1-\delta_1) k_{1t} + x_{k1t}$$

$$(28) \quad h_{t+1} \leq (1-\delta_h) h_t + x_{ht}$$

where m_{1t-1} reflects the consumption transactions demand for money (that is, CIA for c_1) and d_t is deposits in the banking system. Arbitrage implies that $R_{dt} = R_t$.

The financial intermediary accepts deposits and chooses its portfolio (that is, loans and cash reserves) with the goal of maximizing profits. The intermediary is constrained by legal requirements on the makeup of this portfolio (that is, the reserve requirements) as well as by feasibility. Then the intermediary solves the problem

$$(29) \quad \max_{L_t, d_t, m_{2t}} (1+R_{Lt}) L_t + m_{2t} - (1+R_{dt}) d_t$$

subject to

$$(30) \quad m_{2t} + L_t \leq d_t$$

$$(31) \quad m_{2t} \geq \varepsilon d_t$$

where m_{2t} is cash reserves held by the bank, d_t is deposits at the bank, L_t is loans, and ε is the reserve requirement ratio. The reserve requirement ratio is the ratio of required reserves, which must be held in the form of currency, to deposits.

The firm rents capital of type 1 directly from the stock market (that is, the consumer) and purchases capital of type 2 using financing from the bank. Thus the firm faces a dynamic problem:

$$(32) \quad \max \sum_{t=0}^{\infty} \rho_t \{(1-\tau)[p_t F(k_{1t}, k_{2t}, n_t h_t) - p_t w_t n_t h_t - p_t r_t k_{1t} - R_{Lt-1} L_{t-1}] + L_t - p_t x_{k2t} - (1 + R_{Lt-1}) L_{t-1}\}$$

subject to

$$(33) \quad p_{t-1} k_{2t} \leq L_{t-1}$$

$$(34) \quad k_{2t+1} \leq (1-\delta_2) k_{2t} + x_{k2t}$$

where ρ_t is the subjective discount factor used by firms. Note that constraint (33) implies that from the firm's point of view, it may as well be renting k_2 from the bank itself. Because of this situation, the firm can be seen as facing a static problem; hence, one of the equilibrium conditions is that for this version of the model, the choice of ρ_t is irrelevant.

To gain some intuition for the role of reserve requirements in this model, consider the intermediary's problem. The solution to its problem is given by

$$(35) \quad (1+R_{Lt})(1-\varepsilon) d_t + \varepsilon d_t - (1+R_{dt}) d_t = 0.$$

Simplifying this, we obtain that in equilibrium

$$(36) \quad R_{Lt} = R_{dt}/(1-\varepsilon).$$

Thus reserve requirements induce a wedge between borrowing rates and lending rates for the intermediary.

Next, from consumer optimization, we have that the consumer must be indifferent between holding a unit of deposits and holding a unit of capital. This indifference implies that the after-tax real returns on the two ways of saving must be equal. That is,

$$(37) \quad 1 + (1-\tau) R_{dt-1} = (p_t/p_{t-1})[1 - \delta_1 + (1-\tau) r_t].$$

Production firms set their after-tax marginal products of the two types of capital equal to their after-tax real rental rates. Therefore,

$$(38) \quad F_1(t) = r_t$$

and

$$(39) \quad (p_t/p_{t-1})[(1-\tau) F_2(t) + (1-\delta_2)] = 1 + (1-\tau) R_{Lt-1}$$

where $F_1(t)$ and $F_2(t)$ denote the marginal products of the two types of capital. Substituting, we obtain

$$(40) \quad 1 + \left(\{(p_t/p_{t-1})[(1-\tau) F_1(t) + 1 - \delta_1] - 1\}/(1-\varepsilon)\right) = (p_t/p_{t-1})[1 - \delta_2 + (1-\tau) F_2(t)].$$

Inspection of this equation reveals that increases in the reserve requirements (higher ε) or increases in the inflation rate have the effect of raising F_2 relative to F_1. That is, higher reserve requirements or higher inflation rates distort the mix of the two types of capital. The reason for this distortion is that financial intermediaries are required to hold non–interest-bearing assets in their portfolios. This requirement introduces a wedge between the rental rates on the two types of assets, and this wedge distorts the capital mix. It can also be seen that the increased distortion in the capital mix induced by a change in the inflation rate is greater with higher reserve requirements. Thus in this model, inflation acts as a tax on capital, the effect of which is magnified by higher reserve requirements.

Computations

Now we compute the effect of changing the growth rate of the money supply so that the annual inflation rate increases 10 percentage points. This computation is done for two calibrated models: the Lucas model and an *Ak* version of the model.

To do the calibration, we use data on the actual holdings of money in both the banking and nonbanking sectors along with measures of assets intermediated by banks. After taking account of money held outside the United States (Porter 1993), we find that the fraction of money held as reserves by banks (denoted by m_b) is 0.46. We use assets of commercial banks minus their holdings of U.S. government securities, consumer credit, vault cash, reserves at Federal Reserve Banks, and deposits of nonfinancial businesses to obtain a measure of the capital stock intermediated through banks. We obtain these data from the flow of funds accounts published by the Board of Governors of the Federal Reserve System. The average of the ratio of this measure to GDP from 1986 to 1991 is 0.39. We use these facts (along with the assumption that $\delta_1 = \delta_2$) to calibrate the models and obtain estimates of the parameter ε and k_2's share of output (relative to k_1).

The parameters from this calibration for the Lucas version of the model are $A = 0.095$, $\delta_1 = \delta_2 = 0.02$, $\delta_h = 0.016$, $\alpha_1 = 0.306$, $\alpha_2 = 0.054$, $\beta = 0.98$, $\eta = 1.03$, $\lambda = -0.83$, $\sigma = 2.0$, $\psi = 6.412$, and $\varepsilon = 0.042$. Again, all parameters are expressed in annualized terms.

Of course, alternative measures of ε could be taken directly from banking regulations. The difficulty with that approach is that reserve requirements differ greatly among the different types of accounts held in banks. Depending on which types of accounts one looks at, average reserve requirements on banks could be anywhere from 2.5 percent to 12 percent.

Given this calibration, we find that increasing μ in order to increase π from 1.1 to 1.2 on an annual basis decreases the annual growth rate of output by 0.009 percentage points for the *Ak* model and by 0.021 percentage points for the Lucas model. Thus, although these effects are quantitatively larger (for the Lucas model) than those we have seen in the models with transactions demand for money, they are still too small by a factor of roughly 20 than the regression results reported in the literature. [Haslag (1994) finds growth effects of up to 0.4 percentage points.]

Given that the effects on the growth rate of changing μ are still small, we now explore the effects on the growth rate of changing the other aspect of monetary policy in the model: ε. For this exploration, we use the Lucas model. We run two experiments. In the first, we hold constant the rate of inflation at $\pi = 1.1$ and increase ε. The rate of growth of money is determined by the balanced growth equation. In the second, we hold the growth of money fixed and increase ε. The inflation rate is determined by the balanced growth equation. First, consider the effect on the growth rate of holding π constant at 1.1 and adjusting the reserve requirement parameter ε. The results of these experiments are shown in Charts 1 and 2.

As can be seen in the charts, even moderate increases in the reserve requirements can produce the observed changes in the growth rate. For example, an increase from the calibrated level of $\varepsilon = 0.04$ to $\varepsilon = 0.35$ will give the desired effect. In Chart 2, we show the implied money holdings (in reserves) by banks for this experiment. Note that the result is highly nonlinear, and even at very low levels of ε, the resulting equilibrium changes in m_b are quite severe.

Next, consider the effect on the growth rate of increasing ε and letting π adjust, while holding μ constant. Chart 3 and Chart 4 show the impact on γ and m_b, respectively. The results of this experiment are qualitatively similar to those when π is held fixed. The growth effects of changing ε are quite large even for quantitatively reasonable changes. Note that it follows from this discussion that we cannot generate the observed correlation between growth and inflation without simultaneously adjusting ε and μ. That is, from the results of holding μ fixed and adjusting ε, it follows that the correlation between π and γ is positive: as ε is increased, both π and γ decrease.

Does this class of models show quantitative potential? That is, can we explain, through simultaneous adjustments in μ and ε, the observed relationship between growth and inflation? If we don't restrict that question further, the answer is yes. This answer is misleading, however, since the implied relationship between μ and ε may be quite different from that in the data. To subject the model to a more rigorous test, therefore, we must use data on actual countries' performances to get some feel for the magnitude of

Charts 1–4
The Effects of Increasing Reserve Requirements in the Lucas Model

Charts 1 and 2 Inflation Fixed at 10% and Money Growth Adjusted

Chart 1 **Growth Effect**

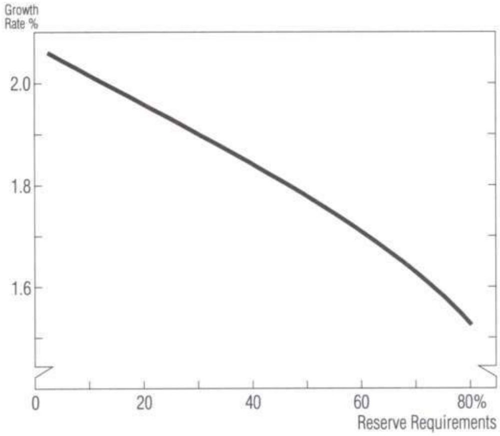
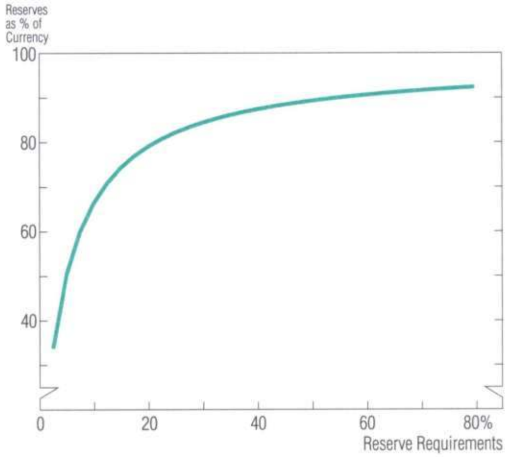


Chart 2 **Bank Reserves Effect**



Charts 3 and 4 Money Growth Fixed at 12.2% and Inflation Adjusted

Chart 3 **Growth Effect**

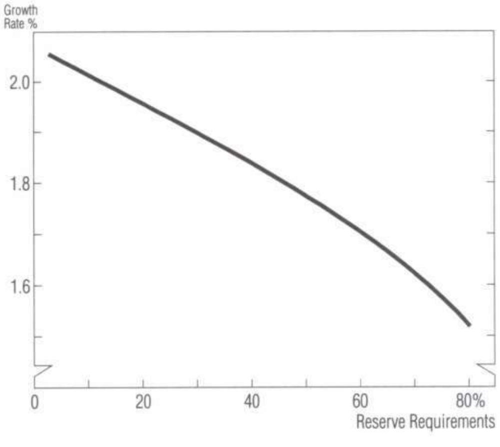


Chart 4 **Bank Reserves Effect**

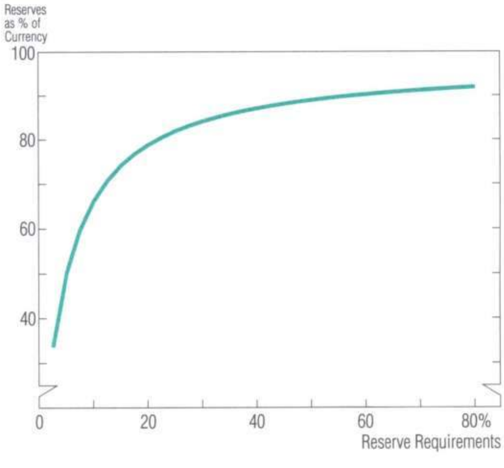


Table 2

How Growth Changes in a Model With Banks When Inflation Increases 10 Percentage Points*

Experiment	Value of Bank Base Money (m_b) Initial	Value of Bank Base Money (m_b) New	Growth Rate (γ) Initial	Growth Rate (γ) New	Growth Rate (γ) Change (% pts.)	Reserve Requirements (ε) Initial	Reserve Requirements (ε) New	Reserve Requirements (ε) Change
1	.286	.332	1.0206	1.0204	−.02	.020	.024	.004
2	.600	.650	1.0203	1.0198	−.05	.076	.010	.066
3	.700	.750	1.0200	1.0192	−.08	.121	.176	.055
4	.800	.850	1.0195	1.0175	−.20	.217	.426	.209

*In each experiment, the inflation rate is increased from 10 percent to 20 percent.

the relationship between actual changes in μ and in ε.

To do this, we collect data from 88 countries from the International Monetary Fund's *International Financial Statistics* (*IFS*). (See Chari, Jones, and Manuelli, forthcoming, for details.) Since measures of ε are not readily available, we instead gather data on m_b that in turn—conditional on the model—allow us to estimate ε. In order to estimate the size of the combined money growth effect and reserve requirement effect, we estimate the relationship between π and m_b from the data and use this estimated effect in comparing computed balanced growth path results. That is, we compute the implied change in the growth rate when the inflation rate is increased 10 percentage points and, at the same time, the reserve requirement is increased so as to change the observed m_b as is seen in the data. To do this computation, we first give the regression result concerning the relationship between π and m_b:

$$(41) \quad m_b = -0.220 + 0.460\pi$$

where m_b is the time series average, by country, of the fraction of the monetary base held in banks, while π is the time series average, by country, of the inflation rate. (The t-ratio for the coefficient on π is 5.98.) For this sample, the mean value of π is 1.16 (which corresponds to an inflation rate of 16 percent), and its standard deviation is 0.18. The mean value of m_b is 0.32 with a standard deviation of 0.16. Thus an increase of 0.1 in π produces an increase of approximately 0.046 in m_b. These results are similar to those found in Brock 1989. They are consistent with the view that in high inflation countries, governments choose high reserve replacement to enhance the base of the inflation tax.

The experiment we perform is to increase π from 1.1 to 1.2 and simultaneously to increase m_b by about 0.046. (We will actually change m_b by 0.05.) The size of the equilibrium growth response depends critically on the initial value of m_b because the relationship between ε and m_b is very nonlinear, as documented in Charts 2 and 4. Therefore, we will report the results for several initial values of m_b. (See Table 2.) Experiment 1 uses the regression results from the *IFS* data to estimate the level of m_b at π = 1.1. Here, the increase of 0.05 in m_b is associated with only a small change in ε (less than 0.005) and hence a small change in the growth rate results. In this experiment, the predicted change in the growth rate is smaller by a factor of 10 than the regression results in the empirical studies. At higher initial levels of m_b, however, the predicted growth effects of the same experiment are substantially higher. At m_b = 0.7, even a relatively small increase in ε (from 0.121 to 0.176) gives a growth effect that is one-fifth as large as that found in the empirical studies. Finally, for substantial initial levels of the reserve requirements (m_b = 0.8), a 10 percentage point increase in inflation decreases the annual growth rate approximately 0.2 percentage points. This estimate—although lower than the average value of 0.5 found in different studies—is similar to the lower bound of 0.20 reported in Barro 1995.

These results suggest that for values of reserve requirements that, although higher than those in the United States, are within a plausible range, the model that allows for simultaneous changes in both money supply and reserve requirements comes close to matching the estimated impact of inflation on growth.

Conclusions

Empirical researchers have found that the average long-run rate of inflation in a country is negatively associated with the country's long-run rate of growth. Moreover, the statistical relationship uncovered by these researchers is large. Roughly, increasing the inflation rate by 10 percentage points in a country otherwise like the United States decreases the growth rate of per capita output by 0.5 percentage points. We have examined a variety of models with transactions demand for money and have seen that none produces results anywhere near this large.

This finding leads us to reconsider our view of monetary policy to include changes in financial regulations as well as changes in the money supply. In the data, we document a high correlation between the rate of inflation in a country and the fraction of the currency in the economy that is held in the commercial banking system. We interpret this to mean that monetary authorities who raise inflation rapidly also require banks to hold more currency. (That is, in those countries, reserve requirements are also higher.) After taking account of this extra dimension of monetary policy, we find that existing models of growth and money demand can indeed approximately reproduce the results found by empirical researchers. In addition, we find that the relationship between changes in reserve requirements and growth rates is highly nonlinear. Thus the estimated effects depend sensitively on the level of the reserve requirements.

Our analysis suggests that inflation rates per se have negligible effects on growth rates. Financial regulations and the interaction of inflation with such regulations have substantial effects on growth. This analysis suggests that researchers interested in studying the effects of monetary policy should shift their focus away from printing money and toward the study of banking and financial regulation.

Appendix
Technology and Preferences in the Models

Here we describe the production functions and the preferences used in the growth and money demand models discussed in the preceding paper.

Models of Growth

Ak Model
The resource constraint is

(A1) $c_{1t} + c_{2t} + g_t + x_{kt} = Ak_t$.

Two-Sector Model
The production function in the investment sector is

(A2) $x_{ht} = A(k_t - k_{1t})$

and in the consumption sector it is

(A3) $c_{1t} + c_{2t} + g_t = Bk_{1t}^{\alpha} n_t^{1-\alpha}$

where k_{1t} is the amount of capital used in the production of consumption goods.

Lucas Model
The production function is

(A4) $c_{1t} + c_{2t} + g_t + x_{kt} = Ak_t^{\alpha}(n_t h_t)^{1-\alpha}$.

Romer Model
The production function is

(A5) $c_{1t} + c_{2t} + g_t + x_{kt} + Ak^{\alpha} n^{1-\alpha} \bar{k}^{1-\alpha}$

where $\bar{k}$ is the aggregate capital stock. Preferences are given by

(A6) $[c_{1t}^{-\lambda} + \eta c_{2t}^{-\lambda}]^{(1-\sigma)/\lambda}(1-n)^{\psi(1-\sigma)}/(1-\sigma)$.

Models of Money Demand

CIA in Consumption Model
Cash goods purchases must satisfy the constraint

(A7) $p_t c_{1t} \leq m_t$

where m_t denotes cash balances.

Shopping Time Model
Time allocated to nonleisure activities n_t is allocated to shopping time n_{ct} and market activity n_{ft} so that

(A8) $n_t = n_{ct} + n_{ft}$.

The technology for purchasing cash goods for all models of growth except the Lucas model is

(A9) $p_t c_{1t} \leq Bm_t n_{ct}^{\varepsilon}$.

For the Lucas model, the shopping time technology is

(A10) $p_t c_{1t} \leq Bm_t^{\varepsilon}(p_t n_{ct} h_t)^{1-\varepsilon}$.

CIA in Everything Model
The cash-in-advance constraint is given by

(A11) $p_t(c_{1t} + \varepsilon c_{2t} + \varepsilon x_{kt}) \leq m_t$.

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