

Debt, Inflation and Central Bank Independence

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Abstract

When governments trade-off maximizing general welfare with maximizing their own expenditure, the degree of central bank independence has implications for inflation, taxes and debt. If the central bank becomes more benevolent than the fiscal authority then, for any given level debt, inflation and taxes decrease, while debt accumulation increases. In the transition, as debt increases, inflation and taxes revert to their pre-reform levels, due to the higher financial burden. In the long-run, only debt varies significantly. Endowing the central bank with an explicit monetary target does not alter this result, but may still affect how policy responds to cyclical shocks. The debt increase and inflation reduction experienced in the U.S. and several other developed countries in the early 1980s is plausibly the combined outcome of increased central bank independence and lower tolerance for inflation by agents.

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1 Introduction

A widely held view is that independence of a central bank from political influence is conducive to low inflation. This notion is supported by cross-country studies, such as Alesina and Summers (1993), who found a negative relationship between inflation and central bank independence for developed countries.¹ However, the causality link between central bank independence and inflation has been contested—e.g., by Campillo and Miron (1997) and Posen (1993).

In formal models, an independent central bank is typically endowed with an explicit inflation objective, following the work by Rogoff (1985).² This approach, although useful for the purpose of policy analysis—as in the literature on Taylor rules—sheds little light on the effects of central bank independence.

In this paper, I study the effects of central bank independence on government policy. Adopting the definition due to Walsh (2008), I specifically ask: what are the implications of protecting a monetary authority from the pressures of politicians in the conduct of policy? To this effect, I consider a monetary economy based on Lagos and Wright (2005), with a government that uses distortionary taxes, money and nominal bonds to finance the provision of a valued public good. The government lacks the ability to commit to policy choices beyond the current period and is further subjected to a political friction: a tension between maximizing the welfare of agents and maximizing its expenditure. I model central bank independence as an institution that shelters—at least partially—the monetary authority from this political friction. An independent central bank will decide monetary policy independently of the fiscal authority, which decides on taxes and expenditure. Both authorities need to take into account how their actions affect current agent behavior and future government policy. Thus, each of the authorities plays a simultaneous game with the other institution and a sequential game with the private sector, its own future-self and the other authority's future-self.

Regardless of the severity of political frictions, the classic incentive to smooth distortions intertemporally (as in Barro, 1979 and Lucas and Stokey, 1983) is weighted against a time-consistency problem created by the interaction between debt and monetary policy. How much debt the government inherits affects its monetary policy since inflation reduces the real value of nominal liabilities. In turn, the anticipated response of future monetary policy affects the current demand for money and bonds, and thereby how the government today internalizes policy trade-offs.

As one would expect, a reform that increases central bank independence results in a shift up of the debt policy functions and a shift down of inflation and tax policy functions. Thus, for any given level of debt, a government with an independent central bank will implement higher debt and lower inflation and taxes than a government without an independent monetary authority. However, in the long-run, only the level of debt is significantly different. With a higher debt policy function, the government with an independent central bank features higher financial liabilities in the future. Thus, as debt increases, so do inflation and taxes. After the reform, the economy ends up with higher debt, but similar inflation, taxes and expenditure. The size of the increase in debt is directly related to the size of the political frictions which afflict the fiscal authority and to the degree of benevolence of the monetary authority after the reform.

Adding an explicit monetary objective as in Rogoff (1985) does not alter the results described above. If anything, it can be used to justify an even higher increase in long-run debt. However, policy targets aimed at flattening the inflation response to debt may have an impact on how policy responds to aggregate shocks.

¹See Cukierman (1992, 2008) for a survey of the related literature.

²See Adam and Bili (2008) and Niemann (2011) for recent applications.

Thus, a salient finding in this paper is that long-run inflation does not depend on the degree of central bank independence, regardless of the additional presence of an explicit policy objective. However, lower inflation can be achieved if agents’ “tolerance” for inflation diminishes, which would support the arguments posed by Posen (1993) and Meltzer (2009).

The paper follows in the tradition of Barro (1979) and Lucas and Stokey (1983), in which the role of government debt is to smooth tax distortions over time. The standard approach, which relies on the assumption that the government can commit to future policy choices, offers valuable normative insights, but is problematic as positive theory. In general, with commitment, the policy prescription is time-inconsistent, long-run debt levels are indeterminate and the predicted behavior of taxes and nominal interest rates is counterfactually smooth. As argued in Martin (2009) and Martin (2011), relaxing the commitment assumption resolves these issues and allows the theory to help explain actual policy.

The recent literature on government policy under limited commitment follows the work of Klein et al. (2008) who characterize Markov-perfect equilibria in a model of optimal taxation. In addition to Martin (2009, 2011), several other papers study fiscal and monetary policy within this context. Díaz-Giménez et al. (2008) compare economies with real vs. nominal debt, with and without commitment, and evaluate the welfare implications of these different institutional arrangements. Niemann, Pichler and Sorger (2009) analyze the properties inflation dynamics under the assumptions of limited commitment and price rigidities. Niemann (2011) studies the effects of monetary conservatism and fiscal impatience in the determination of debt. Martin (2012*b*) studies the response of government policy to war-expenditure shocks and evaluates the model in terms of the U.S. experience.

The paper is organized as follows. Section 2 presents the general monetary framework. Section 3 characterizes government policy and derives theoretical results. Section 4 conducts a numerical analysis for long-run policy. Section 5 extends the model to incorporate aggregate shocks to productivity and expenditure. Section 6 concludes with a discussion on the empirical plausibility of the findings.

2 A Monetary Framework

2.1 Environment

Consider the environment analyzed in Martin (2011), which is a variant of the monetary framework proposed by Lagos and Wright (2005). There is a continuum of infinitely-lived agents. Each period, two markets open in sequence: a “day” and a “night” market. In each stage a perishable good is produced and consumed. At the beginning of each period, agents receive an idiosyncratic shock that determines their role in the day market. With probability $\eta \in (0, 1)$ an agent wants to consume but cannot produce the day-good, x , while with probability $1 - \eta$ an agent can produce but does not want consume. A *consumer* derives utility $u(x)$, where u is twice continuously differentiable, with $u_x > 0 > u_{xx}$. A *producer* incurs in utility cost ϕx , with $\phi > 0$. Let $\hat{x} \in (0, \infty)$ such that $u_x(\hat{x}) = \phi$.

Agents lack commitment and are anonymous, in the sense that private trading histories are unobservable. Thus, credit transactions between agents are not possible. Since the day market features lack of double coincidence of wants, some medium of exchange is essential for trade to occur—see Kocherlakota (1998), Wallace (2001) and Shi (2006).

At night, all agents can produce and consume the night-good, c . The production technology is assumed to be linear in hours worked, n . Utility from consumption is given by $U(c)$, where U is twice continuously differentiable, satisfies Inada conditions and $U_c > 0 > U_{cc}$. Disutility

from labor is given by αn , where n is hours worked and $\alpha > 0$. Let $\hat{c} \in (0, \infty)$ such that $U_c(\hat{c}) = \alpha$. Assume the following regularity condition holds: $U_{cc}c - (U_c - \alpha)(1 + \frac{U_{ccc}c}{U_{cc}}) < 0$ for all $c \in (0, \hat{c}]$ —note that the typically adopted $U(c) = \frac{c^{1-\rho}}{1-\rho}$, with $\rho > 0$, satisfies this requirement.

There is a government that supplies a valued public good g at night. To finance its expenditure, the government may use proportional labor taxes τ , print fiat money at rate μ and issue one-period nominal bonds, which are redeemable in fiat money. The public good is transformed one-to-one from the night-good. Agents derive utility from the public good according to $v(g)$, where v is twice continuously differentiable, satisfies Inada conditions and $v_g > 0 > v_{gg}$. Let $\hat{g} \in (0, \infty)$ such that $v_g(\hat{g}) = \alpha$.

Government policy $\{B', \mu, \tau, g\}$ is announced at the beginning of each day, before agents' idiosyncratic shocks are realized. The government only actively participates in the night-market, i.e., taxes are levied on hours worked at night and open market operations are conducted in the night market. As in Aruoba and Chugh (2010), Berentsen and Waller (2008), Martin (2011) and Martin (2012a), public bonds are book-entries in the government's record. Since bonds are not physical objects and the government does not participate in the day market (i.e., cannot intermediate or provide third-party verification), bonds are not used as a medium of exchange in the day market and thus, money is essential.

All nominal variables—except for bond prices—are normalized by the aggregate money stock. Thus, today's aggregate money supply is equal to 1 and tomorrow's is $1 + \mu$. The government budget constraint is

$$1 + B + pg = p\tau n + (1 + \mu)(1 + qB'), \quad (1)$$

where B is the current aggregate bond-money ratio, p is the—normalized—market price of the night-good c , and q is the price of a bond that earns one unit of fiat money in the following night market. “Primes” denote variables evaluated in the following period. Thus, B' is tomorrow's aggregate bond-money ratio.

2.2 The night market

An agent arrives to the night market with individual money balances m and government bonds b . Since bonds are redeemed in fiat money at par, the composition of an agent's nominal portfolio at the beginning of the night is irrelevant. Let $z \equiv m + b$, i.e., total—normalized—nominal holdings. The budget constraint of an agent at night is

$$pc + (1 + \mu)(m' + qb') = p(1 - \tau)n + z. \quad (2)$$

Let $V(m, b)$ be the value of entering the day market with money balances m and bond balances b , and let $W(z)$ be the value of entering the night market with total nominal balances z . After solving n from (2), the problem of an agent in the night market is

$$W(z) = \max_{c, m', b'} U(c) + v(g) - \frac{\alpha c}{(1 - \tau)} + \frac{\alpha(z - (1 + \mu)(m' + qb'))}{p(1 - \tau)} + \beta V(m', b').$$

The first-order conditions are

$$U_c - \frac{\alpha}{(1 - \tau)} = 0 \quad (3)$$

$$-\frac{\alpha(1 + \mu)}{p(1 - \tau)} + \beta V'_m = 0 \quad (4)$$

$$-\frac{\alpha q(1 + \mu)}{p(1 - \tau)} + \beta V'_b = 0. \quad (5)$$

Focusing on a symmetric equilibrium, we can follow Lagos and Wright (2005) to show that (4) and (5) imply all agents exit the night market with the same money and bond balances: $m' = 1$ and $b' = B'$.³ The night aggregate resource constraint is $c + g = n$, where n is aggregate labor. Note that private consumption c and public consumption g are the same for all agents, whereas individual labor depends on whether an agent was a consumer or a producer during the day. The night-value function W is linear, $W_z = \frac{\alpha}{p(1-\tau)}$. We also get

$$q = \frac{V'_b}{V'_m}. \quad (6)$$

2.3 The day market

During the day, consumers and producers exchange money for goods in a competitive market. The day-resource constraint is $\eta x = (1 - \eta)\kappa$, where x is the individual quantity consumed and κ the individual quantity produced.

A consumer faces a day-budget constraint, $\tilde{p}x \leq m$, where \tilde{p} is the—normalized—market price of good x . Using ξ as the Lagrange multiplier associated with this constraint, the problem of a consumer can be written as

$$V^c(m, b) = \max_x u(x) + W(0) + \frac{\alpha(m + b - \tilde{p}x)}{p(1 - \tau)} + \xi(m - \tilde{p}x).$$

The first-order condition implies

$$\xi = \frac{u_x}{\tilde{p}} - \frac{\alpha}{p(1 - \tau)}.$$

The problem of a producer is

$$V^p(m, b) = \max_{\kappa} -\phi\kappa + W(0) + \frac{\alpha(m + b + \tilde{p}\kappa)}{p(1 - \tau)}.$$

The first-order condition is

$$-\phi + \frac{\alpha\tilde{p}}{p(1 - \tau)} = 0.$$

The day market clearing condition is $\eta = (1 - \eta)\tilde{p}\kappa$, which, given $\eta x = (1 - \eta)\kappa$, implies $\tilde{p} = \frac{1}{x}$. Thus, the equilibrium in the day market is characterized by

$$\phi x = \frac{\alpha}{p(1 - \tau)}. \quad (7)$$

The left-hand side of the second equation above is the marginal utility cost for a producer, expressed in terms of day-purchasing power; the right-hand side is the real marginal benefit of arriving at night with an extra unit of nominal assets. Since producers get compensated with money for their production costs, these two expressions are equated in equilibrium. Clearly, higher production is associated with a higher marginal value of money.

From the envelope conditions we get

$$\begin{aligned} V_m &= x(\eta u_x + (1 - \eta)\phi) \\ V_b &= \phi x. \end{aligned}$$

³Since V is linear in b , a non-degenerate distribution of bonds is possible in equilibrium. Here, we focus on symmetric equilibria. See Aruoba and Chugh (2010) and Martin (2011) for related discussions.

2.4 Monetary equilibrium

We can now collect the conditions that characterize a monetary equilibrium. After some rearrangement, (3), (4), (6) and (7) can be written as

$$\mu = \frac{\beta x'(\eta u'_x + (1 - \eta)\phi)}{\phi x} - 1 \quad (8)$$

$$\tau = 1 - \frac{\alpha}{U_c} \quad (9)$$

$$p = \frac{U_c}{\phi x} \quad (10)$$

$$q = \frac{\phi}{\eta u'_x + (1 - \eta)\phi}. \quad (11)$$

Using the night-resource constraint, $c + g = n$, and conditions (8)—(11), we can write the government budget constraint in a monetary equilibrium as

$$(U_c - \alpha)c - \alpha g + \beta \eta x'(u'_x - \phi) + \beta \phi x'(1 + B') - \phi x(1 + B) = 0, \quad (12)$$

which can be written compactly as $\varepsilon(B, B', x, x', c, g) = 0$.

3 Government Policy

3.1 The government

There are two government agencies: a fiscal authority and a monetary authority (or central bank). The former decides taxes and expenditure, and the latter manages the stock of money. Debt is determined residually, to satisfy the government budget constraint. Policy choices are made at the beginning of the period, before agents make decisions. Both authorities lack the ability to commit to policy choices in future periods. To characterize government policy with limited commitment, I adopt the notion of Markov-perfect equilibrium, i.e., where policy functions depend only on fundamentals.⁴

The literature on optimal policy typically applies what is known as the *primal approach*, which consists of using the first-order conditions of the agent's problem to substitute prices and policy instruments for allocations in the government budget constraint. Following this approach, the problem of a government with limited commitment can be written in terms of choosing debt and allocations. From (8), for a given x' , a higher μ clearly implies a lower x . In other words, given current debt policy and future monetary policy, the allocation of the day-good is a function of *current* monetary policy. Thus, we can interchangeably refer to variations in the day-good allocation and variations in current monetary policy. Similarly, from (9) a higher tax rate is equivalent to lower night-good consumption, c .

Let $\Gamma \in [-1, \bar{B}]$ be the set of possible debt levels, where \bar{B} is large enough so that it does not constrain government behavior. The lower bound on Γ is not restrictive, as shown in Proposition 1(iv) below.

To simplify exposition below, define the ex-ante period utility of an agent as

$$\mathcal{U}(x, c, g) \equiv \eta(u(x) - \phi x) + U(c) + v(g) - \alpha(c + g).$$

⁴See Maskin and Tirole (2001) for a definition and justification of this solution concept. For recent applications to dynamic policy games see Ortigueira (2006), Klein et al. (2008), Díaz-Giménez et al. (2008), Martin (2009, 2010, 2011), Azzimonti et al. (2009) and Niemann (2011), among others.

Note that we simplify the expected day-utility, $\eta u(x) - (1 - \eta)\kappa$ by using the day-market clearing condition, $\eta x = (1 - \eta)\kappa$.

3.2 Fiscal authority

The fiscal authority faces a tension between maximizing agents' welfare and maximizing government expenditure. Let $\omega_F \in (0, 1]$ measure the degree of "benevolence", which is exogenous and constant over time. The fiscal authority takes as given the policy of the monetary authority for the current period and the policies of both authorities in all future periods.

Adopting the primal approach, the problem of the fiscal authority can be written as choosing c and g , given monetary policy $x = \mathcal{X}(B)$ and future policy inducing net present value represented by the function $\mathcal{F}(B)$. Debt is determined as a residual to satisfy (12), but the fiscal authority understands it can affect it by its choice of policy.

The problem of the fiscal authority is then

$$\max_{B', c, g} \omega_F \mathcal{U}(\mathcal{X}(B), c, g) + (1 - \omega_F)g + \beta \mathcal{F}(B')$$

subject to $\varepsilon(B, B', \mathcal{X}(B), \mathcal{X}(B'), c, g) = 0$ and given

$$\mathcal{F}(B') \equiv \omega_F \mathcal{U}(\mathcal{X}(B'), \mathcal{C}(B'), \mathcal{G}(B')) + (1 - \omega_F)\mathcal{G}(B') + \beta \mathcal{F}(\mathcal{B}(B')).$$

3.3 Monetary authority

The monetary authority may also be afflicted by political frictions. Let $\omega_M \in (0, 1]$ be the corresponding degree of benevolence. The problem of the monetary authority can be written as choosing x , given current fiscal policy $c = \mathcal{C}(B)$ and $g = \mathcal{G}(B)$, and future government policy inducing a value $\mathcal{M}(B)$. Again, debt is determined as a residual to satisfy (12), but the central bank understands it can affect it by its choice of policy.

The problem of the monetary authority is then

$$\max_{B', x} \omega_M \mathcal{U}(x, \mathcal{C}(B), \mathcal{G}(B)) + (1 - \omega_M)\mathcal{G}(B) + \beta \mathcal{M}(B')$$

subject to $\varepsilon(B, B', x, \mathcal{X}(B'), \mathcal{C}(B), \mathcal{G}(B)) = 0$ and given

$$\mathcal{M}(B') \equiv \omega_M \mathcal{U}(\mathcal{X}(B'), \mathcal{C}(B'), \mathcal{G}(B')) + (1 - \omega_M)\mathcal{G}(B') + \beta \mathcal{M}(\mathcal{B}(B')).$$

3.4 Equilibrium

Definition 1 A Markov-Perfect Monetary Equilibrium (MPME) is a set of functions $\{\mathcal{B}, \mathcal{X}, \mathcal{C}, \mathcal{G}, \mathcal{F}, \mathcal{M}\} : \Gamma \rightarrow \Gamma \times \mathbb{R}_+^3 \times \mathbb{R}^2$, such that for all $B \in \Gamma$:

- (i) $\{\mathcal{B}(B), \mathcal{C}(B), \mathcal{G}(B)\} = \operatorname{argmax}_{B', c, g} \omega_F \mathcal{U}(\mathcal{X}(B), c, g) + (1 - \omega_F)g + \beta \mathcal{F}(B')$ subject to $\varepsilon(B, B', \mathcal{X}(B), \mathcal{X}(B'), c, g) = 0$;
- (ii) $\{\mathcal{B}(B), \mathcal{X}(B)\} = \operatorname{argmax}_{B', x} \omega_M \mathcal{U}(x, \mathcal{C}(B), \mathcal{G}(B)) + (1 - \omega_M)\mathcal{G}(B) + \beta \mathcal{M}(B')$ subject to $\varepsilon(B, B', x, \mathcal{X}(B'), \mathcal{C}(B), \mathcal{G}(B)) = 0$;
- (iii) $\varepsilon(B, \mathcal{B}(B), \mathcal{X}(B), \mathcal{X}(\mathcal{B}(B)), \mathcal{C}(B), \mathcal{G}(B)) = 0$;
- (iv) $\mathcal{F}(B) = \omega_F \mathcal{U}(\mathcal{X}(B), \mathcal{C}(B), \mathcal{G}(B)) + (1 - \omega_F)\mathcal{G}(B) + \beta \mathcal{F}(\mathcal{B}(B))$;
- (v) $\mathcal{M}(B) = \omega_M \mathcal{U}(\mathcal{X}(B), \mathcal{C}(B), \mathcal{G}(B)) + (1 - \omega_M)\mathcal{G}(B) + \beta \mathcal{M}(\mathcal{B}(B))$.

3.5 Characterization

Assume the policy functions followed by the authorities are differentiable.⁵ Let $\omega_F \lambda_F$ be the Lagrange multiplier associated with the constraint of the fiscal authority's problem. The first-order conditions are

$$\mathcal{F}'_B + \omega_F \lambda_F \phi x' + \omega_F \lambda_F \{\eta(u'_{xx}x' + u'_x - \phi) + \phi(1 + B')\} \mathcal{X}'_B = 0 \quad (13)$$

$$U_c - \alpha + \lambda_F(U_c - \alpha + U_{cc}c) = 0 \quad (14)$$

$$\omega_F(v_g - \alpha) + 1 - \omega_F - \omega_F \lambda_F \alpha = 0. \quad (15)$$

The envelope condition implies

$$\frac{\mathcal{F}_B}{\omega_F} = -\lambda_F \phi x + \{\eta(u_x - \phi) - \lambda_F \phi(1 + B)\} \mathcal{X}_B.$$

Using $\omega_M \lambda_M$ and ζ as the Lagrange multipliers associated with the constraints in the monetary authority's problem, the first-order conditions are

$$\mathcal{M}'_B + \omega_M \lambda_M \phi x' + \omega_M \lambda_M \{\eta(u'_{xx}x' + u'_x - \phi) + \phi(1 + B')\} \mathcal{X}'_B = 0 \quad (16)$$

$$\eta(u_x - \phi) - \lambda_M \phi(1 + B) = 0. \quad (17)$$

The envelope condition implies

$$\frac{\mathcal{M}_B}{\omega_M} = -\lambda_M \phi x + \{U_c - \alpha + \lambda_M(U_c - \alpha + U_{cc}c)\} \mathcal{C}_B + \left\{v_g - \alpha + \frac{1}{\omega_M} - 1 - \lambda_M \alpha\right\} \mathcal{G}_B.$$

From (15) and (17) we get

$$\lambda_F = \frac{v_g}{\alpha} - 1 + \frac{1 - \omega_F}{\alpha \omega_F}$$

$$\lambda_M = \frac{\eta(u_x - \phi)}{\phi(1 + B)}.$$

Using these expressions, together with (14), (15), (17) and the envelope conditions, we can rewrite (13) and (16) as follows:

$$\phi x'(\lambda_F - \lambda'_F) + \lambda_F \{\eta(u'_{xx}x' + u'_x - \phi) + \phi(1 + B')\} \mathcal{X}'_B + (\lambda'_M - \lambda'_F) \phi(1 + B') \mathcal{X}'_B = 0 \quad (18)$$

and

$$\begin{aligned} & \phi x'(\lambda_M - \lambda'_M) + \lambda_M \{\eta(u'_{xx}x' + u'_x - \phi) + \phi(1 + B')\} \mathcal{X}'_B \\ & + (\lambda'_M - \lambda'_F) \{(U'_c - \alpha + U'_{cc}c') \mathcal{C}'_B - \alpha \mathcal{G}'_B\} + \left(\frac{1}{\omega_M} - \frac{1}{\omega_F}\right) \mathcal{G}'_B = 0. \end{aligned} \quad (19)$$

A MPME is a set of functions $\{\mathcal{B}, \mathcal{X}, \mathcal{C}, \mathcal{G}\}$ that satisfy (12), (14), (18) and (19) for all $B \in \Gamma$.

3.6 Benchmark policy: aligned preferences

A useful benchmark for building intuition is the case when both authorities agree on how to weight policy objectives. In other words, assume $\omega_F = \omega_M = \omega \in (0, 1]$. Given that both authorities share the same objective, they would agree on what policies to implement and how restrictive the budget constraint is. Thus, $\lambda_F = \lambda_M = \lambda$. The following result follows.

⁵This is a refinement that rules out equilibria where discontinuities in policy are not rooted in the environment fundamentals, but are rather an artifact of the infinite horizon. For an analysis and discussion of non-differentiable Markov-perfect equilibria see Krusell and Smith (2003) and Martin (2009). See also Martin (2011) for further discussion in a similar context.

Proposition 1 Assume $\omega_F = \omega_M = \omega \in (0, 1]$. In a MPME, for all $B \in \Gamma$: (i) $\lambda > 0$; (ii) $\mathcal{X}_B < 0$; and (iii) $\mathcal{B}(B) > -1$ and $q < 1$.

Proof. Let $\tilde{v}(g) \equiv v(g) + \frac{(1-\omega)g}{\omega}$ and apply Proposition 1 in Martin (2012a). ■

The intuition for Proposition 1(i) is that, given the incentives to smooth distortions over time, the government will not implement the first-best allocation in the current period if there are expected distortions in the future. In order to eliminate policy distortions, the government needs to: contract the money supply at rate $\beta - 1$; impose zero taxes; and provide the first-best level of expenditure. In principle, there are two ways it could achieve this. First, the government could start with sufficient claims on the private sector (negative debt) to implement the first-best. The level of steady state debt that implements the first-best policy is $\hat{B} = -1 - \frac{\alpha \hat{g}}{(1-\beta)\phi \hat{x}}$, which is outside of Γ . A second possibility is that the government implements the first-best allocation by continually rolling over the debt. This policy is inconsistent with equilibrium. From (9) and (14), $\lambda > 0$ implies $\tau > 0$, i.e., tax rates are always positive, for all levels of debt. Similarly, from (15) the public good provision is always below the efficient level, even when $\omega = 1$.

Proposition 1(ii) rules out the possibility that the day-good allocation could be (weakly) increasing in debt. This would be inconsistent with an equilibrium since it would imply the government could increase debt and welfare at the same time, which in turn would mean it is not constrained by a budgetary restriction, a contradiction with Proposition 1(i). In equilibrium, we obtain $\mathcal{X}(-1) = \hat{x}$ and $\mathcal{X}(B) < \hat{x}$ for all $B > -1$.

Finally, Proposition 1(iii) offers two important results. First, $\mathcal{B}(B) > -1$, which means the government always chooses to carry over strictly positive net nominal liabilities (money plus bonds). Second, the Friedman rule of zero nominal interest rate ($q = 1$) is not implemented in equilibrium, for any level of debt.

In equilibrium, government policy results from the interaction between monetary policy and government debt. This interaction introduces both intratemporal and intertemporal trade-offs.

First, the government has an incentive to inflate away its inherited nominal liabilities, at the cost of distorting the allocation of the day-good. Given $\lambda > 0$ by Proposition 1, condition (17) states that an increase in beginning-of-period debt, B , implies a decrease in day-good consumption, x . In other words, the incentive to use inflation increases with the level of debt and thus, $\mathcal{X}_B < 0$. This is the channel through which debt affects monetary policy.

Second, the government faces an intertemporal trade-off, as stated in (18) and (19), which for the case $\omega_F = \omega_M$ collapse into a single equation:

$$\phi x'(\lambda - \lambda') + \lambda \mathcal{X}'_B \{ \eta(u'_{xx}x' + u'_x) + (1 - \eta)\phi + \phi B' \} = 0. \quad (20)$$

The term $\phi x'(\lambda - \lambda')$ is the standard trade-off between current and future distortions, and is the basis for the classic tax-smoothing argument, due to Barro (1979), which involves setting this wedge to zero. The government's limited commitment introduces an additional term, $\lambda \mathcal{X}'_B \{ \eta(u'_{xx}x' + u'_x) + (1 - \eta)\phi + \phi B' \}$. From the envelope conditions in the day, note that $\eta(u'_{xx}x' + u'_x) + (1 - \eta)\phi + \phi B' = \frac{dV'_m}{dx'} + \frac{dV'_b}{dx'} B'$. Given $\lambda \mathcal{X}'_B < 0$ by Proposition 1, the sign of this last expression will determine how policy distortions are substituted intertemporally, i.e., how debt evolves over time.

Suppose the model primitives are such that $\frac{dV'_m}{dx} = \eta(u_{xx}x + u_x) + (1 - \eta)\phi < 0$ and focus on $B > 0$. On the one hand, if the government increases the debt today, $\frac{dV'_m}{dx'} \mathcal{X}'_B > 0$ implies there is an increase in tomorrow's marginal value of money. I.e., agents tomorrow, facing higher inflation due to higher debt, would have preferred to have arrived with more money. Thus, the

current demand for money increases, which *relaxes* the government budget constraint today. On the other hand, since $\phi > 0$, $\frac{dV'_b}{dx'} \mathcal{X}'_B < 0$, i.e., increasing debt today implies higher future inflation, which reduces the current demand for bonds. In other words, the interest rate paid on debt increases, which *tightens* the government budget constraint. For low levels of debt, the former effect dominates, providing an incentive to increase the debt, whereas for large levels of debt the latter effect dominates, providing an incentive to decrease debt. The gains from these incentives are offset by the losses due to lower intertemporal distortion smoothing, i.e., a larger wedge $\lambda - \lambda'$.

3.7 Independent authorities

Although the fiscal and monetary authorities are by construction independent, in the sense that they each control different policy instruments, this independence is only meaningful when they disagree on how to weight different policy objectives. The discussion below will center around conditions (18) and (19) when $\omega_F \neq \omega_M$.

Consider the GEE for the fiscal authority, (18). The first term is the trade-off between current and future policy distortions, as viewed by the fiscal authority. The second term appears due to the time-consistency problem, as analyzed above. The third term, $(\lambda'_M - \lambda'_F)\phi(1+B')\mathcal{X}'_B$, arises from disagreement in preferences. Specifically, $\phi(1+B')\mathcal{X}'_B$ measures the future effect on the government budget constraint due to a change in monetary policy induced by higher debt. This effect is weighted by the wedge $\lambda'_M - \lambda'_F$, given that the fiscal authority does not control monetary policy and disagrees with the central bank on how to allocate government resources.

Focus now on the GEE for the monetary authority, (19). Again, the first two terms arise from the distortion-smoothing incentive and the time-consistency problem. The third and fourth terms appear due to preference disagreement. The term $(U'_c - \alpha + U'_{cc}c')\mathcal{C}'_B - \alpha\mathcal{G}'_B$ measures the future effect on the government budget constraint due to a change in fiscal policy induced by higher debt. This effect is weighted by the wedge $\lambda'_M - \lambda'_F$, given that the monetary authority does not control fiscal policy and disagrees with the fiscal authority on how to allocate government resources. The term $(\frac{1}{\omega_M} - \frac{1}{\omega_F})\mathcal{G}'_B$ states the disagreement in the level of future government expenditure, which the central bank will not control.

Suppose we start from a situation where $\omega_F = \omega_M$ and unexpectedly increase ω_M . We can interpret this change as a reform that makes the central bank more independent. For the analysis that follows, assume equilibrium allocations are decreasing in debt, i.e., $\mathcal{X}_B < 0$, $\mathcal{C}_B < 0$ and $\mathcal{G}_B < 0$. Since the central bank prefers a lower expenditure level than the fiscal authority (by virtue of its increased benevolence), we can expect the government budget constraint to bind more tightly for the monetary than the fiscal authority. In other words, when $\omega_F < \omega_M$, $\lambda_F < \lambda_M$. After the reform, the new terms that appear of the central bank's GEE are all positive, meaning an increase in anticipated future distortions. The central bank's optimal response is to lower current distortions today, i.e., lower λ_M by increasing the da-good allocation, x . Thus, for any given level of debt, we can expect a reduction in the money growth rate, relative to the pre-reform equilibrium. Since less of the deficit and accumulated debt is monetized in every period, the fiscal authority has stronger incentives to delay taxation, i.e., increase the debt. However, as debt increases, so will inflation.

A reform that makes the central bank more independent will have two effect on monetary policy. First, there is a shift in the monetary policy function. In particular, if the central bank becomes more benevolent it will be less willing to inflate the deficit and debt away. Second, a change in debt accumulation occurs, which results in a movement along the inflation policy curve. This latter effect mitigates the reduction in inflation due to the former.

3.8 Long-run policy

A steady state $\{B^*, x^*, c^*, g^*\}$ is characterized by

$$\begin{aligned} \lambda_F^* \eta(u_{xx}^* x^* + u_x^* - \phi) + \lambda_M^* \phi(1 + B^*) &= 0 \\ (\lambda_M^* - \lambda_F^*) \{ \eta(u_{xx}^* x^* + u_x^* - \phi) \mathcal{X}_B^* + (U_c^* - \alpha + U_{cc}^* c^*) \mathcal{C}_B^* - \alpha \mathcal{G}_B^* \} + \left(\frac{1}{\omega_M} - \frac{1}{\omega_F} \right) \mathcal{G}_B^* &= 0 \\ U_c^* - \alpha + \lambda_F^* (U_c^* - \alpha + U_{cc}^* c^*) &= 0 \\ (U_c^* - \alpha) c^* - \alpha g^* + x^* \{ \beta \eta(u_x^* - \phi) - (1 - \beta) \phi(1 + B^*) \} &= 0. \end{aligned}$$

When $\omega_F = \omega_M$, the second equation implies $\lambda_F^* = \lambda_M^*$ and the steady state can be solved locally as it does not depend on the derivatives of policy functions. Although small changes in debt choice at B^* still have an effect on future policy, since $\mathcal{X}_B^* < 0$, the positive and negative effects of these changes on the current government budget constraint are balanced out. In other words, the time-consistency problem, which is driving the change in debt, cancels out at the steady state. It follows that if the governments starts at B^* , it will stay there, regardless of its ability to commit.

Proposition 2 *Irrelevance of commitment at B^* .* *Assume $\omega_F = \omega_M = \omega \in (0, 1]$ and set initial debt is equal to B^* . Then, a government with commitment and a government without commitment will both implement the allocation $\{x^*, c^*, g^*\}$ and choose debt level B^* in every period.*

Proof. Let $\tilde{v}(g) \equiv v(g) + \frac{(1-\omega)g}{\omega}$ and apply Proposition 3 in Martin (2012a). ■

Thus, the steady state is constrained-efficient, since endowing the government with commitment at B^* would not affect the allocation. This is an important property of this monetary framework: limited commitment by the government provides a mechanism that explains the level of debt and thus, policy in general, but is not a primary concern in terms of institutional design and welfare. Another implication is that time-consistency of the optimal (commitment) policy is not necessarily linked to the optimality of the Friedman rule, as previously suggested by the results in Alvarez et al. (2004). At B^* there is no time-consistency problem, even though the government is inflating away its nominal liabilities.

4 Numerical Evaluation

4.1 Calibration

Consider the following functional forms:

$$\begin{aligned} u(x) &= \frac{x^{1-\sigma}}{1-\sigma} \\ U(c) &= \frac{c^{1-\rho}}{1-\rho} \\ v(g) &= \ln g. \end{aligned}$$

Set $\eta = \frac{1}{2}$. The parameters left to calibrate are α , β , ρ , σ and ϕ .

Define nominal GDP as the sum of nominal output in the day and night markets. Let Y be nominal GDP normalized by the aggregate money stock, i.e., $Y \equiv \eta \tilde{p} x + p(c + g)$, where $\tilde{p} = x^{-1}$ is the (normalized) price of the day-good. Note that by the equation of exchange, Y is also equal to velocity of circulation.

Calibration targets are taken from 1955-2006 averages for the U.S. economy. Period length is set to a fiscal year. Government in the model corresponds to the federal government. The calibration targets are: debt over GDP, annual inflation, interest payment over GDP, outlays (excluding interest) over GDP and revenues over GDP. Inflation is measured from the CPI, while the rest of the variables are taken from the Congressional Budget Office. Government debt is defined as debt held by the public, excluding holdings by the Federal Reserve system.

Next, we need to specify the model steady state statistics that correspond to the selected calibration targets. For debt over GDP use $\frac{B(1+\mu)}{Y}$, since debt is measured at the end of the period in the data. Let π be annual inflation in the model, which in steady state is equal to μ . Interest payments over GDP are defined as $\frac{B(1+\mu)(1-q)}{Y}$. Given that debt over GDP is already targeted, this implies a target for the nominal interest rate i , where $i = \frac{1}{q} - 1$. Interest payments are 2.1% of GDP in the data, which implies a target nominal interest rate of 7.0% annual. Outlays and revenues are defined as $\frac{pg}{Y}$ and $\frac{p\tau n}{Y}$, respectively, where $n = c + g$ from the night-resource constraint. Table 1 summarizes the target statistics and calibration parameters.

Table 1: Benchmark Calibration

α	β	ρ	σ	ϕ
7.9464	0.9680	6.1841	3.8505	2.1223

Note: $\eta = 0.5$.

4.2 The effects of central bank independence

To evaluate the effects of a reform that makes the central bank independent, we can compare the policy functions and steady state statistics of the environments with and without central bank independence. I consider four cases: “BNV” (benevolent) corresponds to the case $\omega_F = \Omega_M = 1$ and is presented as a benchmark; “PRE” (pre-reform) features $\omega_F = \Omega_M = 0.5$ and corresponds to an environment with political frictions and without an independent central bank; “ICB” (independent central bank) features $\omega_F = 0.5, \omega_M = 1$ and corresponds to an environment with political frictions and an independent (benevolent) central bank.

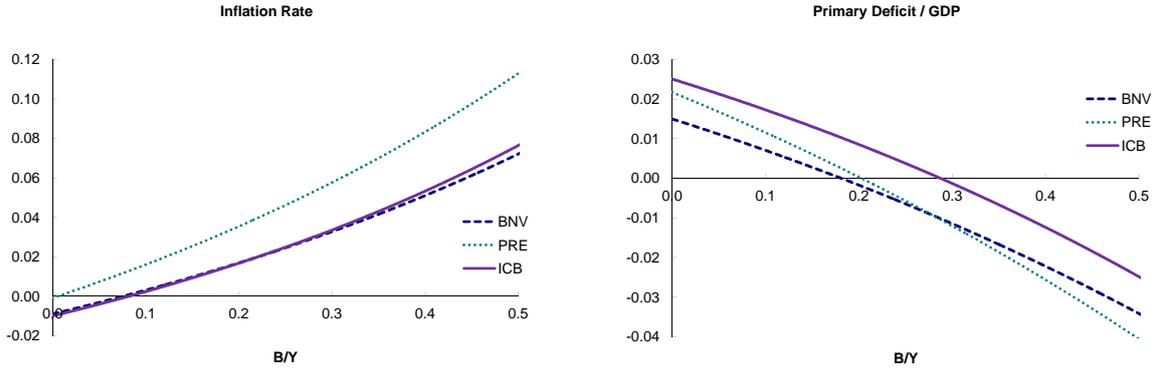
Table 2: Steady state statistics

	BNV	PRE	ICB
$\frac{B(1+\mu)}{Y}$	0.218	0.210	0.333
π	0.019	0.036	0.038
i	0.053	0.070	0.072
$\frac{p\tau n}{Y}$	0.138	0.180	0.184
$\frac{pg}{Y}$	0.135	0.180	0.180

Note: BNV: $\omega_F = \omega_M = 1$; PRE: $\omega_F = \omega_M = 0.3$; ICB: $\omega_F = 0.3, \omega_M = 1$.

A reform that makes the central bank independent from political frictions implies higher debt, lower inflation and lower taxes. Table 2 shows that the differences in inflation and tax rates between the cases with and without an independent central bank vanish in the long-run. In effect, the only salient difference between these two cases is debt over GDP, which increases substantially post-reform. What happens is the following. An independent central bank implements an inflation policy similar to a benevolent government. This in turn, generates

Figure 1: Policy Effects of Central Bank Independence



more debt as a lower fraction of the expenditure is financed with inflation. As debt grows, both taxes and inflation grow to finance the added financial burden. In the end, debt increases and both inflation and taxes roughly return to their original levels. Figure 1 complements the analysis by showing inflation and deficit, as a function of debt, for all cases considered.

Some have argued that the successful overturn of the Great Inflation of the 1970s was not associated with the degree of central bank independence. As Posen (1993) argues, the inflation performance of the 1970s may have created a demand for both lower long-run inflation and central bank independence. Similarly, Meltzer (2009) argues that the end of the 1970s inflation in the U.S. was mainly due to a change in public attitudes about inflation. Below, I test this hypothesis in the context of the model presented here.

Lower “tolerance” for inflation can be modeled as an increase in the parameter ρ . As we can see in Table 3, the change in long-run inflation does not alter the main lessons from Table 2, namely, that a higher debt is the only quantitatively significant long-run effect of central bank independence.

Table 3: Steady states: institutional reform & lower inflation tolerance

	$\rho = 6.1841$	$\rho = 8.9000$	
	PRE	PRE	ICB
$\frac{B(1+\mu)}{Y}$	0.210	0.189	0.310
π	0.036	0.019	0.020
i	0.070	0.053	0.054
$\frac{p\tau n}{Y}$	0.180	0.174	0.178
$\frac{pg}{Y}$	0.180	0.172	0.172

Note: PRE: $\omega_F = \omega_M = 0.3$; ICB: $\omega_F = 0.3, \omega_M = 1$.

5 Explicit monetary policy objective

5.1 Problem of the government

The central bank may be explicitly endowed with a specific policy objective, such as low inflation. Let $\omega_T \in [0, 1 - \omega_M]$ be the weight placed on this “target” policy. The monetary authority

takes as given the policy of the fiscal authority for the current period and the policies of both authorities in all future periods.

To simplify exposition, suppose the target policy is defined in terms of deviations from a specific money growth rate. Given that by (8) μ is a function of x and x' , we can define a general loss function, $\Upsilon(x, x') \leq 0$, where $\Upsilon_x > 0 \geq \Upsilon_{x'}$.⁶

The problem of the monetary authority can be written as choosing x , given current fiscal policy $c = \mathcal{C}(B)$ and $g = \mathcal{G}(B)$, and future government policy inducing a value $\mathcal{M}(B)$. Again, debt is determined as a residual to satisfy (12), but the central bank understands it can affect it by its choice of policy.

The problem of the monetary authority is then

$$\max_{B', x} \omega_M \mathcal{U}(x, \mathcal{C}(B), \mathcal{G}(B)) + \omega_T \Upsilon(x, \mathcal{X}(B')) + (1 - \omega_M - \omega_T) \mathcal{G}(B) + \beta \mathcal{M}(B')$$

subject to $\varepsilon(B, B', x, \mathcal{X}(B'), \mathcal{C}(B), \mathcal{G}(B)) = 0$. See Appendix A for a characterization of the MPME in this setting.

A useful benchmark is the case $\omega_M = 0$, $\omega_T = 1$, which stands for the ‘‘conservative central bank’’ in Rogoff (1985). The problem of the monetary authority simplifies to

$$\max_{B', x} \Upsilon(x, \mathcal{X}(B')) + \beta \mathcal{M}(B')$$

subject to $\varepsilon(B, B', x, \mathcal{X}(B'), \mathcal{C}(B), \mathcal{G}(B)) = 0$.

Using λ_T as the Lagrange multiplier associated with the constraint in the monetary authority’s problem, the first-order conditions are

$$\begin{aligned} \mathcal{M}'_B + \lambda_T \phi x' + \beta^{-1} \Upsilon_{x'} \mathcal{X}'_B + \lambda_T \{ \eta(u'_{xx} x' + u'_x - \phi) + \phi(1 + B') \} \mathcal{X}'_B &= 0 \\ \Upsilon_x - \lambda_T \phi(1 + B) &= 0 \end{aligned}$$

and where

$$\mathcal{M}_B = \lambda_T \{ -\eta \phi x + (U_c - \alpha + U_{cc} c) \mathcal{C}_B - \alpha \mathcal{G}_B \}.$$

Thus,

$$\phi x' (\lambda_T - \lambda'_T) + \{ \beta^{-1} \Upsilon_{x'} + \lambda_T \{ \eta(u'_{xx} x' + u'_x - \phi) + \phi(1 + B') \} \} \mathcal{X}'_B + \lambda'_T \{ (U'_c - \alpha + U'_{cc} c') \mathcal{C}'_B - \alpha \mathcal{G}'_B \} = 0, \quad (21)$$

where

$$\lambda_T = \frac{\Upsilon_x}{\phi(1 + B)}.$$

Assume the policy loss function is a simple policy target such as $\Upsilon(x, x') \equiv -\frac{(\hat{x} - x)^2}{2}$; label this case ‘TRG’. This rule penalizes the central bank for deviations from the first-best level of day-good consumption. As an alternative specification, labeled ‘TRG2’, let $\Upsilon(x, x') \equiv -\frac{(\mu - \mu^{PRE})^2}{2}$, where μ is a function of (x, x') as stated in (8). Table 4 displays steady state statistic with weights ω_M and ω_T chosen so that both cases yield the same steady state.

Adding an explicit monetary target has little effect in the long-run, except for an even greater increase in debt, especially as ω_T approaches 1. The logic is the same as above: a lower incentive to inflate debt, especially a higher levels, results in a larger long-run debt. Although having an explicit monetary target does not alter long-run statistics significantly, policy as a

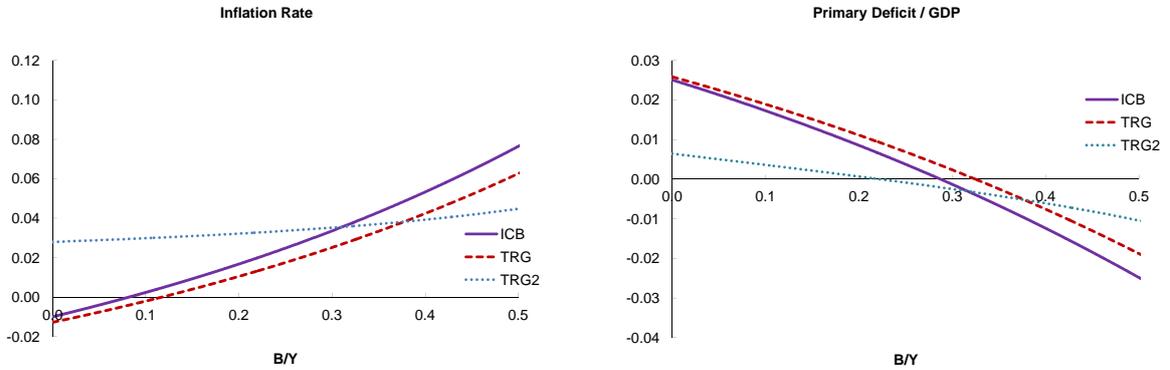
⁶In general, we could specify other policy objectives, such as inflation targeting. In this case the target function would depend on other variables, such as c and possibly c' . The results would not be altered significantly, as the monetary authority does not directly affect these other allocations.

Table 4: Steady state statistics with an explicit monetary target

	ICB	TRG	TRG2
$\Upsilon(x, x')$	—	$-\frac{(x-\hat{x})^2}{2}$	$-\frac{(\mu-\mu^{PRE})^2}{2}$
ω_M	1.000	0.500	0.100
ω_T	0.000	0.500	0.900
$\frac{B(1+\mu)}{Y}$	0.333	0.392	0.392
π	0.038	0.038	0.038
i	0.072	0.073	0.073
$\frac{p\tau n}{Y}$	0.184	0.185	0.185
$\frac{p\bar{g}}{Y}$	0.180	0.180	0.180

Note: $\omega_F = 0.3$.

Figure 2: Policy Effects of Central Bank Independence



function of debt is different. This suggests that the policy response to aggregate shocks may be affected by the inclusion of an explicit policy target.

As we can see in Figure 2, however, the two cases with an explicit policy objective differ substantially outside the steady state. The case TRG is quite similar to the benchmark ICB, although these cases start to diverge for higher levels of debt, when the natural incentives to inflate get stronger. The case TRG2 features a much flatter inflation policy than any other case, for all levels of debt.

6 Policy response to shocks

6.1 Stochastic environment

Even though central bank independence may not have an effect on long-run policy, except for the level of debt, it may still have an effect in how the government responds to shocks. In this section, I augment the model to include productivity and government expenditure shocks, and analyze policy response with and without an independent central bank. I closely follow Aruoba and Chugh (2010) and Martin (2012a).

Suppose there are two aggregate shocks: one to the marginal value of the public good (an “expenditure” shock) and one to the productivity of labor. The utility derived from the public

good is now $\psi v(g)$ where ψ is a random variable. Let A be labor productivity, which affects both day and night output, and follows a random process. Thus, day-good producers incur a utility cost $\frac{\phi x}{A}$, and night-output is equal to An .

Let $s \equiv \{\psi, A\}$ follow a Markov process and let $E[s'|s]$ be the expected value of s' given s . The set of all possible realizations for the stochastic state is S . After solving for the monetary equilibrium, we can write the government budget constraint as

The government budget constraint is now

$$\left(U_c - \frac{\alpha}{A} \right) c - \frac{\alpha g}{A} - \frac{\phi x(1+B)}{A} + \beta E \left[\eta x' \left(u'_x - \frac{\phi}{A'} \right) + \frac{\phi x'(1+B')}{A'} \mid s \right] = 0, \quad (22)$$

or, more compactly, $E[\varepsilon(B, B', x, \mathcal{X}(B', s'), c, g) \mid s] = 0$. The ex-ante period utility of agents is defined by

$$\mathcal{U}(x, c, g, s) \equiv \eta \left(u(x) - \frac{\phi x}{A} \right) + U(c) + \psi v(g) - \frac{\alpha(c+g)}{A}.$$

The problem of the current fiscal authority is

$$\max_{B', c, g} \omega_F \mathcal{U}(\mathcal{X}(B, s), c, g, s) + (1 - \omega_F)g + \beta E[\mathcal{F}(B', s') \mid s]$$

subject to $E[\varepsilon(B, B', \mathcal{X}(B, s), \mathcal{X}(B', s'), c, g) \mid s] = 0$, whereas the problem of the monetary authority is

$$\max_{B', x} \omega_M \mathcal{U}(x, \mathcal{C}(B, s), \mathcal{G}(B, s), s) + \omega_T E[\Upsilon(x, \mathcal{X}(B'), s) \mid s] + (1 - \omega_M - \omega_T) \mathcal{G}(B, s) + \beta E[\mathcal{M}(B', s') \mid s]$$

subject to $E[\varepsilon(B, B', x, \mathcal{X}(B', s'), \mathcal{C}(B, s), \mathcal{G}(B, s)) \mid s] = 0$.

6.2 Simulations

For the simulation exercise, I keep the benchmark parametrization and assume

$$\begin{aligned} \psi' &= 1 - \varrho_g + \varrho_g \psi + \epsilon'_g \\ \ln A' &= \varrho_A \ln A + \epsilon'_A, \end{aligned}$$

where $\varrho_g, \varrho_A \in (0, 1)$, $\epsilon_g \sim N(0, \sigma_g^2)$ and $\epsilon_A \sim N(0, \sigma_A^2)$. Note that both ψ and A average 1, as in the economies without aggregate uncertainty. The model is solved globally using a projection method. See Appendix B for a description of the algorithm and other details of the numerical approximation.

There are many alternative ways to calibrate or estimate the stochastic processes for ψ and A . Here, I follow Martin (2012a) and adopt an approach that allows for a single parameterization to offer empirically plausible dynamics. Specifically, the stochastic process for ψ is set to match the autocorrelation and variance of government expenditure over GDP, assuming labor productivity is constant and equal to its long-run value; the process for A is set to match the autocorrelation and variance of detrended (log) real GDP (i.e., $d\text{GDP}$), assuming the marginal value for public good consumption is fixed at its long-run value. In both cases, I target the statistics for the case with competitive markets, but the assumed processes also match the statistics for the other two cases, with only very minor deviations in the autocorrelation of expenditure and $d\text{GDP}$. The calibrated parameters are: $\varrho_g = 0.804$, $\varrho_A = 0.726$, $\sigma_g = 0.045$; $\sigma_A = 0.061$.

Artificial economies are simulated for 1,000,000 periods, starting from their respective non-stochastic steady states. Table 5 shows average, standard deviation and autocorrelation of selected policy variables. The variable dy in the model corresponds to $d\text{GDP}$, i.e., linearly detrended (log) real GDP. See Appendix B for a description of how it was computed.

Table 5: Simulation over 1,000,000 periods

	PRE			ICB			TRG		
	Mean	St.Dev.	Autocorr.	Mean	St.Dev.	Autocorr.	Mean	St.Dev.	Autocorr.
$\frac{B(1+\mu)}{Y}$	0.214	0.044	0.982	0.336	0.043	0.982	0.392	0.045	0.984
π	0.038	0.036	0.393	0.040	0.035	0.337	0.040	0.034	0.298
$\frac{p(g-\tau n)}{Y}$	0.001	0.014	0.647	-0.003	0.015	0.661	-0.005	0.016	0.667
dy	0.000	0.037	0.703	0.000	0.037	0.704	0.000	0.037	0.704

Note: PRE: $\omega_F = \omega_M = 0.3$; ICB: $\omega_F = 0.3, \omega_M = 1$; TRG: $\omega_F = 0.3, \omega_M = \omega_T = 0.5$.

6.3 Money demand

Let us evaluate the model’s implication for the money demand, i.e., the relationship between the nominal interest rate and the inverse of velocity of circulation. Note that neither of these variables were calibration targets. For the U.S. data, define velocity of money as nominal GDP divided by average M_1 , which is the measure typically adopted by the literature. For the interest rate, I use the 1-year treasury constant maturity rate published by the Federal Reserve, which is closely related to the nominal interest rate in the model. One issue with the data is that velocity of circulation has a secular trend whereas the interest rate does not. To remove this effect, I linearly detrend the series for the inverse of velocity. In the model, velocity of circulation is defined as (normalized) nominal aggregate output, Y , and the interest rate is $i = 1/q - 1$.

Consider the money demand regression $dk_t = \gamma di_t + \varepsilon_t$, where dk and di are deviations from mean of the (detrended) inverse of velocity and the nominal interest rate, respectively. Table 6 reports the results of the money demand regressions in the data and the model. For the artificial economies, the demand equation is estimated using the simulated sample of 1,000,000 periods. This method provides an estimate of the “true” relationship between k and i in the model. Fit can be evaluated by checking whether the model estimate for γ falls within the one-standard error band in the data.

Table 6: Money demand regression: $dk_t = \gamma di_t + \varepsilon_t$

	U.S. 1960-2010	PRE	ICB	TRG
γ	-0.470 (0.056)	-0.436 (0.000)	-0.437 (0.000)	-0.417 (0.000)
R^2	0.591	0.754	0.700	0.627

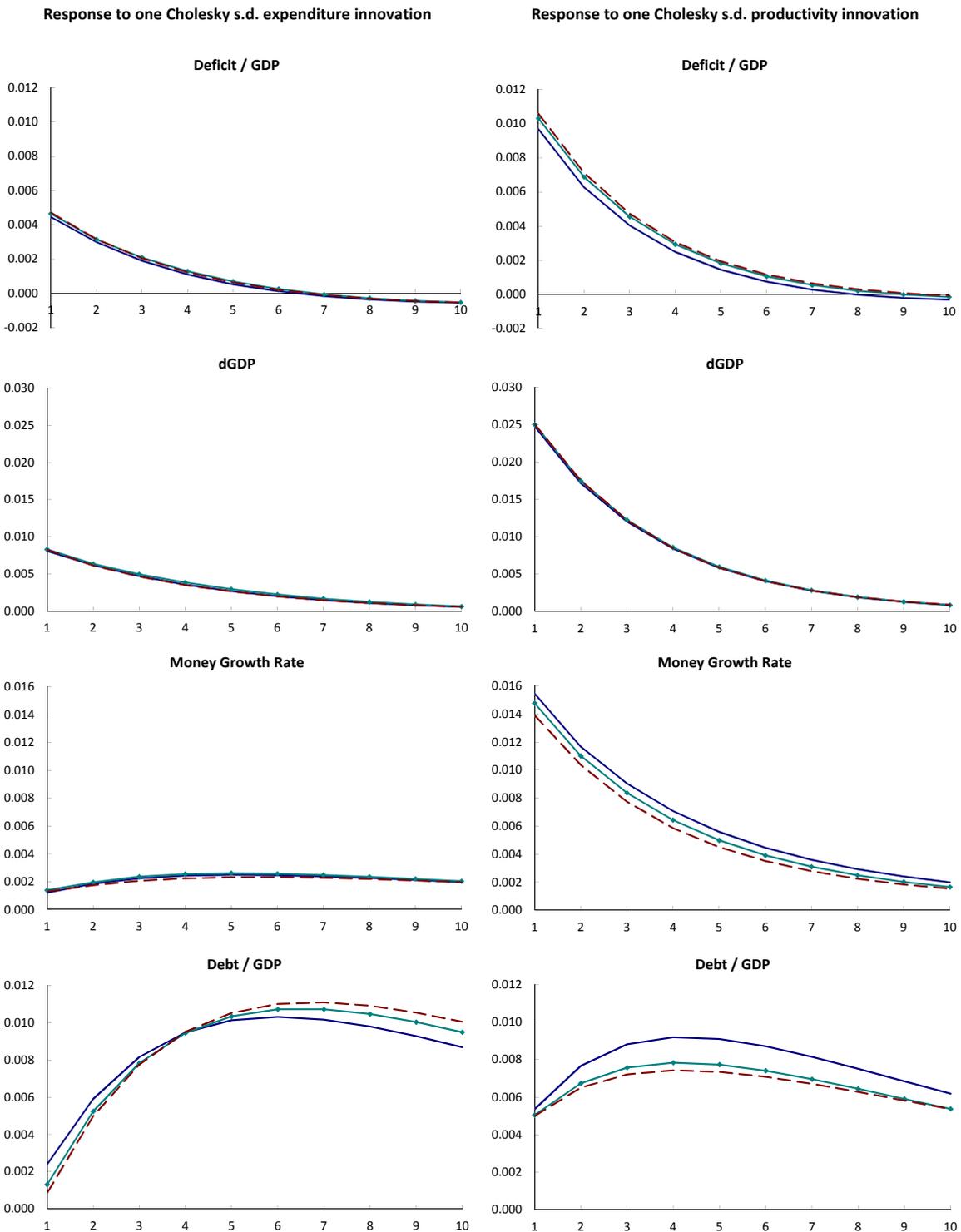
Note: U.S. data corresponds to Fiscal Years. Standard errors are shown in parenthesis.

As we can see in Table 6, all cases feature a money demand curve that closely corresponds to the data.

6.4 Phillips curve

We can also compare the effects of central bank independence on the implied relationship between inflation and output, i.e., a variant of the standard Phillips curve. For the U.S. annual data between 1955 and 2010, the regression $d\pi_t = \gamma dy_t + \varepsilon_t$ implies $\gamma = 0.521$, with a standard error of 0.150. Table 7 displays the Phillips curve regression for the U.S. data and simulated

Figure 3: Impulse Response Functions



Note. PRE: solid lines; ICB: solid lines with diamonds markers; TRG: dashed lines.

economies.

The positive correlation between inflation and GDP in the model obtains despite a negative policy trade-off between the two variables (since inflation is distortionary), and results from the interaction between policy and aggregate shocks over time. Table 7 shows that the positive

Table 7: Phillips curve regression: $d\pi_t = \gamma dy_t + \varepsilon_t$

	U.S. 1955-2010	PRE	ICB	TRG
γ	0.345 (0.094)	0.348 (0.001)	0.300 (0.001)	0.261 (0.001)
R^2	0.199	0.128	0.101	0.080

Note: U.S. data corresponds to Fiscal Years. Standard errors are shown in parenthesis.

relationship between inflation and output weakens under an independent central bank, especially if we add a specific monetary target. In the data, the Phillips curve relationship is stronger pre-1980: for data between 1955 and 1980 we obtain $\gamma = 0.490$ with a standard deviation on 0.146. Post-1980, the estimated coefficient drops to 0.220, with a similar standard deviation.

7 Concluding thoughts

A quick survey of news articles would indicate that the perceived independence of the Federal Reserve from other political bodies has changed dramatically in the last three decades, especially in terms of inflation policy. Though there has been no major formal reform since the Treasury-Federal Reserve Accord of 1951, the general perception is that the Federal Reserve has become more independent in recent time. A notable example is given by Abrams (2006) who elaborates on how then Fed chairman Arthur Burns was successfully pressured by President Nixon to run expansionary monetary policy.

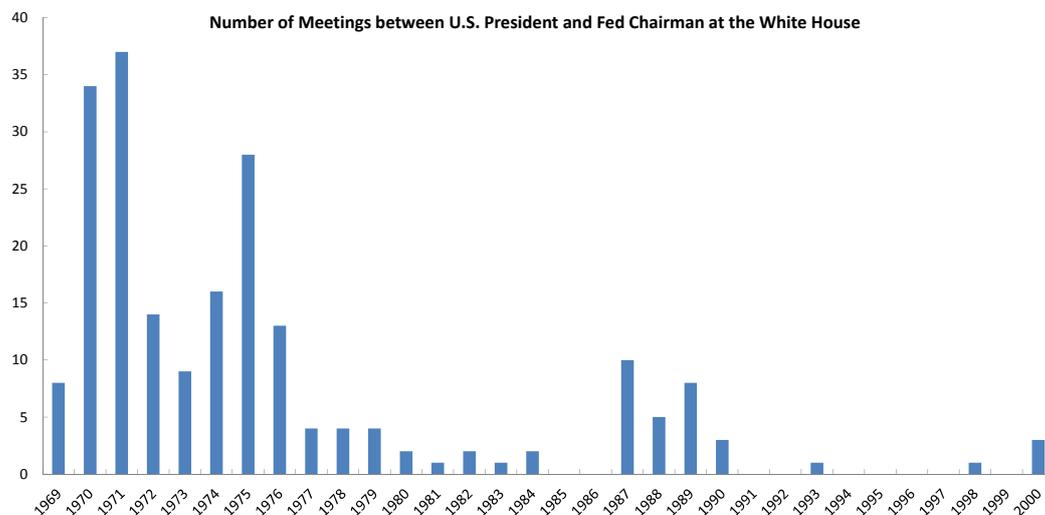
One could proxy central bank independence by the number of meetings at the White House between the U.S. President and the Fed Chairman. Figure 4 shows that these meetings were quite frequent in the 1970s and rather infrequent afterwards. Presidents Nixon and Ford (1969-1977) meet four times as much as the next four presidents put together. Although not shown in the chart, President Johnson (1963-1969) met with Fed chairmen even more often: almost 300 times during his five years in office.

Looking at examples of formal policy or institutional reform in other countries is problematic since these reforms may not have been binding. For example, Bernanke et al. (1999) argue that both Canada and New Zealand adopted formal inflation targets only after inflation was significantly reduced and the success of achieving the targets appeared likely. In this view, inflation targeting did not put a constraint of policy, but rather made pre-existing policy objectives explicit. The “real” central bank reform came about whenever the central bank managed to set its monetary policy independent from the fiscal authority’s financing needs or other policy objectives.

During the 1980s, the U.S. and other industrialized countries experienced sharp increases in debt that were not associated with corresponding increases in financing needs.⁷ This increase in debt follows a decade of high and volatile inflation. The data shows that between 1981 and 1991, the increase in debt over GDP was about 20 percentage points, whereas federal outlays and revenue kept roughly constant. Inflation, although lower than in the 1970s, stabilized around historical levels. The theory in this paper provides a plausible explanation for the large increase in debt, under the hypothesis that the Federal Reserve became more independent around the late 1970s or early 1980s, as the anecdotal evidence cited above suggests. The theory

⁷The debt increase has long puzzled economist, although some theories have been proposed, mainly in the political economy literature. See Persson and Tabellini (1998) for a survey. See also Azzimonti et al. (2011) for recent alternative take.

Figure 4: Number of Meetings at the White House between U.S. President and Fed Chairman



also suggests that the Great Inflation of the 1970s and its resolution were not associated with the degree of central bank independence, but rather a lower tolerance for inflation, which is consistent with the explanations proposed by Posen (1993) and Meltzer (2009).

Central bank independence may have been responsible for the increase in debt during the 1980s, but does not appear to be the cause for the lower inflation observed. This last result is consistent with previous work—most notably Campillo and Miron (1997) and Posen (1993)—which suggested that central bank independence does not determine inflation performance.

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A Loss function for monetary policy

Let λ_F be the Lagrange multiplier associated with the constraint of the fiscal authority's problem. The first-order conditions are

$$\mathcal{F}'_B + \lambda_F \{ \Phi(x') + (\Omega'_x + \Phi'_x(1+B')) \mathcal{X}'_B \} = 0 \quad (23)$$

$$\omega_F(U_c - \alpha) + \lambda_F(U_c - \alpha + U_{cc}c) = 0 \quad (24)$$

$$\omega_F(v_g - \alpha) + 1 - \omega_F - \lambda_F \alpha = 0. \quad (25)$$

The envelope condition implies

$$\mathcal{F}_B = -\lambda_F \Phi(x) + \{ \omega_F \eta(u_x - f_\kappa) - \lambda_F \Phi_x(1+B) \} \mathcal{X}_B. \quad (26)$$

Thus, (23) can be written as

$$\Phi(x') \{ \lambda_F - \lambda'_F \} + \{ \lambda_F (\Omega'_x + \Phi'_x(1+B')) + \omega_F \eta(u'_x - f'_\kappa) - \lambda'_F \Phi'_x(1+B') \} \mathcal{X}'_B = 0. \quad (27)$$

Using λ_M as the Lagrange multiplier associated with the constraint in the monetary authority's problem, the first-order conditions are

$$\mathcal{M}'_B + \beta^{-1} \omega_T \Upsilon_{x'} \mathcal{X}'_B + \lambda_M \{ \Phi(x') + (\Omega'_x + \Phi'_x(1+B')) \mathcal{X}'_B \} = 0 \quad (28)$$

$$\omega_M \eta(u_x - f_\kappa) + \omega_T \Upsilon_x - \lambda_M \Phi_x(1+B) = 0. \quad (29)$$

The envelope condition implies

$$\begin{aligned} \mathcal{M}_B = & -\lambda_M \Phi(x) + \{ \omega_M (U_c - \alpha) + \lambda_M (U_c - \alpha + U_{cc}c) \} \mathcal{C}_B \\ & + \{ \omega_M (v_g - \alpha) + 1 - \omega_M - \omega_T - \lambda_M \alpha \} \mathcal{G}_B. \end{aligned} \quad (30)$$

Thus, (28) can be written as

$$\begin{aligned} \Phi(x') \{ \lambda_M - \lambda'_M \} + \{ \beta^{-1} \omega_T \Upsilon_{x'} + \lambda_M (\Omega'_x + \Phi'_x(1+B')) \} \mathcal{X}'_B \\ + \{ \omega_M (U'_c - \alpha) + \lambda'_M (U'_c - \alpha + U'_{cc}c') \} \mathcal{C}'_B + \{ \omega_M (v'_g - \alpha) + 1 - \omega_M - \omega_T - \lambda_M \alpha \} \mathcal{G}'_B = 0. \end{aligned} \quad (31)$$

We can simplify (27) and (31) considerably by using (24), (25) and (29). Define $\Lambda_F = \omega_M \lambda_F$ and $\Lambda_M = \omega_F \lambda_M$. We get

$$\Phi(x') (\Lambda_F - \Lambda'_F) + \{ \Lambda_F \Omega'_x + (\Lambda_F + \Lambda'_M - \Lambda'_F) \Phi'_x(1+B') - \omega_F \omega_T \Upsilon'_x \} \mathcal{X}'_B = 0 \quad (32)$$

and

$$\begin{aligned} \Phi(x') (\Lambda_M - \Lambda'_M) + \{ \beta^{-1} \omega_F \omega_T \Upsilon_{x'} + \Lambda_M (\Omega'_x + \Phi'_x(1+B')) \} \mathcal{X}'_B \\ + (\Lambda'_M - \Lambda'_F) \{ (U'_c - \alpha + U'_{cc}c') \mathcal{C}'_B - \alpha \mathcal{G}'_B \} + (\omega_F - \omega_M) \mathcal{G}'_B = 0. \end{aligned} \quad (33)$$

We can solve for the Lagrange multipliers using (23) and (29):

$$\begin{aligned} \lambda_F &= \frac{\omega_F (v_g - \alpha) + 1 - \omega_F}{\alpha} \\ \lambda_M &= \frac{\omega_M \eta(u_x - f_\kappa) + \omega_T \Upsilon_x}{\Phi_x(1+B)}. \end{aligned}$$

Using these expressions an equilibrium is characterized by (12), (24), (32) and (33).

B Numerical approximation of stochastic economies

The monetary economies with aggregate uncertainty are solved globally using a projection method with the following algorithm:

- (i) Define a grid of N_Γ points over Γ . The stochastic state space S is discretized in N_S states, using the method described in Tauchen (1986).⁸ Create the indexed functions $\mathcal{B}^i(B)$, $\mathcal{X}^i(B)$, $\mathcal{C}^i(B)$, and $\mathcal{G}^i(B)$, for $i = \{1, \dots, N_S\}$, and set an initial guess.
- (ii) Construct the following system of equations: for every point in the debt and exogenous state grids, evaluate the equations characterizing a MPME. Since some equations contain the derivative of policy functions, use cubic splines to interpolate between debt grid points and calculate the derivatives of policy functions.
- (iii) Use a non-linear equations solver to solve the system in (ii). There are $N_\Gamma \times N_S \times 4$ equations. The unknowns are the values of the policy function at the grid points. In each step of the solver, the associated cubic splines need to be updated so that the interpolated evaluations of future choices are consistent with each new guess.

Finally, we need to construct measures of real GDP and the inflation rate. In the model, real GDP is measured using the non-stochastic steady state as the base period for prices. Thus, let $y_t = \ln(\tilde{p}^* x_t + p^*(c_t + g_t))$ be the measure of log real GDP in the artificial economy and let dy_t be log real GDP in period t minus its sample average. To calculate the inflation rate, define the aggregate (normalized) price level P as the weighted average of prices in the day and night markets. I.e., for any period t , let $P_t \equiv s_D \tilde{p}_t + s_N p_t$, where s_D and s_N are the expenditure shares for the day and night markets, respectively. Expenditure shares are constructed using the non-stochastic steady state statistics as the base period: $s_D \equiv \frac{\tilde{p}^* x^*}{Y^*}$ and $s_N \equiv \frac{p^*(c^* + g^*)}{Y^*}$. The inflation rate is defined as: $\pi_t \equiv \frac{P_t(1 + \mu_t - 1)}{P_t - 1} - 1$.

⁸See Flodén (2008) for a recent comparison with alternative methods.