Monetary Policy, Taxes and the Business Cycle

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June 11, 2004

ABSTRACT

In this paper, we model the interaction of inflation with the tax code, examining the contribution of this interaction to aggregate fluctuations. Our innovation is to combine persistent monetary policy shocks with taxes on nominal capital gains in a model in which the central bank operates policy using an interest rate rule. All three features are necessary for us to generate large effects of monetary shocks, but they are also realistic features of the U.S. economy. All three have been examined in isolation and, by themselves, do not contribute much to aggregate fluctuations. Capital gains taxes are important when there are persistent changes in the inflation rate. Money growth shocks do not cause persistence changes in inflation when the central bank uses a money growth rule. When the central bank operates policy using an interest rate rule persistent monetary policy shocks lead to persistence in inflation, raising the effective marginal capital gains tax rate, thereby suppressing capital accumulation.

Introduction

Does the interaction of inflation and the tax code contribute to aggregate fluctuations? There is a large body of work showing that the steady state welfare effects of moderate inflation are large when nominal capital gains are taxed. These include the partial equilibrium analyses of Fischer (1981), Feldstein (1997) and Cohen, Hassett, and Hubbard (1999). The literature also includes the steady state analysis of general equilibrium models in Abel (1997), Leung and Zhang (2000), and Bullard and Russell (2004). In general equilibrium the welfare costs arise because, for any given capital income tax rate, an increase in the inflation rate raises the real pre-tax rate of return to capital and lowers the after-tax return. The lower after-tax return causes a decline in the capital stock and a reduction in labor productivity. These analyses are about steady states and only suggestive about the cyclical impacts. This paper examines the impact of the interaction between inflation and the capital gains tax on business cycle fluctuations.

We specify a DSGE model that combines persistent shocks to the inflation trend with taxes on nominal capital gains in a setting where the central bank operates policy using an interest rate rule. All three features are necessary for us to generate large effects of monetary shocks, but they are also realistic features of the U.S. economy.

Cooley and Hansen (1989) and Pakko (1998) show that the real effects of persistent money growth shocks are large relative to money supply shocks, but still small. Studies with models using money supply rules will not find much interaction between the tax system and monetary policy shocks because there is little or no persistence in inflation following a money growth shock. A persistent money growth shock leads to a large jump in the price level, but inflation does not persist and does not affect expected returns to investment.

Inflation persistence is needed to induce changes in expected tax rates. Dittmar, Gavin and Kydland (2004) show that that inflation persistence is common in models where the central bank uses an interest rate rule. When the central bank is using an interest rate rule, a persistent one-percent shock to the inflation trend appears as a shock to the inflation target. It is followed by a persistent deviation of inflation from the steady state and, in the presence of a nominal tax on capital gains, a persistent change in the effective marginal tax rate on capital. Thus, a positive shock to the inflation target distorts the consumption/saving decision and may have a long-lasting effect on the capital stock.

Altig and Carlstrom (1991) use an overlapping generations model with nominal prices (but without money explicitly included) to show that the lack of perfect indexation for inflation in the tax code could have a large cyclical effect in principle, but find that their model could not account for the magnitude of cyclical variation in hours worked and it predicted a large decline in the capital stock in the 1980s that never materialized.

Having established that monetary policy shocks can produce persistent deviations of the inflation rate from the steady state, it is important to revisit the interaction of such shocks with the tax code. We begin by describing a model with taxes, including separate taxes for income from labor, capital, bonds and capital gains. In the United States, the rise of inflation in the 1970s without indexation of tax brackets and exclusion restrictions led the government to index some aspects of the tax code and to make ad hoc adjustments in other aspects. We assume constant statutory tax rates in order to examine the interaction of variable inflation with the nominal tax on capital gains. Then, we discuss the dynamics of the model, showing how inflation affects the business cycle through the tax on nominal capital gains. Finally, we use the

model with estimates of persistence in the inflation objective to show what our model predicts

for capital, hours and productivity in the U.S. economy.

A Monetary Model with Nominal Taxes

Technology

Output is produced with a standard CRTS production technology:

(1) $$Y_t = z_t F(K_t, x_t N_t) = z_t K_t^{\alpha} (x_t N_t)^{1-\alpha}$$

where z_t is a stationary technology shock and x_t is an index of labor-augmenting technical

progress that increases at a (gross) growth rate $\gamma_x^{1/(1-\alpha)}$. The implied growth rate for output,

capital and consumption, γ_x, defines a steady-state growth path for the real economy.

The firm sells output at price P_t, and purchases labor and capital services from the

household at nominal wage, W_t, and rental price of capital, V_t. Along with the CRTS

assumption, profit-maximization under perfect competition implies that the real wage rate,

$w_t = W_t/P_t$, and rental price, $v_t = V_t/P_t$, will be equated with the marginal products of labor and

capital.

Capital—owned by the households—follows the law of motion

(2) $$K_{t+1} = (1-\delta)K_t - I_t,$$

where I_t is gross investment and δ is the depreciation rate on capital.

Government with a Nominal Tax Code

A government issues nominal claims to money and bonds, and collects revenues by

imposing proportional taxes on nominal income from labor, bond interest and capital ownership

(with possibly differing tax rates). Government revenues, *T*, from income taxes are:

(3) $T_t = \tau_t^N W_t N_t + \tau_t^B R_t B_t + \tau_t^K (v_t - \delta) P_t K_t + \tau_t^G (P_t - P_{t-1}) K_t$,

where R_t is the nominal interest rate on bonds from the previous period. The third term in

equation (4) represents the revenue from taxes assessed on capital returns net of depreciation

charges.   The fourth term represents the income from the tax on nominal capital gains.

Revenues from the income taxes are returned to the household via a lump-sum rebate.

This allows us to consider the pure distortionary effects of taxation, abstracting from wealth

affects associated with reallocations between the public and private sectors. The government

also carries out transfers of bonds and money to the public directly in the form of nominal assets,

B_t and M_t.

Households

A representative household maximizes a discounted stream of utility from consumption

and leisure,

$$max \sum_{t=0}^{\infty} \beta^t u(C_t, L_t),$$

$$\text{with } u(C_t, L_t) = (C_t^{\theta} L_t^{1-\theta})^{1-\sigma} /(1-\sigma),$$

subject to a nominal budget constraint and a constraint on the allocation of time. The

household's nominal budget constraint can be written:

(4) $(1 - \tau_t^N) W_t N_t + (1 - \tau_t^K)(v_t - \delta) P_t K_t - \tau_t^G (P_t - P_{t-1}) K_t + \overline{T}_t$

$\quad + [1 + (1 - \tau_t^B) R_t] B_t + M_t + \Delta M_t = P_t C_t + P_t [K_{t+1} - K_t] + B_{t+1} + M_{t+1}$,

where ΔM_t is the transfer of money in period t. The bar over T_t, the lump sum transfer of

government revenue, indicates that the household takes the lump-sum transfer as exogenous to

its maximization problem.

The household endowment of time (normalized to one) can be allocated to leisure, labor input to the production process, or to transaction related activities such as shopping-time, trips to the bank, etc.:

(5) $L_t + N_t + S_t = 1$.

Transactions-related costs are minimized via a shopping-time function that is assumed to be increasing in the nominal value of consumption purchases and decreasing in the quantity of money held for facilitating transactions,

(6) $S_t = \xi \left(\frac{P_t C_t}{M_t} \right)^{\eta}$,

with ξ, $\eta > 0$. This specification of shopping time may appear to be nonstandard because money received in the transfer is not used in the shopping time function. The timing was used Kydland (1989). It is a consistent with cash-in-advance timing. If we included the transfer, then it would be equivalent to end-of-period balances and more comparable with typical analysis of models in which money enters the utility function directly. Both variants of this shopping time function are discussed in Goodfriend and McCallum (1987). The only important result that depends on this timing is the real determinacy of the equilibrium with a contemporaneous policy rule. Carlstrom and Fuerst (2001) show that the determinacy conditions depend crucially on these somewhat arbitrary timing conventions.

Stationary Transformation and Household Optimization

The model contains two sources of nonstationarity: Technological progress implies growth in all real variables, while nominal variables are also subject to growth due to inflation. Allowing for the technology growth rate and inflation to have stochastic components, the

stationary representation of the model approximates the dynamics of a difference-stationary economy. The real-valued variables—output, consumption and investment—share a common trend, γ_x. The price level is assumed to be difference stationary, so all nominal values also share a common trend with the (stochastic) trend inflation rate, γ_p. To assure that the government's intertemporal budget constraint is satisfied, we impose the condition that the growth rate of bonds and money are cointegrated with the nominal growth trend, $\gamma_x\gamma_p$. In the computational experiments, we treat γ_p as stochastic, allowing for shocks the inflation trend.

To model the model's dynamics, we require a stationary representation, which can be derived by deflating all real variables by $(\gamma_x)^t$ and deflating all nominal variables by a similar index of the trend rate of inflation, $(\gamma_p)^t$.[1] The resulting transformed household optimization problem, in which all nominal and real variables are stationary, can be written:

$$max \sum_{t=0}^{\infty} \beta^t (c_t^\theta L_t^{1-\theta})^{1-\sigma} / (1-\sigma)$$

subject to

(7) $\qquad (1-\tau_t^N)w_t N_t + (1-\tau_t^K)(v_t - \delta)k_t - \tau_t^G\left(1 - \dfrac{p_{t-1}}{\gamma_{pt}p_t}\right)k_t + \dfrac{\overline{t}_t}{p_t}$

$\qquad\qquad + [1 + (1-\tau_t^B)R_t]\dfrac{b_t}{p_t} + \dfrac{m_t}{p_t} + \dfrac{\Delta m_t}{p_t} = c_t + [\gamma_{xt+1}k_{t+1} - k_t] + \gamma_{pt+1}\gamma_x \dfrac{b_{t+1}}{p_t} + \gamma_{pt+1}\gamma_x \dfrac{m_{t+1}}{p_t}$

(8) $\qquad L_t + N_t + \xi\left(\dfrac{p_t c_t}{m_t}\right)^\eta = 1$

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[1] This transformation also affects the value of the appropriate discount factor (as described in King, Plosser and Rebelo (1988).

In the transformed problem, lower-case variables represent inflation-adjusted, growth-adjusted stationary values. The timing convention is such that R_{t+1}, and γ_{pt+1} represent growth rates from t to $t+1$.

The first-order conditions to the household's optimization problem can be expressed as follows:

(9) $\qquad U_c(\cdot_t) = \lambda_t + \omega_t \eta(S_t / c_t)$

(10) $\qquad U_L(\cdot_t) = \omega_t$

(11) $\qquad \lambda_t(1 - \tau_t^N)w_t = \omega_t$

(12) $\qquad \beta[\lambda_{t+1} + \omega_{t+1}p_{t+1}\eta(S_{t+1}/m_{t+1})] = \gamma_{pt+1}\gamma_x\lambda_t(p_{t+1}/p_t)$

(13) $\qquad \beta\lambda_{t+1}[1 + (1 - \tau_{t+1}^B)R_{t+1}] = \gamma_{pt+1}\gamma_x\lambda_t(p_{t+1}/p_t)$

(14) $\qquad \beta\lambda_{t+1}\left\{1 + [(1 - \tau_{t+1}^K)(v_{t+1} - \delta)] - \tau_{t+1}^G\left(1 - \dfrac{p_t}{\gamma_{pt+1}p_{t+1}}\right)\right\} = \gamma_x\lambda_t$

where λ_t and ω_t are utility-denominated, present-valued shadow prices of goods and time, respectively.

Equation (9) sets the marginal utility of consumption equal to the shadow goods-price plus a factor reflecting the shopping-time cost. Equations (10) and (11) determine the shadow value of time, and reflect the optimal condition that the marginal utility of leisure is equal to after tax wage rate (denominated in utility-units).

Equations (12)-(14) determine portfolio allocations for money, bonds and capital. From (13), the gross nominal rate of return on a tax-free bond would be:

(15) $\qquad (1 + \tilde{R}_{t+1}) = \pi_{t+1}\dfrac{\gamma_x\lambda_t}{\beta\lambda_{t+1}}$

where $\pi_{t+1} = \gamma_{pt+1} p_{t+1} / p_t$. In general equilibrium, equation (15) represents the after-tax nominal interest rate. Relative to the real after-tax interest rate, $(1 + \tilde{r}_{t+1}) = (1 + \tilde{R}_{t+1}) / \pi_{t+1}$, the tax distortions in equations (12)-(14) can be summarized in the following relationships:

$$(16) \qquad (1 + \tilde{r}_{t+1}) = \left[1 + \eta(\omega_{t+1} p_{t+1} / \lambda_{t+1})(S_{t+1} / m_{t+1})\right] / \pi_{t+1} \qquad \text{(Money)}$$

$$= \left[1 + (1 - \tau_{t+1}^B) R_{t+1}\right] / \pi_{t+1} \qquad \text{(Bonds)}$$

$$= \left\{1 + \left[(1 - \tau_{t+1}^K)(v_{t+1} - \delta)\right] - \tau_{t+1}^G (1 - 1/\pi_{t+1})\right\} \qquad \text{(Capital)}$$

The distorting effects of taxes on interest and capital income are directly represented by the tax wedges, $(1 - \tau^B)$ and $(1 - \tau^K)$. An increase in the tax on interest income lowers the demand for bonds, raising the nominal bond rate. The direct effect of an increase in the capital tax is to lower real after tax returns, reducing investment demand and capital accumulation.

The seigniorage tax (inflation) lowers real returns on money and bonds. For a given baseline real return, an increase in inflation requires a higher nominal bond rate and a higher return to money holdings in equilibrium. In the case of money, higher returns are associated with a lower demand for real money balances and an increase in shopping-time costs.

Inflation also interacts with the tax structure in the expression for capital returns through the last term, which reflects the taxation of nominal capital gains. A higher inflation rate lowers after tax returns to capital through this channel, lowering investment demand and capital accumulation. It is this mechanism that primarily drives the model dynamics in response to shocks to the inflation trend.

Stochastic General Equilibrium

Equations (8), (10) and (11) in the household's optimization problem determine the household allocation of time between labor and leisure (net of shopping-time)—implying a labor demand function—and determine the shadow price of time. The firm's profit-maximization condition setting the marginal product of labor equal to the real wage,

$$(17) \qquad w_t = (1-\alpha)(y_t / N_t),$$

completes the labor market and determines the equilibrium real wage. Similarly the firm's demand for capital determines that the real rental price will be equal to capital's marginal product:

$$(18) \qquad v_t = \alpha(y_t / k_t).$$

Equations (9) and (14), along with a transformed stationary representation of the capital accumulation equation,

$$(2') \qquad \gamma_t k_{t+1} = (1-\delta)k_t + i_t$$

imply household demand functions for consumption and real investment—and hence, the future capital stock, k_{t+1}. The presence of marginal shopping-time costs in the consumption-demand equation (9), defined by the shopping-time function

$$(6') \qquad S_t = \xi \left(\frac{p_t c_t}{m_t} \right)^{\eta},$$

demonstrates one source of non-neutrality in the model. In addition, the presence of π_t in equation (14) implies another source of interaction between the goods market and the nominal asset market.

Assuming equilibrium in the nominal asset markets, the condition for equilibrium in the goods market can be derived from the household's budget constraint:

$$(4'') \qquad y_t = c_t + i_t$$

by imposing the constraint that this demand for goods equals the supply of goods, defined by the production function,

(1′) $y_t = z_t k_t^\alpha N_t^{1-\alpha}$.

Equilibrium in the goods market determines consumption, investment, and output—with the equilibrating price being the shadow value of capital, λ_{t+1}; i.e., the after-tax real interest rate,

$$(1+\tilde{r}_{t+1}) = \frac{\gamma_x \lambda_t}{\beta \lambda_{t+1}} .$$

Summarizing to this point, (1′), (2′), (4″), (6′), (8)-(11), (14), (17) and (18) comprise eleven equations determining equilibrium values for y_t, c_t, i_t, k_{t+1}, N_t, L_t, S_t, v_t, w_t, ω_t and λ_{t+1}. The remaining first-order conditions from the household's problem, (12) and (13), represent demand functions for bonds and money. Together with government supply processes, specified below, equilibrium in the asset market determines the price level and the nominal interest rate (inflation).

With lump-sum rebates of tax revenue and no real government assets, the bond market plays no independent role in terms of equilibrium allocations. Without loss of generality, we will assume that government borrowing is zero in each period. Equation (13) therefore stands as a definition of the nominal interest rate.

Equation (12) describes a relationship that can be interpreted as a money demand function. Substituting (11), (13), (17) and (6'), equation (12) can be solved for real money balances to yield:

(20) $\dfrac{m_{t+1}}{p_{t+1}} = \left[\dfrac{\eta \xi (1-\tau_{t+1}^N)(1-\alpha)(y_{t+1}/N_{t+1})c_{t+1}^\eta}{(1-\tau_{t+1}^B)R_{t+1}} \right]^{\frac{1}{1+\eta}}$.

Calibrating the shopping-time function with $\eta=1$ implies an interest elasticity of -½ . Note also that because consumption and productivity are cointegrated, the scale variable in the numerator of (20) implies a *long-run* income elasticity equal to one. Because both consumption and labor

productivity tend to be procyclical—but with smaller amplitude than output—the short-run

income elasiticity of the money demand relationship will be less than one.

Policy Functions and Exogenous Processes

Closing the model requires the specification of the policy functions determining the money

supply process and tax rates.   In this paper we treat the tax rates as constant. We consider two

alternative monetary policy strategies—a money growth rule and an interest rate rule aimed at

achieving an inflation target. In both cases, we define the monetary policy shock to be a shock the

inflation trend (γ_{pt}). When the central bank is using a money growth rule, we refer to this shock as

a shock to money growth and when it is using an interest rate rule, we refer to the shock as a shock

to the inflation target.

It is common in the literature on money growth rules to specify the policy shock as a shock

to the money growth rate. However in the literature on interest rate rules, the shock is usually

appended to the equation in which the central bank determines the one-period interest rate. We

think of this as a shock to liquidity. In the money growth rule, the liquidity shock is an innovation

to the level, rather than to the growth rate of the money supply. In this paper we do not consider

shocks to short-term liquidity because there is no special role for liquidity except that embodied in

the shopping time function. These effects are small in a model with flexible prices.

Under the interest rate rule, the central bank targets the inflation rate, with the money

stock determined endogenously from the money demand relationship (12). As typically written,

an interest rate rule specifies that the monetary authority adjusts the nominal interest rate in

response to deviations of inflation from a target rate, π^*, and to deviations of output from potential

(the output gap). Although we examined some rules with output in them, our model does not

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include the standard notion of an output gap. In models where prices do not adjust to clear

markets, the output gap is defined as the difference between the models output and the level that

would occur in a flexible price equilibrium. In the past we have defined the output gap as the

deviation of output from the steady state. In preliminary results for this study, we found that none

of our qualitative results depended on having output in the policy rule.[2] Therefore we focus on

policy in which the central bank responds only to inflation.

(21) $R_{t+1} = \bar{r} + \pi^* + \varphi_\pi(\pi_t - \pi^*)$.

Assuming a constant inflation target, this rule can be written

(21′) $R_{t+1} = (\bar{r} - \varphi_\pi\pi^*) + (1 + \varphi_\pi)\pi_t$.

In the context of this model, a rule of this type can be specified as

(22) $(1 + R_{t+1}) = (1 + \bar{r})\pi_t \left(\dfrac{\pi_t}{\pi^*}\right)^{\varphi_\pi}$.

In terms of log-deviations from a constant steady-state,

(22′) $\hat{R}_{t+1} = (1 + \varphi_\pi)\hat{\pi}_t$

Recall that π_t includes both the endogenous rate of change in prices, p_t/p_{t-1}, and an exogenous

component representing the inflation trend, γ_{pt}. Interpreting the exogenous component as a target

rate of inflation that is subject to occasional deviations from the constant steady-state, the rule can

be generalized to allow for changes in the inflation target:

(23) $\hat{R}_{t+1} = (1 + \varphi_\pi)\hat{\pi}_t - \varphi_\pi\hat{\gamma}_{pt}$.

The remaining exogenous variables—z_t, and γ_{pt}—are similarly assumed to follow

independent first order autoregressive processes that are calibrated from the data.

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[2] We also confirmed the result in Edge and Rudd (2002) that adding taxes to the model restricts the size of the

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$$z_t = \rho_z z_{t-1} + \varepsilon_t^z$$
$$\gamma_{pt} = \rho_\pi \gamma_{pt-1} + \varepsilon_t^\pi$$

The monetary policy shock, ε_t^π, is a shock to the inflation trend. The model's dynamics are simulated in terms of proportional deviations from a baseline, constant steady state.

Steady-State and Model Calibration

The model's dynamics will be approximated as proportional deviations from a baseline steady state, defined by the model parameters (including the baseline growth rates of technology and prices, γ_x and γ_p). The model is calibrated by matching the steady-state values to long-run macroeconomic data (see Table 1).

[Table 1]

Some of the model's parameters are calibrated directly using long-run average values for post-1960 U.S. data: the capital share is set equal to 0.38, and the depreciation δ=.02. The discount factor, β, is set to 0.99. We set the relative risk aversion parameter equal to 2. The shopping-time parameter, η is set at one, implying an interest-elasticity of money demand equal to minus one half. Steady state allocations of time are set exogenously, with market labor comprising 30 percent of time, and shopping time equaling 0.3 percent of time and the remaining 69.70 percent of time allocated to leisure. The growth rate parameters are set at γ_x=1.004 and γ_p=1.01, reflecting the average annual growth rates of productivity growth and inflation equal to approximately 1.6 percent and 4 percent, respectively. The money growth trend is a product of the technology and inflation growth trends.

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parameter space for which the model has a unique equilibrium. In our model, increasing the weight on output restricts the space even more.

Several key steady-state ratios are useful for deriving values for the remaining model parameters, and for specifying the linear approximations used to calculate the model's dynamics. First, equations (14) and (18) can be used to derive the steady state capital/output ratio:

$$(24) \quad \frac{k}{y} = \frac{\alpha\beta(1-\tau^K)}{\gamma_x - \beta(1-\delta) + \beta\tau^K\left[(\gamma_p - 1)/\gamma_p - \delta\right]}.$$

From (2′) the share of output used for investment will be

$$(25) \quad \frac{i}{y} = [\gamma_x - (1-\delta)]\frac{k}{y},$$

and from (4″) the consumption share is

$$(26) \quad \frac{c}{y} = 1 - \frac{i}{y}.$$

From (9) and (10), the marginal rate of substitution between consumption and leisure is related to the two shadow-prices and the parameters of the shopping-time function. Substituting the values of the relative shadow prices from (11), we can derive the following relationship:

$$(27) \quad \frac{\theta}{1-\theta}\left(\frac{L}{N}\right) = \frac{1}{(1-\tau_N)(1-\alpha)}\left(\frac{c}{y}\right) + \eta\left(\frac{S}{N}\right).$$

Given a calibrated allocation of time among labor, leisure, and shopping—along with a value of η (selected to generate money demand elasticies) and the consumption/output ratio from (27)—equation (28) determines the value of the parameter θ to be used.

Combining equations (11) and (12) yields

$$(28) \quad 1 + (1-\tau^N)(1-\alpha)\left(\frac{py}{m}\right)\eta\left(\frac{S}{N}\right) = \frac{\gamma_x\gamma_p}{\beta},$$

which defines the steady state ratio of nominal output to money (velocity), With this value in hand, we can use the shopping-time definition (6′), along with the consumption-output ratio above, to specify a value for the scale parameter, ξ, consistent with the calibrated allocation of time to shopping.[3]

Steady state tax rates are all set to equal the average marginal tax rates for 1960 to 2002 calculated using the NBER TAXSIM model and reported in Table 9 of Feenberg and Poterba (2003). They are 24 percent for labor, 26 percent for interest income, 34 percent for capital income and 20 percent for capital gains. In this paper, we consider only two shocks: the first is to the level of technology and the second is to the inflation trend.[4] We calibrate the technology shock with a 0.95 first-order autocorrelation parameter and a standard deviation equal to 0.75 percent at a quarterly rate, calibrations widely used in the real business cycle literature.

In principle, the time-series process for the inflation trend can be calibrated using either money growth or inflation data. Because the data were generated in an era in which the central bank usually followed an interest rate rule, the model suggests that we should calibrate the model to the persistence in the inflation data. Gavin and Kydland (2000), among many others, show that the autocorrelation of inflation dropped significantly after the policy change in October 1979. Therefore, we estimate the persistence in the inflation rate separately for pre and post 1979 periods. Using an augmented Dickey Fuller method, we estimate the persistence to be 0.97 before 1979 and 0.84 afterwards. The standard deviation of the residual is approximately 0.4

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[3] Alternatively, equation (29) can be used to calibrate S and ξ to be consistent with a pre-selected value for velocity.

[4] See Pakko (2002) for an analysis of persistent shocks to the growth trend in technology.

percent at a quarterly rate in both periods. Under this specification, the lower unconditional variance of inflation after 1979 is all due to lower persistence.[5]

Steady-state welfare costs

The main operative mechanism of the model – the interaction of inflation with the nominal tax code—is illustrated in the steady-state welfare calculations presented in Table 2.

[Table 2]

The small welfare costs of inflation attributable to non-neutrality from the shopping-time function are shown in the first row. These losses are associated with typical "welfare triangle" type calculations: Higher rates of inflation induce households to economize on real money holdings, requiring greater shopping-time (at the expense of leisure and work-effort). For an inflation rate of 10 percent, output and consumption are only 0.42 percent lower than they would be in a zero-inflation steady-state.   Leisure is only marginally lower than in the zero-inflation environment. The final two columns of the table show the combined effects of lower consumption and leisure on household utility, using a measure of compensating variation calculated as the κ that solves

$$U(c_t^{10}, L_t^{10}) = U((1-\kappa)c_t^0, L_t^0) ,$$

where superscripts denote the stead-state inflation rate. For the first row, this value represents a cost of only 0.47 percent of steady-state consumption in the zero-inflation environment. As a fraction of output, this amounts to little more than one-third of one percent.

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[5] Using Bayesian methods, Kim, Nelson, and Piger (2003) find that the posterior mean of the persistence parameter falls from 0.94 before 1979:Q2 to 0.72 afterwards. They also estimate a separate breakpoint for the innovation variance which occurs in 1991.

The second row shows that—with the exception of the capital gains tax—the addition of taxes to the model have no effect on the welfare costs of inflation. In fact, the costs of 10 percent inflation are even smaller in this case because the zero-percent baseline economy is already distorted by taxes on real labor and capital income.

The third row shows the dramatic effect that nominal taxation of capital gains has on the steady state. In the high-inflation environment, output is about 12 percent lower than it would be at zero inflation, while consumption is lower by about 8 percent. The main effect of inflation is revealed in the capital/output ratio, which is nearly 13 percent lower in the 10 percent inflation regime. As a result, wages and employment are suppressed (so that leisure is actually higher for this case). In terms of the compensating variations, 10 percent inflation represents a cost of about 7 percent of steady-state consumption, or about 5 to 6 percent of output.

These calculations confirm that our model framework captures the effects highlighted by Feldstein, Fisher, and others; namely, that the nominal taxation of capital gains implies that inflation suppresses capital accumulation. In the model dynamics presented below, our interest is in evaluating how this mechanism generates aggregate fluctuations in response to stochastic inflation.

Model Dynamics

We show how the model economy responds to monetary policy shocks under alternative assumptions about tax policy and the central bank policy rule. In general, the real effects of monetary policy shocks are magnified if the central bank follows an interest rate rule. The reason for this is shown in Figure 1 which plots the response of inflation to a monetary policy shock under both monetary policy rules with the baseline tax rates. With a money growth rule, a

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persistent one-percent money growth shock leads to a jump in the price level of 10 percent with little persistence in the inflation rate. With an interest rate rule, however, inflation rises to 1 percent on impact, and persists for many years. Note that the bond tax magnifies the effect on inflation. Without the bond tax, a one percent shock to the inflation trend causes the inflation rate to jump to 0.7 percent before gradually returning to the steady state. By using an interest rate rule, the central bank eliminates the price "jumping" that occurs in general equilibrium models with money supply rules.[6] Instead, the money supply endogenously accommodates the shift in money demand.

[Figure 1]

The effect on the real economic dynamics of our model is best seen by comparing the response of the capital stock under these alternative regimes. Figure 2 shows the no tax and all taxes cases under both monetary policy regimes. With no taxes, there is almost no measurable effect of a monetary policy shock under either monetary policy regime. Including taxes makes these effects measurable. Under a money growth rule, the capital stock gradually falls to a trough about 1 percent below the steady state level after five years. With the interest rate rule, a one percent shock to the money growth rate causes the capital stock to fall much further—more than 2-1/2 percent after 7 years—and it stays well below the steady state for 25 years. For all of the results below, the pattern of responses for real variables is similar under both money growth rules and interest rate rules. The effects under interest rate rules, however, are magnified. Since most central banks implement policy with some form of interest rate targeting and none do so with monetary aggregates, we consider only the case with interest rate rules for the remainder of the paper.

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[6] See Friedman (1969) for an early exposition of the jumping that occurs in models with money supply rules. Miller

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[Figure 2]

The impulse responses of the capital stock a monetary policy shock under four tax regimes are shown in Figure 3. The tax regime with the smallest impact is the one with the seigniorage tax only. Here a persistent 1 percent shock to the inflation target causes capital to decline only a tiny fraction of a percent. When we include all taxes except capital gains taxes, the decline, on impact, is about 0.1 percent. The decline is entirely due to the bond tax because it drives a larger wedge between the before- and after-tax interest rate. Braun (1994) and McGrattan (1994) show that both the labor tax and the capital tax have large welfare effects, but the size of the tax wedges do not change with inflation and do not interact with fluctuations in the inflation rate as does the bond tax.[7] In the third tax regime, we reinstate the capital gains tax but eliminate the tax on bond income. Here the large effect of the capital gains tax is clearly evident. The impact effect is 1.3 percentage points larger than the impact effect with no taxes. When we include all taxes, a 1 percent increase in the inflation target reduces the capital stock by 2.7 percent. The bond tax is important because it raises the impact on inflation by about half and therefore magnifies the increase in the effective tax on nominal capital gains.

[Figure 3]

Figure 4 shows the impulse-responses of some key macroeconomic variables following a one percent inflation shock. Both output and hours worked decline sharply upon impact with the decline in investment demand. Output follows capital stock along a protracted path of below-trend growth. Hours converge back to the steady state over time—the rate convergence has half-life of about 4 years. The model produces a counterfactual increase in consumption because there is no cost of adjusting capital and it is freely consumed if the stock is too high. Figure 4

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and Upton (1974) refer to this jumping as the Friedman surge.

shows that this effect is quite short-lived compared to the long period of depressed consumption that follows an inflationary shock. Labor productivity also displays a short-lived increase upon impact, followed by a long period of convergence back to the trend.

[Figure 4]

Business Cycle Effects

This model can also be used to show how much cyclical output variation might be attributed to the interaction of inflation with the tax code. As shown by Gavin and Kydland (1999), Kim, Nelson and Piger (2003) and others, there has been at least one significant structural break in the inflation process over the sample period. In particular, the persistence of shocks to inflation diminished significantly after 1979. Consequently, we calculate the business cycle effects of inflation innovations under two separate regimes for inflation: In the first regime (corresponding to the pre-1979 period) the autoregressive parameter ρ_π is set to 0.97, while for the latter period we simulate the model using a value of 0.84.[8] In each of the simulations, the technology shock is assumed to have a first-order AR parameter of 0.95 and a shock variance of 0.0075.

[Table 3]

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[7] Chang (1995) considered the capital income tax, but also did not investigate the interaction with inflation.
[8] These values were estimated using Dickey-Fuller regressions for sample periods of 1954:Q1-1979:Q3 and 1979:Q4 – 2003:Q4. The estimate for the early period should probably be adjusted upward for the bias reported in Stock (1991). If we were to delete the transition years, 1980 to 1982, the estimate of the persistence would fall to 0.72 for the later period.

Analysis of HP Filtered Moments: Table 3 shows standard deviations and correlations with output for some key macroeconomic variables (HP filtered), comparing versions of the model with and without the nominal capital gains tax.   It is clear from the top panel of Table 3 that the interaction between inflation and the nominal capital gains tax has a substantial effect when inflation is highly persistent—as before 1980.

In the early period, the RBC model without capital gains taxes explains 72 percent of the variability in the cyclical variance in output. In this simple model without taxes, the variability of hours and productivity are unrealistically low and the co-movement between output and other variables far to high relative to the data—particularly for productivity. These simulated moments are nearly identical to those that would obtain in a model without either taxes of inflation. Persistent shocks to the inflation objective have no measurable impact on output in the model without a capital gains tax.

Adding the capital gains tax increases the standard deviation of each of the variables considered. The variability of output rises to account for 80 percent of the variability in the data. Hours and productivity variability rise considerably. In addition, the inclusion of capital gains taxes introduces a propagation channel for inflation shocks that lowers the high correlation between output and other macroeconomic variables that is typical of standard RBC models.   As we saw in Figure 4, when the shock to inflation is highly persistent, the resulting increase in the expected future effective capital gains tax causes households to consume capital, generating a low contemporaneous correlation with output and very volatile investment. Indeed, in the model with capital gains taxes, the correlation of consumption and output is far too low relative to U.S. data. On the other hand, the short-run dynamics illustrated in Figure 4 also imply a lower

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correlation of output and productivity, brining that statistic very close to its observed value in the data.

In the later period, with $\rho_\pi = 0.84$, the qualitative results are similar but much smaller. The standard deviation of output deviations is no higher than without the capital gains tax. Both hours and productivity are slightly more volatile and less highly correlated with output. With the lower persistence, the variability of consumption, investment and hours are only slightly higher than in the model without a capital gains tax. The first-order autocorrelations are slightly lower in the model that includes capital gains taxes, but the effect is not nearly as pronounced as in the high-persistence case.

Frequency Decomposition: The impulse responses in Figures 2-4 showed that the effects of persistent monetary policy shocks operating through the capital gains tax have effects at a frequency that is tends to be lower than that of business cycles. Therefore, we investigated the model's dynamics at different frequencies using a band-pass filter.[9]

The results of these decompositions—reported in Table 4—show that when inflation has high persistence (Panel A), the interaction of inflation with the capital gains tax has significant effects on the model dynamics at all frequencies. For example, the introduction of capital gains taxes to the model raises the standard deviation of output by 9.4 percent at high frequencies, by 11.2 percent at business cycle frequencies, and by 16.5 percent at low frequencies. The standard deviation of hours is approximately twice as large in the model with a capital gains tax than without. This is true across the full range of frequency bands. Note that the low correlation

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[9] The statistics for U.S. data reported in Table 4 are calculated using the band-pass filter suggested by Christiano and Fitzgerald (2003). Statistics for the model simulations are filtered using ideal band-pass filters applied to a

between output and consumption noted above is not inconsistent with the corresponding high-frequency component of the data.

When the persistence in the inflation process is calibrated at 0.84 (Panel B) the impact of inflation shocks declines dramatically. Along many dimensions, the versions of the model with and without capital gains taxes generate nearly identical implications for volatility across all frequencies. However, there remains a noticeable increase in the variability of investment and hours when capital gains taxes are introduced. For investment, the effect of introducing capital gains taxes is greatest in the high-frequency range. For hours, the effect is largest at business cycle frequencies.

The statistics for U.S. data reported in Tables 3 and 4 illustrate the widely-documented decline in the volatility of real macroeconomic variables since 1979. The analysis the model suggests that the lower persistence of inflation since 1979 might have played a role in this volatility decrease. With high persistence in the inflation process, inflation shocks interact with the capital gains tax to have large effects on real variables. This impact declines dramatically with the decline in inflation persistence.

Simulations of U.S. Data: The model simulations suggest that we should see important cyclical effects from the interaction of inflation and the capital gains tax before 1980, but the effects may be too small to be measurable afterwards. To illustrate this feature of the model, we use estimated shocks to the inflation trend to see what our model implies for movements of capital, hours worked and labor productivity for U.S. history with a policy break in 1979:Q3. We use the same calibration for the policy process as was used in Table 3. The contribution of estimated inflation shocks to the real economy are summarized in Figure 5.

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frequency domain decomposition of the model's population moments. The parameters of the bands are as follows:

[Figure 5]

In the period leading up to 1980, the effects of the interaction between inflation and the capital gains tax are of the same order of magnitude as the effects of technology shocks. As we saw in Figure 2, the effects on the capital stock take such a long time to peak that the damage from rising inflation in the 1960s and 1970s continued to have a depressing effect on the capital stock into the 1990s.

The impact on hours worked works though the economy quickly. The upward drift upward of inflation caused hours worked to fall below the steady state level for most of the 1970s. Corresponding to the inflationary effects of the oil price shocks of the 1970s, the model implies sharp declines in employment associated with those events. Since 1980, the effect on hours worked is insignificant.

The impact on productivity reflects a combination of the effect on the capital stock and on hours worked. The upward drift in inflation combined with the nominal tax on capital to exert an increasingly negative impact on labor productivity from the late 1960s until after 1980. Since the 1980s, this effect has helped to raise labor productivity slightly.

Conclusion

When the central bank operates with an interest rate, persistent shocks to the trend in money growth (or, equivalently, the inflation target) can have large real effects on the business cycle if the tax system is not indexed for inflation. In our model, there is a tax on nominal capital gains. The business cycle effects are large when the shocks to the expected inflation objective are highly persistent. We found those effects to be large in the United States before

high frequency, 2-6 quarters; business cycle frequency, 6-32 quarters; and low frequency, 32-64 quarters.

1980, but not afterwards. The reduction of persistence in shocks to the inflation target was the critical aspect of the change in monetary policy. Before 1980, the inflation objective appeared to follow a random walk. After 1980, we estimated the largest root in the inflation process to be no larger than 0.84. At this level, the shocks do not have much impact on the cycle, raising the cyclical deviations by only about 5 percent above the case with no monetary policy shocks.

Using a common calibration for all parameters except the persistence in the shock to the long-run inflation objective, we find that bad monetary policy may partially explain the slowdown in productivity growth before 1980. The upward trend in the average inflation rate probably interacted with the tax on nominal capital gains to reduce productivity growth in the 1960s and 1970s. Better policy after 1980 may partially explain the revival of productivity and the lower variability of real variables since then.

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Table 1: Parameter Calibration for the Baseline Case

Parameter	Symbol	Value
Depreciation rate	δ	0.02
Discount factor	β	0.99
Relative risk aversion	σ	2
Labor tax rate	τ^N	0.24
Capital tax rate	τ^K	0.34
Bond tax rate	τ^B	0.26
Capital gains tax rate	τ^{Kg}	0.20
Steady state output growth	γ_x	1.004
Steady state money growth	γ_p	1.01
Shopping time parameter	η	1
Capital share in production	α	0.38
Steady state share of shopping time	S	0.003
Steady state share of time supplying labor services	N	0.3
Fed's reaction to inflation	φ_π	0.5
Fed's reaction to output gap	φ_y	0
Persistence in the technology shock	ρ_z	0.95
Persistence in the money growth shock	ρ_π	0.95
Standard deviation of Shocks		
Production Technology	σ_z	0.0075
Monetary policy	σ_π	0.0040

Table 2: Welfare Effects of a Steady-State 10 percent Inflation Rate

| | Effects on Steady-State Values (Percent) | | | | | Compensating Variation As Percent of: | |
	Y	C	L	W	K/Y	C	Y
No Taxes	- 0.42	- 0.42	- 0.02	0.00	0.00	0.47	0.35
Taxes w/o Capital Gains	- 0.34	- 0.34	- 0.06	0.00	0.00	0.42	0.33
Taxes Incl. Capital Gains	-11.82	- 8.37	+1.10	- 9.12	-12.73	7.01	5.61

Table 3: Second Moments (HP Filtered)

Panel A: $\rho_\pi = 0.97$

	U.S. data 1954:1 – 1979:3		Model w/o Capital Gains Tax		Model with Capital Gains Tax	
	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.81	1.00	1.30	1	1.44	1
Consumption	0.84	0.83	0.56	0.98	0.99	0.20
Investment	5.18	0.80	4.08	0.99	7.51	0.86
Hours	1.94	0.87	0.55	0.95	1.13	0.77
Productivity	1.22	0.61	0.79	0.98	0.91	0.62

Panel B: $\rho_\pi = 0.84$

	U.S data 1979:4 - 2003:4		Model w/o Capital Gains Tax		Model with Capital Gains Tax	
	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.35	1.00	1.29	1	1.29	1
Consumption	0.71	0.79	0.56	0.98	0.59	0.90
Investment	4.43	0.79	4.08	0.99	4.47	0.97
Hours	1.62	0.89	0.52	0.98	0.56	0.93
Productivity	0.88	0.37	0.79	0.99	0.80	0.97

Table 4: Frequency Analysis of Second Moments (Band Pass Filter)

Panel A: $\rho_\pi = 0.97$

High Frequency	U.S. data 1954:1 – 1979:3		Model w/o Capital Gains Tax		Model with Capital Gains Tax	
	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	0.48	1.00	0.53	1.00	0.58	1.00
Consumption	0.22	0.24	0.22	1.00	0.40	0.18
Investment	0.96	0.53	1.69	1.00	3.05	0.85
Hours	0.36	0.63	0.23	0.97	0.45	0.79
Productivity	0.49	0.83	0.31	0.98	0.36	0.63

Business Cycle Frequency	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.77	1.00	1.16	1	1.29	1
Consumption	0.85	0.89	0.50	0.98	0.88	0.19
Investment	5.04	0.83	3.67	0.99	6.74	0.86
Hours	1.94	0.89	0.49	0.96	1.02	0.78
Productivity	1.16	0.60	0.71	0.98	0.81	0.61

Low Frequency	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.91	1.00	1.27	1	1.48	1
Consumption	0.95	0.77	0.64	0.94	1.03	0.30
Investment	5.77	0.93	3.82	0.98	7.31	0.84
Hours	1.74	0.94	0.51	0.92	1.11	0.75
Productivity	0.85	0.61	0.83	0.97	0.98	0.66

Table 4: Frequency Analysis of Second Moments (Band Pass Filter)

Panel B: $\rho_\pi = 0.84$

High Frequency	U.S. data 1979:4 – 2003:4		Model w/o Capital Gains Tax		Model with Capital Gains Tax	
	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	0.32	1.00	0.53	1.00	0.53	1.00
Consumption	0.17	0.22	0.22	1.00	0.24	0.88
Investment	0.75	0.29	1.69	1.00	1.86	0.97
Hours	0.24	0.65	0.22	0.99	0.23	0.94
Productivity	0.32	0.77	0.31	1.00	0.32	0.97

Business Cycle Frequency	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.21	1.00	1.16	1	1.16	1
Consumption	0.64	0.82	0.49	0.98	0.53	0.90
Investment	4.26	0.85	3.66	1.00	4.01	0.97
Hours	1.40	0.88	0.46	0.98	0.51	0.93
Productivity	0.79	0.44	0.71	0.99	0.71	0.96

Low Frequency	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)	SD(•)	Corr(•,y)
Output	1.76	1.00	1.27	1	1.26	1
Consumption	1.31	0.91	0.64	0.94	0.62	0.93
Investment	7.33	0.35	3.81	0.98	4.12	0.97
Hours	2.41	0.73	0.47	0.95	0.50	0.94
Productivity	1.41	0.30	0.83	0.99	0.81	0.98

Figure 1: Inflation Response to a 1% Monetary Policy Shock
(With all taxes)

Percent deviations from the steady state

Money Growth Rule

$(\rho_\pi = 0.95$ in both cases$)$

Taylor Rule
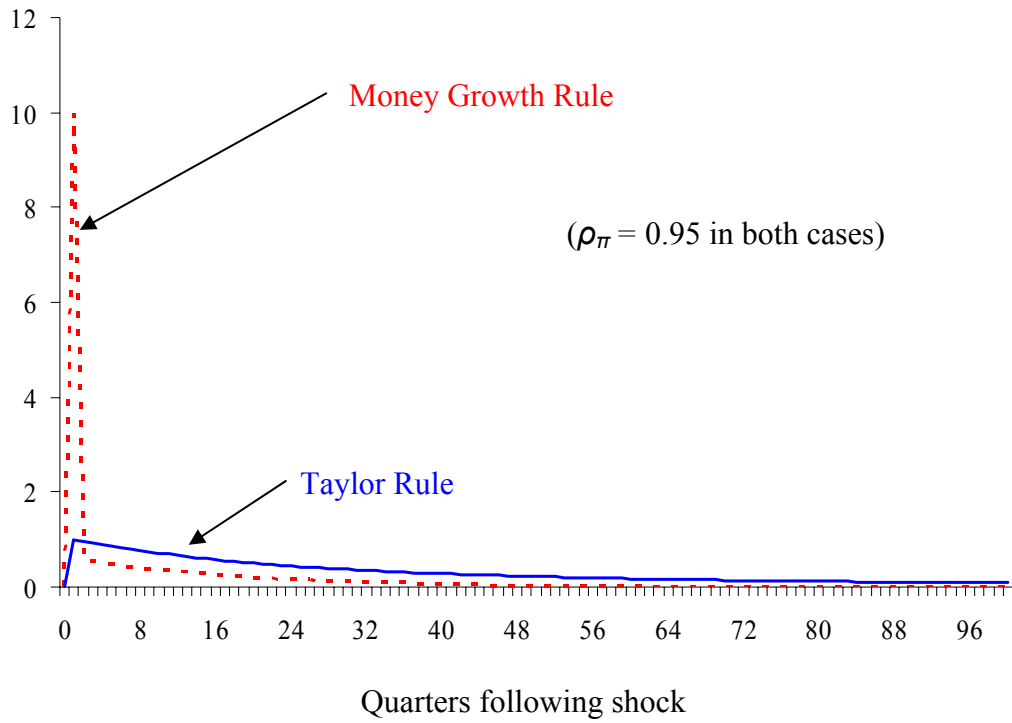
Quarters following shock

Figure 2: Capital Response to a 1% Monetary Policy Shock
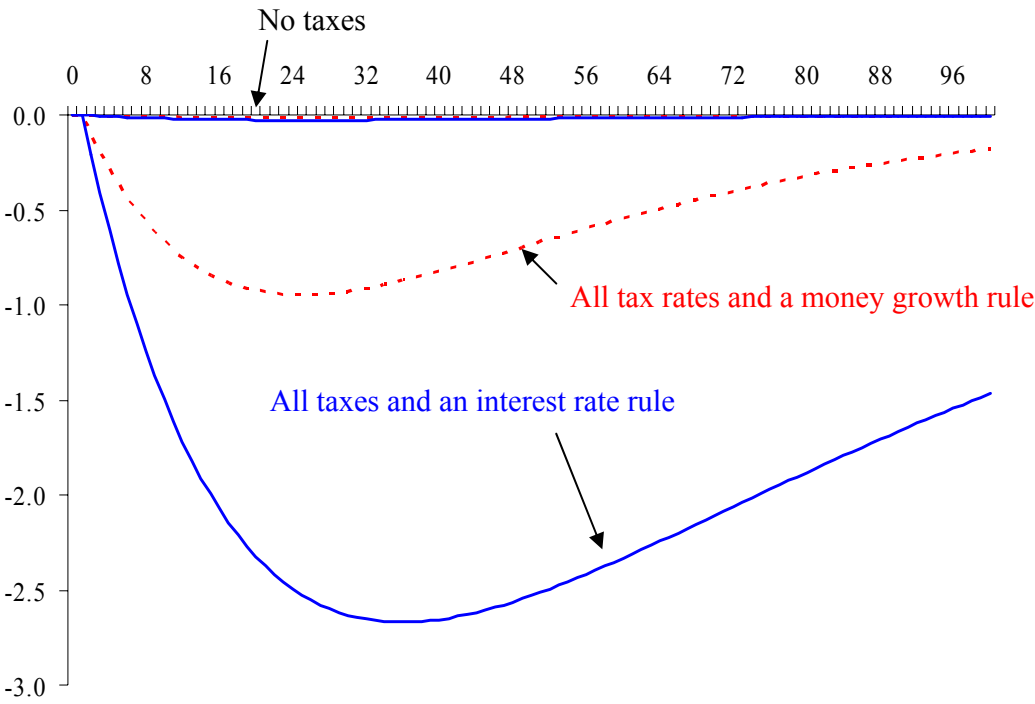(Effects of Different Policy Rules)

Figure 3: Capital Response to a 1% Monetary Policy Shock
(Effects of different taxes)

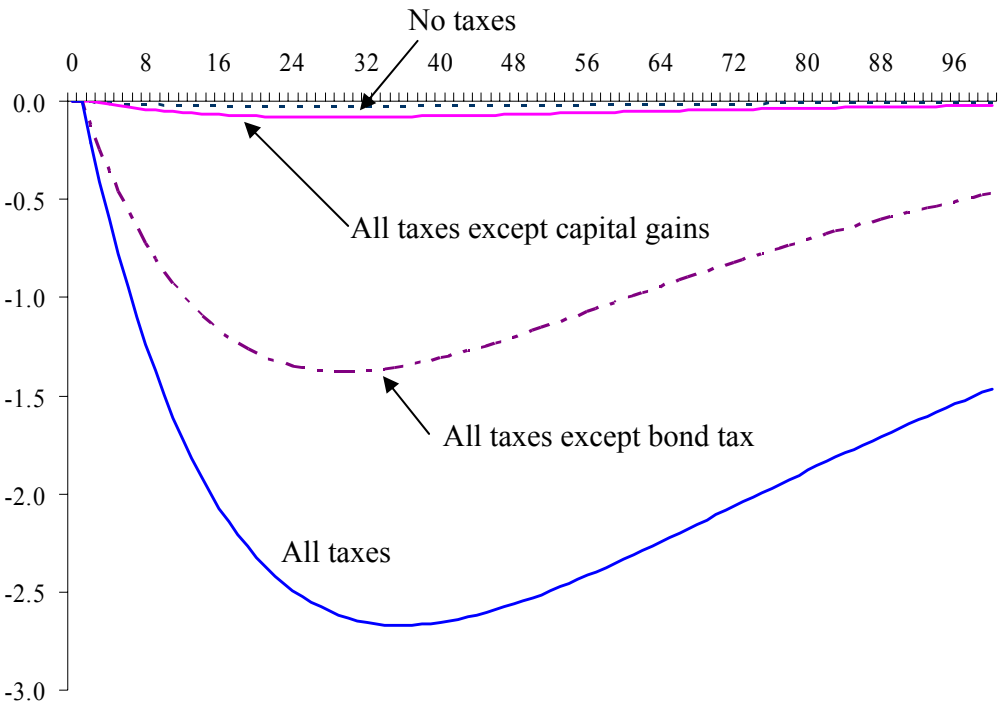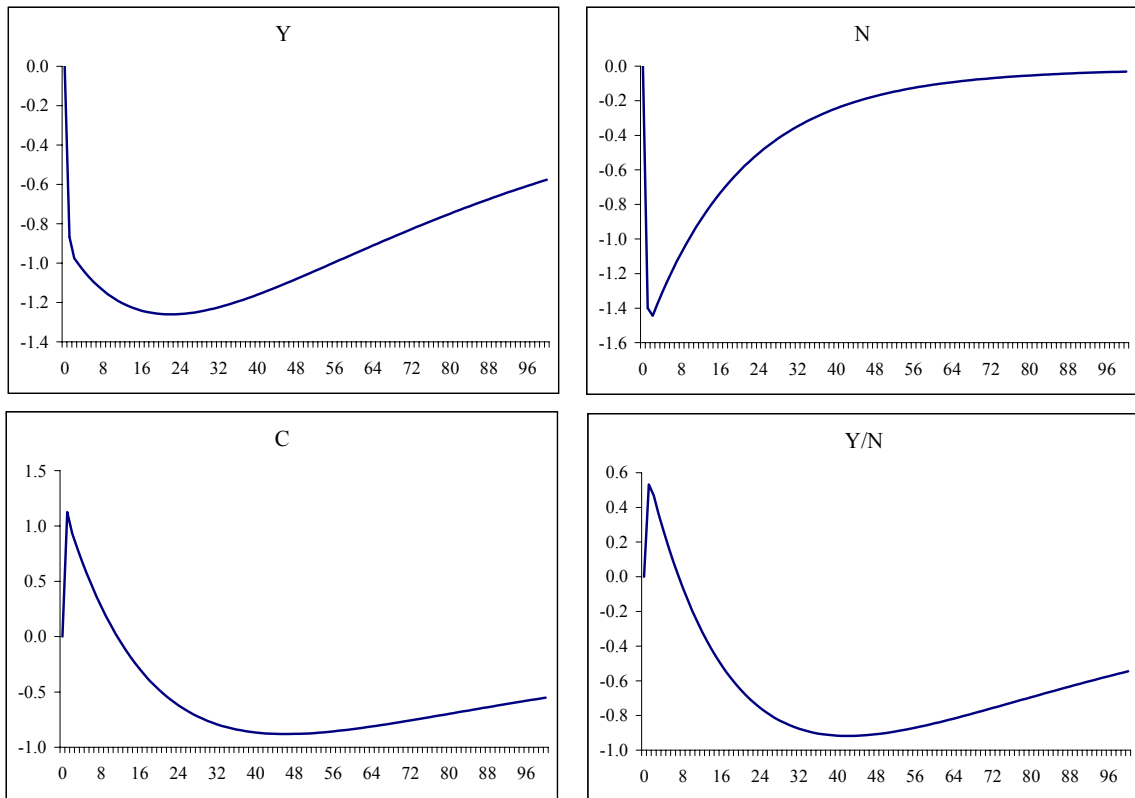Figure 4: Responses to a 1% Monetary Policy Shock

Figure 5: Contribution of Monetary Policy Shocks