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Fiscal Foundations of Inflation: Imperfect Knowledge*

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Abstract

This paper proposes a theory of the fiscal foundations of inflation based on imperfect knowledge and learning. Because imperfect knowledge breaks Ricardian equivalence the scale and composition of the public debt matter for inflation. High moderate-duration debt generates wealth effects on consumption demand that impairs the intertemporal substitution channel of monetary policy: aggressive monetary policy is required to anchor inflation expectations. Counterfactual experiments, in an estimated medium-scale DSGE model, reveal the US economy would have been substantially more volatile over the Great Inflation and Great Moderation periods, had average debt been consistent with levels currently observed in Italy or Japan.

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1 Introduction

In the aftermath of the 2007-2009 global recession many countries experienced a sharp increase in their public debt-to-GDP ratios as a result of expansionary fiscal policy. An important theoretical and practical issue concerns the consequences of these fiscal developments for future macroeconomic stability, in particular for inflation. This paper proposes a theory of the inflation consequences of fiscal policy based on imperfect knowledge and learning. Permitting beliefs to depart from those consistent with rational expectations equilibrium leads to deviations from Ricardian equivalence, creating a link between the path of government debt, taxes and inflation. For economies with a high level of government debt of average duration commonly observed in many countries, this link is sufficiently strong to hinder a central bank's pursuit of price stability.

These findings stand in stark contrast with the conventional view of stabilization policy which emerged during the years of the Great Moderation — see Clarida, Gali, and Gertler (1999). According to this view fiscal policy satisfies a strong neutrality property. Changes in the size and maturity composition of nominal government liabilities have no impact on inflation. Monetary policy provides the nominal anchor by responding aggressively to inflation, while fiscal policy maintains the value of the public debt. In the language of Leeper (1991) monetary policy is active, fiscal policy is passive, and the equilibrium is Ricardian. This result, however, depends strongly on the assumption of rational expectations and, in particular, a complete understanding of the current and future policy regime at any point in time. Given the profound uncertainty surrounding recent monetary and fiscal frameworks in many countries, and a constantly changing economic environment, this benchmark can only be viewed as a very stringent assumption.[1]

A simple thought experiment frames the basic ideas of the paper. Consider standing at the peak of the Great Inflation in the late 1970s. Inflation has risen to historic highs, eroding the real value of fiscal liabilities, and so too interest rates. Having consistently under-predicted interest rates and over-predicted the level of real debt and taxes, you adjust, using a simple filtering algorithm, your long-run mean estimate of inflation and real interest rates, and also your tax obligations.[2] Using these assessments, holdings of the public debt and associated tax obligations are valued: expecting permanently lower taxes and higher interest rates, perceived net wealth from holding government debt rises. These positive effects on demand limit the restraining influence of higher real interest rates, impairing inflation control. Yet, at that same time, had you correctly anticipated interest rates and inflation were to fall to very low levels, and debt and tax obligations to rise, by the late 1990s, these non-Ricardian effects would not have emerged, given policy is Ricardian under rational expectations.

Using a simple endowment economy, we characterize analytically the conditions under which forecast errors of this kind lead to non-neutralities of fiscal policy. Agents have imperfect knowledge about the long-run objectives of policy, and use a simple statistical model to form inferences about these objects. Higher debt economies, with moderate maturity

[1] See Davig and Leeper (2006) and Bianchi (2010).

[2] See Adam, Marcet, and Nicolini (2012), Adam, Beutel, and Marcet (2013), Eusepi and Preston (2011), Milani (2007) and Slobodyan and Wouters (2012a). This kind of belief structure is an example of "end-point uncertainty" — see, for example, Kozicki and Tinsley (2001) for an asset pricing application — which asserts long-run conditional means are driven by short-run forecast errors.

structures, are challenging environments for central banks: relative to rational expectations, monetary policy must be substantially more aggressive to stabilize inflation. Wealth effects from holdings of the public debt diminish the efficacy of the intertemporal substitution channel of monetary policy, a central mechanism of contemporary theories of aggregate demand management.[3] These destabilizing wealth effects arise from shifting views of the present value of taxation, relative to the perceived market value of public debt holdings.[4] They are more important when forecast errors are to some degree self-fulfilling — a property called 'self-referentiality' by Marcet and Sargent (1989) — which occurs precisely when fiscal policy is characterized by high debt of moderate duration.

The theoretical results suggest fiscal policy is potentially important to our understanding of US monetary history. To assess this conjecture, we estimate a medium-scale dynamic stochastic general equilibrium model of the US economy. A core goal of the empirical model is to measure movements in perceived wealth and their consequences for aggregate demand and inflation. The empirical model seeks to account for the joint dynamics of both standard macroeconomic time series and also survey data on expectations. The sample period spans both the Great Inflation of the 1970s and the Great Moderation of the 1980s and 1990s. Our model permits understanding the source of low-frequency movement in long-term expectations, and specifically the role of fiscal policy in unanchoring inflation expectations in the 1970s, and the subsequent decline in macroeconomic volatility during the Great Moderation.

The estimated model accounts well for the observed behavior in long-term inflation and interest rate expectations, while at the same time, predicting persistent deviations of the expected tax obligations from model-consistent forecasts — consistent with non-Ricardian effects from fiscal policy. However, the results reveal fiscal non-neutralities had limited influence on economic activity and inflation dynamics. This is largely due to the fact that the US economy displayed a low average debt-to-GDP ratio over the sample. Nonetheless, counterfactual experiments imply, had the US operated with an average debt-to-GDP ratio of the kind currently observed in many economies, macroeconomic volatility would have been substantially higher given the estimated shocks. Much of the decline in volatility observed in the Great Moderation would disappear. Furthermore, the recessions associated with the Volcker disinflation and the technology boom the 1990s would have witnessed deflation, with monetary policy constrained by the zero lower bound on nominal interest rates.

The findings of this analysis have clear predictions for the near-term evolution of the US and many other economies which face severe fiscal imbalances. To support aggregate demand, these economies have shifted to high levels of public indebtedness and a shortened maturity structure due to large-scale asset purchase programs. The above results indicate that further deterioration in fiscal conditions could lead to macroeconomic volatility, as central banks' ability to stabilize inflation would be severely impaired.

[3] See Clarida, Gali, and Gertler (1999) and Woodford (2003).

[4] In effect, imperfect knowledge re-weights standard wealth and substitution effects of consumption demand. In this way the theory is close related but distinct from the fiscal theory of the price level — see Leeper (1991), Sims (1994), Woodford (1996) and Cochrane (2001). See also Adam, Beutel, and Marcet (2013) for a discussion of the consequences of such re-weighting for asset pricing.

2 An Endowment Economy

This section presents a simple flexible-price endowment economy with long-term nominal bonds. The central modeling departure from standard analyses is the assumption that agents have incomplete knowledge about the economic environment: they form expectations using data from the economic system in which they operate. Learning is introduced following the anticipated utility approach as described by Kreps (1998) and Sargent (1999). The analysis follows Marcet and Sargent (1989) and Preston (2005), solving for optimal decisions conditional on current beliefs.

2.1 Households

A continuum of households maximize future expected discounted utility

$$\hat{E}_t^i \sum_{T=t}^{\infty} \beta^{T-t} \frac{C_T(i)^{1-\sigma}}{1-\sigma} \tag{1}$$

where $\sigma > 0$, $0 < \beta < 1$ and $C_t(i)$ denotes household$-i$ consumption in period t. The operator $\hat{E}_t^i$ denotes the beliefs at time t held by each household i, described below. Households have access to two types of nominal assets supplied by the government: one-period debt, B_t^s, with price P_t^s; and a more general portfolio of debt, B_t^m, with price P_t^m. Following Woodford (1998, 2001), the latter asset has payment structure $\rho^{T-(t+1)}$ for $T > t$ and $0 \leq \rho \leq 1$. The value of such an instrument issued in period t in any future period $t+j$ is $P_{t+j}^{m,-j} = \rho^j P_{t+j}^m$. The asset can be interpreted as a portfolio of infinitely many bonds, with weights along the maturity structure given by $\rho^{T-(t+1)}$. Varying the parameter ρ varies the average maturity of the asset.[5] For example, when $\rho = 0$ the portfolio comprises one-period debt; and when $\rho = 1$ the portfolio comprises console bonds.

Define P_t as the price level at period t. Letting $b_t^s(i) \equiv B_t^s(i)/P_t$ and $b_t^m(i) \equiv B_t^m(i)/P_t$, household i's real wealth is defined by $\mathbb{W}_t(i) \equiv P_t^s b_t^s(i) + P_t^m b_t^m(i)$. The budget constraint is given by

$$\mathbb{W}_t(i) \leq R_t^m \pi_t^{-1} \mathbb{W}_{t-1}(i) + \left(R_{t-1}^s - R_t^m\right) \pi_t^{-1} P_{t-1}^s b_{t-1}^s(i) + y_t(i) - \tau_t(i) - C_t(i) \tag{2}$$

where $R_t^m = (1 + \rho P_t^m)/P_{t-1}^m$ and $R_{t-1}^s = 1/P_{t-1}^s$ denote realized returns from holding each asset, with the latter implicitly defining the period nominal interest rate, the instrument of central bank policy. Each period households receive a stochastic endowment, $y_t(i)$, assumed for simplicity to be an i.i.d. random variable, and pay lump-sum taxes $\tau_t(i)$. In addition agents face a no-Ponzi constraint of the form

$$\lim_{T\to\infty} \hat{E}_t^i \left(\prod_{s=0}^{T-t} R_{t+s}^m \pi_{t+s}^{-1} \right)^{-1} \mathbb{W}_T(i) \geq 0 \tag{3}$$

where $\pi_t = P_t/P_{t-1}$.

[5] An elegant feature of this structure is that it permits discussion of debt maturity with the addition of a single state variable.

To summarize, households choose sequences $\{C_T(i), \mathbb{W}_T(i), b^s_T(i)\}_{T=t}^{\infty}$ to maximize utility, (1), subject to (2) and (3), given initial wealth $\mathbb{W}_{t-1}(i)$ and their beliefs regarding the evolution of the endowment, taxes and asset returns. Conditional on beliefs, optimality requires (2) and (3) hold with equality and satisfaction of

$$C_t^{-\sigma}(i) = \hat{E}_t^i \left[R_t^s \frac{C_{t+1}^{-\sigma}(i)}{\pi_{t+1}} \right]; \; C_t^{-\sigma}(i) = \hat{E}_t^i \left[R_{t+1}^m \frac{C_{t+1}^{-\sigma}(i)}{\pi_{t+1}} \right]$$

the Euler equations corresponding to the two assets.

2.2 Monetary and fiscal policy

The central bank implements monetary policy according to the family of interest-rate rules

$$R_t^s = R^s \pi_t^{\phi_\pi} \tag{4}$$

where $\phi_\pi \geq 0$ and R^s the steady-state gross interest rate. The steady-state inflation rate is assumed to be zero. The fiscal authority finances exogenously determined government purchases, G_t, assumed here to be zero in each period, by issuing public debt and levying lump-sum taxes. One-period debt, B_t^s, is in zero supply, while $B_t^m > 0$ in all periods t. Imposing the restriction that one-period debt is in zero supply, the real flow budget constraint of the government is given by

$$P_t^m b_t^m = \pi_t^{-1} b_{t-1}^m (1 + \rho P_t^m) - \tau_t, \tag{5}$$

where it is assumed that each agent faces the same tax burden, $\tau_t(i) = \tau_t$ for $i \in [0, 1]$.[6] Tax policy is determined by a rule of the form

$$\tau_t = \tau + \phi_b P^m \left(b_{t-1}^m - b^m \right) + \bar{\tau}_t, \tag{6}$$

where $\phi_b \geq 0$ and τ and $P^m b^m$ denote the steady-state level of taxes and debt. Taxes respond to changes in the real amount (at face value) of issued debt and an i.i.d. exogenous shock $\bar{\tau}_t$.[7]

2.3 Market clearing and equilibrium

The analysis considers a symmetric equilibrium in which all households are identical, though they do not know this to be true. Given that households have identical initial asset holdings, preferences, endowment, taxes and beliefs, and face common constraints, they make identical state-contingent decisions. Equilibrium requires all goods and asset markets to clear. The former requires the aggregate restriction

$$\int_0^1 C_t(i)\, di = C_t = \int_0^1 y_t(i)\, di \tag{7}$$

[6] Generalizing to permit heterogeneity in tax obligations, where these obligations remain in fixed proportion, delivers identical results.

[7] The results do not change if taxes respond instead to the changing value of nominal debt.

where C_t denotes aggregate consumption demand. The latter requires

$$\int_0^1 B_t^s(i)\,di = 0 \text{ and } \int_0^1 B_t^m(i)\,di = B_t^m \tag{8}$$

with $B_{-1}^s(i) = 0$ and $B_{-1}^m(i) = B_{-1}^m > 0$ for all households $i \in [0,1]$. Equilibrium is then a sequence of prices $\{P_t, P_t^m, R_t^s\}$ and allocations $\{C_t(i), B_t^m(i), \tau_t\}$ satisfying individual optimality and market clearing conditions, given $y_t(i)$ for $i \in [0,1]$.

The policy regime. Focus is given to a policy regime where monetary policy is 'active', satisfying the Taylor principle $\phi_\pi > 1$, and fiscal policy is 'passive', $\beta^{-1} - 1 < \phi_b < \beta^{-1} + 1$. Under the assumption of rational expectations, this policy regime implies a locally unique bounded equilibrium in which the evolution of nominal liabilities have no monetary consequences; the size and duration of public debt do not affect inflation — see Leeper (1991).

Globally, the policy regime displays multiple equilibria under rational expectations. These equilibria, including deflationary traps and explosive equilibria, are well understood and have been discussed extensively in the New Keynesian literature.[8] Our analysis is restricted to the neighborhood of the locally unique equilibrium under rational expectations with zero inflation. Introducing incomplete knowledge and learning is shown to dramatically change the properties of this 'good' equilibrium. Studying the global properties of the model is left to future research.

3 Aggregate Dynamics

Employ a first-order approximation in the neighborhood of the non-stochastic steady state of zero inflation. For any variable k_t denote $\hat{k}_t = \ln(k_t/k)$ the log deviation from steady state with the exception of the short-term interest rate, $\hat{\imath}_t = \ln(R_t^s/R^s)$, and debt and taxes defined as

$$\tilde{b}_t^m = \frac{P^m(b_t^m - b^m)}{y} \text{ and } \tilde{\tau}_t = \frac{\tau_t - \tau}{y}.$$

Optimal consumption decision. Household optimization yields the demand function

$$\begin{aligned}\hat{C}_t \;&=\; (1-\beta)\,\hat{y}_t - \sigma^{-1}\beta\hat{E}_t\sum_{T=t}^{\infty}\beta^{T-t}\left(\hat{\imath}_T - \hat{\pi}_{T+1}\right) + \\ &\quad + \left(\beta^{-1}-1\right)\times\left\{\left(\tilde{b}_{t-1}^m - \delta\hat{\pi}_t + \delta\beta\rho\hat{P}_t^m\right) + \beta\hat{E}_t\sum_{T=t}^{\infty}\beta^{T-t}\left[\delta\left(\hat{R}_{T+1}^m - \hat{\pi}_{T+1}\right) - \tilde{\tau}_T\right]\right\}\end{aligned} \tag{9}$$

where σ^{-1} denotes the consumption intertemporal elasticity of substitution, and $\delta = P^m b^m/y$ measures the steady-state debt-to-output ratio. As we analyze a symmetric equilibrium in which households have identical decision problems and beliefs, so $\hat{E}_t = \hat{E}_t^i$ for every $i \in [0,1]$, drop the index i.

Net of the endowment, consumption demand is determined by the expected path of the real interest rate (top line) and by a constant fraction of perceived net wealth from holding

[8] See for example Benhabib, Schmitt-Grohe, and Uribe (2001), Woodford (2003) and Cochrane (2011).

bonds (bottom line). The first term represents the standard transmission mechanism of monetary policy in a Ricardian economy, which operates through the intertemporal substitution of consumption. The second term introduces a new channel of policy, and is referred to as the 'non-Ricardian', or 'net wealth', component of consumption demand. It comprises three parts: the real market value of debt holdings, the present value of real returns from holding debt (purchased in the current period), and the expected present value of lump-sum taxes. In a rational expectations equilibrium these terms sum precisely to zero. Under imperfect knowledge, subjective expectations of returns and taxes may imply the public debt is perceived as net wealth, even in the absence of distortionary taxation. Model dynamics depend on the relative strength of the standard and non-Ricardian components of demand, referred to loosely as 'substitution' and 'wealth' effects. We show the relative importance of these sources of demand are regulated by the intertemporal elasticity of consumption, σ^{-1}, the debt-to-output ratio, δ, and the average duration of debt measured by ρ.

Worth emphasizing is that departures from Ricardian equivalence are quite plausible in a heterogeneous agent economy. Only when agents know they are the representative agent would they conclude the government budget constraint implies the present discounted value of their individual taxes equals the value of their individual bond holdings. Indeed, a central result of Evans, Honkapohja, and Mitra (2012) — which provides a detailed discussion of the conditions under which Ricardian equivalence will hold under non-rational beliefs — is Ricardian equivalence will obtain if agents' beliefs are such that the present value of their individual taxes equals the value of their individual bond holdings. Under our information assumptions, there is no reason this need be true.

Asset pricing. A log-linear approximation to the first-order conditions for asset holdings yields the no-arbitrage restriction

$$\hat{\imath}_t = \hat{E}_t \hat{R}^m_{t+1}$$

and determines the price of the bond portfolio as

$$\hat{P}^m_t = -\hat{E}_t \sum_{T=t}^{\infty} (\beta\rho)^{T-t} \hat{\imath}_T. \tag{10}$$

The multiple-maturity debt portfolio is priced as the expected present discounted value of all future one-period interest rates, where the discount factor is given by $\beta\rho$, an example of the expectations hypothesis of the yield curve. The average duration of the portfolio is given by $(1-\beta\rho)^{-1}$. The assumption of symmetric beliefs ensures this relation is consistent with the existence of a unique equilibrium bond price. This paper abstracts from asset pricing issues arising from financial market participants having heterogeneous non-nested information sets, as implied by our information assumptions. For simplicity it is assumed that each agent supposes they are the marginal trader in all future periods when determining desired asset allocations. Equilibrium affirms this supposition as all agents are identical.[9]

[9]How to handle asset pricing in incomplete markets setting with subjective beliefs requires further study. There are two sources of complication. First, with multiple assets, projected returns under arbitrary subjective beliefs may not satisfy no-arbitrage. In a first-order approximation, such beliefs are inconsistent with bounded portfolio decisions. We therefore follow Sinha (2016) and impose no-arbitrage consistent beliefs by using the price relation (10). Second, the fact that this model is technically one in which agents have heterogeneous information sets, raises questions about asset price determination and, specifically, which agent

Government debt. Combining a linear approximation to the government budget constraint, (5), the tax rule, (6) and the bond price, (10), yields

$$\tilde{b}_t^m = \left(\beta^{-1} - \phi_b\right) \tilde{b}_{t-1}^m - \bar{\tau}_t - \delta \left[\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right) \pi_t - (1-\rho)\,\rho\beta \hat{E}_t \sum_{T=t}^{\infty} (\beta\rho)^{T-t}\, \hat{\imath}_{T+1} \right] \quad (11)$$

where fiscal policy satisfies $|\beta^{-1} - \phi_b| < 1$. In equilibrium the evolution of debt depends on expectations about the future path of monetary policy. The degree to which policy expectations affect the evolution of debt, equivalently taxes, depends both on the size of debt, δ, and on its average duration, ρ. For very low and very long-debt maturities these effects are small, and vanish in the case of one-period debt, $\rho = 0$, and console bonds, $\rho = 1$. At low levels of duration, the bond price only reflects changes in the short-term interest rate. At very high levels of duration, changes in policy expectation are fully reflected in the price of debt, with little effect on debt issuance and taxes.[10] In contrast, for intermediate values of duration, changes in policy expectations are reflected both in the price and quantity of debt.

4 Information, Learning and non-Ricardian Effects

4.1 Beliefs

Specifying beliefs completes the model. Households have incomplete knowledge about the true structure of the economy. They observe only their own objectives, constraints and realizations of aggregate variables as well as prices that are exogenous to their decision problems and beyond their control. They have no knowledge of the beliefs, constraints and objectives of other agents in the economy: even though their decision problems are identical, they do not know this to be true. The fact that agents have no knowledge of other agents' preferences and beliefs, and have imperfect knowledge about the prevailing policy regime, implies that they do not know the equilibrium evolution of inflation, debt and taxes.

Rational Expectations equilibrium. To anchor ideas, the model has a unique bounded rational expectations equilibrium of the form

$$\pi_t = -\sigma\phi_\pi^{-1}\hat{y}_t \quad (12)$$

and

$$\tilde{b}_t^m = \left(\beta^{-1} - \phi_b\right) \tilde{b}_{t-1}^m + \delta \left(\beta^{-1} - (1-\rho)\,\phi_\pi\right) \sigma\phi_\pi^{-1}\hat{y}_t - \bar{\tau}_t. \quad (13)$$

Inflation is a linear function of the endowment process and independent of fiscal variables. The equilibrium is Ricardian — debt has no monetary consequences.

Learning about long-term drifts. To learn about equilibrium dynamics, agents employ a simple linear econometric model in the variables $z_t = \begin{pmatrix} \hat{\pi}_t & \tilde{b}_t^m & \tilde{\tau}_t \end{pmatrix}'$. For expositional

is the marginal trader of the asset. Again, we do not solve this complicated issue, and simply assume each agent supposes they are the marginal trader, which is true in equilibrium. Progress on this second issue has been made by Adam and Marcet (2011), who show how to determine equity prices in an incomplete markets model with short-sale constraints, and subjective beliefs of the kind studied here.

[10] As the average duration of the government debt portfolio increases, the quantity of newly issued debt in any period declines. In the limit of consol debt, the price effect therefore vanishes.

purposes, we assume agents understand the monetary policy rule so they need not forecast the interest rate independently of inflation. The results do not depend on this assumption, which we later drop in the empirical analysis. The forecasting model is

$$z_t = \omega_{t-1} + \Phi z_{t-1} + e_t \tag{14}$$

where e_t is a noise term. The model nests the minimum-state-variable rational expectations solution which satisfies

$$\omega^* = \mathbf{0}_{3\times 1};\ \Phi^* = \begin{bmatrix} 0 & 0 & 0 \\ 0 & \beta^{-1} - \phi_b & 0 \\ 0 & \phi_b & 0 \end{bmatrix}.$$

We assume agents only face uncertainty about long-run conditional means, as captured by ω_{t-1}, with beliefs about time-varying slope coefficients satisfying $\Phi = \Phi^*$. This assumption places emphasis on the role of imperfect knowledge about long-run policy objectives, such as the inflation target or tax obligations attached to government debt holdings. The advantage of belief structures of this kind is they permit use of standard linear methods, which is particularly valuable for subsequent analytical and empirical work, while giving a non-trivial role to shifting long-term expectations as a source of dynamics. Importantly, such beliefs have been shown to be consistent with defining properties of survey forecast data from households and professional forecasters which exhibit low-frequency drift — see, for example, Kozicki and Tinsley (2012) and Crump, Eusepi, and Moench (2015). And Eusepi and Preston (2011) adduce evidence that, for learning models solved under the anticipated utility assumption, the quantitatively relevant "self-referential dynamics" are generated by incomplete information about constants, not learning about slope coefficients.

Expectations and recursive estimation. In period t agents form expectations using the forecasting model based on data available up to period $t-1$.[11] Denoting period-t beliefs $\hat{\omega}_{t-1} = \begin{pmatrix} \hat{\omega}^{\pi}_{t-1} & \hat{\omega}^{b}_{t-1} & \hat{\omega}^{t}_{t-1} \end{pmatrix}$, agents use (14) to evaluate expectations for taxes and inflation to provide[12]

$$\hat{E}_t \sum_{T=t+1}^{\infty} \beta^{T-t} \tilde{\tau}_{T+1} = \frac{1}{1-\beta} \left(\hat{\omega}^{\tau}_{t-1} + \hat{\omega}^{b}_{t-1} \right) + \beta^{-1} \tilde{b}^m_t \tag{15}$$

$$\hat{E}_t \sum_{T=t}^{\infty} \left(\beta \rho^{j-1} \right)^{T-t} \hat{\pi}_{T+1} = \frac{1}{1-\beta\rho^{j-1}} \hat{\omega}^{\pi}_{t-1},\ j = 1, 2. \tag{16}$$

Time$-t$ estimates, $\hat{\omega}_t$, are updated using the recursive algorithm

$$\hat{\omega}_t = \hat{\omega}_{t-1} + g_t \eta_t \tag{17}$$

where

$$\eta_t = z_t - (\hat{\omega}_{t-1} + \Phi^* z_{t-1})$$

[11] To avoid a difficult simultaneity problem, agents use previous-period estimates when forming current forecasts. This is standard in the learning literature. Beliefs are a state variable.

[12] Recall, forecasts of the interest rate are constructed using the monetary policy rule, so $\hat{E}_t \hat{\imath}_T = \phi_\pi \hat{E}_t \pi_T$ for $T > t$.

is the prediction error.[13]

Beliefs of this kind embody a defining property of all signal-extraction and filtering problems: perceived drifts in macroeconomic data (i.e. long-term conditional expectations) are tied to short-term forecast errors. Observing short-term fluctuations, agents attempt to infer low-frequency movements in aggregate data. The sensitivity of the estimated drift to short-term surprises is governed by the gain parameter g_t. When $g_t = t^{-1}$ the updating rule, (17), is recursive least squares. When $g_t = \bar{g}$ the recursive updating is given by a constant-gain algorithm, implying that past observations are discounted more heavily. An observation n periods old receives a weight of $(1-\bar{g})^n$. A constant $\bar{g}$ insures against potential shifts in the structure of the economy (i.e. a policy regime shift). This case can be interpreted as a steady-state Kalman filter in which the prior on the variance of innovations, e_t, in (14), is proportional to the prior on the variance of low-frequency drift.[14] The analysis employs both gain assumptions for reasons explicated in the next section. Learning algorithms of the form (17) have been widely used in the literature on learning and imperfect information and are a convenient and elegant way to capture imperfect knowledge about policy — see Orphanides and Williams (2005), Eusepi and Preston (2010, 2012) and Kozicki and Tinsley (2012).

4.2 Self-Referential dynamics and wealth effects

The data-generating process implicitly defines a mapping between subjective beliefs, $\hat{\omega}_{t-1}$, and the actual drift describing observed dynamics. Substituting the forecasts, (15) and (16), into the consumption and debt equations, (9) and (11), and imposing market clearing in the goods market, $C_t = y_t$, gives the true data-generating process

$$\hat{\pi}_t = -\frac{\beta - \phi_\pi^{-1}}{1-\beta}\hat{\omega}^\pi_{t-1} - \sigma\phi_\pi^{-1}\hat{y}_t + n_{w,t}. \tag{18}$$

The first term captures the only channel through which inflation beliefs affect inflation in a Ricardian economy: intertemporal substitution of consumption. The second term, $n_{w,t}$, measures the perceived net wealth effects from holding bonds which satisfies

$$n_{w,t} = \sigma\left(\beta^{-1}-1\right)\delta \times \left[\frac{\beta - \phi_\pi^{-1}}{1-\beta} - \frac{(1-\rho)\,\beta\rho}{1-\beta\rho} - \frac{\beta\rho^2}{1-\beta\rho}\right]\hat{\omega}^\pi_{t-1} - \sigma\phi_\pi^{-1}\left(\hat{\omega}^b_{t-1} + \hat{\omega}^\tau_{t-1}\right), \tag{19}$$

revealing that shifting views about long-term inflation, debt and tax obligations can in principle lead to movements in perceived net wealth. Debt is described by

$$\tilde{b}^m_t = \left(\beta^{-1} - \phi_b\right)\tilde{b}^m_{t-1} - \delta \times \left[\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\pi_t - \frac{(1-\rho)\,\beta\rho}{1-\beta\rho}\phi_\pi\hat{\omega}^\pi_{t-1}\right] - \bar{\tau}_t \tag{20}$$

[13] Formally, this belief structure combined with the optimal decision rules provides the anticipated utility solution of the model. For a detailed discussion of how this solution concept relates to the internal rationality approach of Adam and Marcet (2011) the reader is referred to Eusepi and Preston (2016). For present purposes it suffices to note that the anticipated utility approach assumes agents do not take into account future revisions of beliefs when making current decisions but are otherwise fully optimal, whereas the internal rationality approach considers Bayesian beliefs which take account of such revisions.

[14] See Sargent, Williams, and Zha (2006) and Eusepi, Giannoni, and Preston (2015) for discussion, and examples of more general specifications of Kalman gain matrices.

so that only shifting inflation expectations, through the price of long-term debt, affect debt dynamics.

Equations (18) and (20), along with the updating rule for beliefs, (17), completely characterize equilibrium. Together they clarify the self-referential dynamics of inflation and debt. Beliefs affect the actual evolution of inflation, debt and taxes, which in turn are used to update beliefs. As a result, beliefs become partially *self-fulfilling*: the true data-generating process displays a time-varying drift. We are interested in evaluating under what conditions such self-referential dynamics produce fluctuations in perceived net wealth $n_{w,t}$ and how this impacts the economy. Anticipating subsequent results, drifting beliefs induce revaluation of the government debt which engender deviations from Ricardian equivalence. What follows explores various dimensions of this model property. While results are derived in the simple endowment economy, they provide indispensable intuition for the richer empirical model.

Drifts are driven by short-term forecast errors. These, in turn, are driven by the history of shocks, the endowment and tax disturbances $\hat{y}_t$ and $\bar{\tau}_t$. To study the dynamic properties of the model we can therefore characterize, without loss of generality, the evolution of both beliefs and realized outcomes assuming the system starts at rational expectations.[15] The first result establishes tax innovations do not generate non-Ricardian consumption demand effects. They satisfy Ricardian Equivalence.

Result 1. *Tax shocks $\bar{\tau}_t$ do not induce any perceived wealth effects: conditional on tax shocks only, $\hat{\pi}_t = n_{w,t} = 0$ in every period.*

Proof. Assume $\hat{\omega}^{\pi}_{t-1} = \hat{\omega}^{\tau}_{t-1} = \hat{\omega}^{b}_{t-1} = 0$. From (18) and (19) the tax shock has no immediate impact on inflation, $\hat{\pi}_t = 0$. From the updating rule (17), debt and tax beliefs are given by $\hat{\omega}^{\tau}_t = g_t\bar{\tau}_t$ and $\hat{\omega}^{b}_t = -g_t\bar{\tau}_t$, so that $\hat{\omega}^{b}_t = -\hat{\omega}^{\tau}_t$. Moreover, as $\hat{\pi}_t = 0$, $\omega^{\pi}_t = 0$. This implies $n_{w,t+1} = 0$ and $\hat{\pi}_{t+1} = 0$. It then follows from (17) in all subsequent periods $T \geq t+1$, $\hat{\omega}^{\pi}_T = 0$ and $\hat{\omega}^{b}_T = -\hat{\omega}^{\tau}_T$ and, therefore, $n_{w,T} = 0$ and $\hat{\pi}_T = 0$.

This result depends on specific model assumptions, such as the belief structure and class of tax rules. Richer specifications of beliefs in which long-run conditional expectations display more general dependency on short-run forecast errors (such as different gains attached to forecast revisions of each variable), or a tax rule that responds to expected macroeconomic developments, would predict departures from Ricardian equivalence. However, given our assumptions are conventional in the literature, the paper instead gives focus to the fiscal effects of other disturbances driving macroeconomic dynamics. Given **Result 1**, the remainder of this section assumes $\bar{\tau}_t = \hat{\omega}^{\tau}_t = 0$ without loss of generality.[16] We now identify which properties of debt are consistent with positive wealth effects on consumption demand, and therefore self-referential dynamics.

Result 2. *Consider the simple endowment economy driven by shocks $\hat{y}_t$. Then: i) with $\delta = 0$ or $\rho = 0, 1$ perceived wealth effects are exactly zero, $n_{w,t} = 0$, in every period; and ii) with $\delta > 0$ and $\rho \in (0, 1)$ an inflation surprise at time t (resulting from variations in $\hat{y}_t$), implies*

$$n_{w,t+1} = \frac{\beta\rho(1-\rho)}{1-\beta\rho}\sigma\delta \times \hat{\omega}^{\pi}_t, \tag{21}$$

[15] Assuming arbitrary initial beliefs induces some additional temporary dynamic behavior.

[16] Tax beliefs only move in response to tax disturbances, which themselves satisfy Ricardian equivalence.

generating self-referential beliefs.

Proof. Again assume $\omega^{\pi}_{t-1} = \omega^{\tau}_{t-1} = \omega^{b}_{t-1} = 0$. Start with a zero debt economy, $\delta = 0$. The true data generating process for debt is

$$\tilde{b}^m_T = \left(\beta^{-1} - \phi_b\right) \tilde{b}^m_{T-1} \text{ for } T \geq t.$$

From the updating rule, (17), and the expression for net wealth, (19), $\hat{\omega}^b_T = n_{w,T} = 0$ for $T \geq t$. Consider now the average duration of debt. For $\rho = 0, 1$ from (20) we have

$$\tilde{b}^m_T = \left(\beta^{-1} - \phi_b\right) \tilde{b}^m_{T-1} - \delta \left(\beta^{-1} - (1-\rho)\,\phi_\pi\right) \hat{\pi}_T \text{ for } T \geq t.$$

From the updating rule (17), $\omega^b_T = -\delta\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\omega^{\pi}_T$ for $T \geq t$. Substituting this restriction in (18) for $\rho = 0, 1$ yields $n_{w,T} = 0$ for $T \geq t$. Finally, consider $\delta > 0$ and $\rho \in (0, 1)$. From the updating rule (17) a surprise in inflation leads to $\omega^b_t = -\delta\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\omega^{\pi}_t$. Substituting into (18) and (19) gives

$$\begin{aligned} n_{w,t+1} &= \frac{\beta\rho(1-\rho)}{1-\beta\rho}\sigma\delta\hat{\omega}^{\pi}_t; \;\; \hat{\pi}_{t+1} = -\left[\frac{\beta - \phi_\pi^{-1}}{1-\beta} - \frac{\beta\rho(1-\rho)}{1-\beta\rho}\sigma\delta\right]\hat{\omega}^{\pi}_t, \\ \tilde{b}^m_{t+1} &= \left(\beta^{-1} - \phi_b\right)\tilde{b}^m_t - \delta \times \left[\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\hat{\pi}_{t+1} - \frac{(1-\rho)\,\beta\rho}{1-\beta\rho}\phi_\pi\hat{\omega}^{\pi}_t\right]. \end{aligned}$$

This leads to a revision in both inflation and debt beliefs in period $t+2$, in turn affecting actual variables and future beliefs.

Observe that the term (21) captures the effects on net wealth of all expectation terms in the asset pricing relation (10), movements in which determine the market value of debt holdings in the consumption demand equation (9). Only when these shifting interest-rate expectations are relevant do movements in net wealth generate self-fulfilling dynamics, and demand effects. Because these effects operate through the price of newly issued debt, we refer to them as valuation effects. Economies with zero debt on average, or only one-period or consol debt, do not display movements in perceived net wealth. And in absence of revaluation effects of the public debt which generate movements in net wealth, debt evolves independently of inflation beliefs, which prevents self-fulfilling tax expectations. This happens despite debt and inflation beliefs being revised in response to a shock, because changes in the present discounted value of taxes are exactly matched by changes in the real value of debt and its expected returns, leaving net wealth unchanged. With positive debt and intermediate maturity structures $\rho \in (0, 1)$, shifts in expected interest rates affect debt issuance and tax expectations which, in turn, impact consumption demand and inflation. Expectations become then partially self-fulfilling, with important implications for economic stability and, in particular, the conduct of monetary policy.[17]

Following Marcet and Sargent (1989) and Evans and Honkapohja (2001), the limiting behavior of beliefs are described by an ordinary differential equation, reflecting the mapping

[17]Note for one-period debt, $\rho = 0$, the monetary policy rule is critical to the finding of no wealth effects. Policy rules that respond to inflation expectations generate revised beliefs which feed back into debt dynamics, breaking Ricardian equivalence. The appendix contains further discussion.

between the perceived drift $\hat{\omega}_t$ in (14) and the actual drift as described in the true data-generating process. This can be obtained by substituting (18) and (20) in the updating rule (17) for debt and inflation drifts. The learning literature refers to the implied dynamics as the 'mean dynamics'. In compact terms, the ODE is

$$\begin{bmatrix} \dot{\hat{\omega}}^{\pi} \\ \dot{\hat{\omega}}^{b} \end{bmatrix} = (T - I) \begin{bmatrix} \hat{\omega}^{\pi} \\ \hat{\omega}^{b} \end{bmatrix} \tag{22}$$

where the coefficients on beliefs in (18) and (20) determine the respective elements the matrix T.[18] The fixed point of (22) is the rational expectations equilibrium $\omega^* = 0$. The self-referential behavior of the economy depends on the interaction between the perceived drift and the realized drift. This in turn depends on the properties of the matrix T.

Two kinds of stability result can be established. If the fixed point of the ODE is stable, implying all eigenvalues have negative real parts, then: 1) for decreasing gain algorithms, $g_t = t^{-1}$, as $g_t \to 0$ beliefs $\hat{\omega}_t$ converge point-wise to rational expectations equilibrium ω^*. Such convergence is called expectational stability; and 2) for constant-gain algorithms, $g_t = \bar{g}$, and $\bar{g}$ sufficiently small, $\hat{\omega}_t$ converges to a limiting distribution centered on ω^* — see Evans and Honkapohja (2001). The first stability result is exploited to understand the interactions of monetary and fiscal policy, and the constraints placed by long-term debt on inflation control. The second stability result, premised on the first, is then exploited to explore model dynamics and the empirical relevance of our theory. Worth underscoring is that the conditions derived for expectational stability apply to a broad range of adaptive learning algorithms, of which least-squares learning is but one example. In this sense the results are quite general — see, for example, Evans and Honkapohja (2001). The following proposition summarizes the main theoretical result.

Proposition 1. *Consider the policy regime defined by: $\phi_\pi > 1$; $\beta^{-1} - 1 < \phi_b < \beta^{-1} + 1$. Then: i) Under rational expectations, neither δ nor ρ affect inflation; and ii) under learning, provided $\delta > 0$ and $\rho \neq 0, 1$ convergence to rational expectations occurs if and only if*

$$\phi_\pi > \max \left[1, \left(1 + (1 - \beta) \left(1 - \sigma \times \delta \frac{(1 - \rho)\, \rho\beta}{1 - \rho\beta} \right) \right)^{-1} \right]$$

Corollary 1. *Under learning, with $\delta = 0$ or $\rho = 0, 1$ convergence to rational expectations always occurs.*

For a given average maturity of debt, higher average levels of indebtedness require more aggressive monetary policy. For a given scale of public debt, variation in the average maturity of public debt engenders non-monotonic constraints on monetary policy. Importantly, expectation dynamics are determined by the relative strength of substitution and wealth effects arising from debt revaluation. When wealth effects are weak, the Taylor principle, $\phi_\pi > 1$, is necessary and sufficient to promote stability, as shown by Bullard and Mitra (2002) and

[18] Details are available in the appendix.

Preston (2005). Suppose a positive inflation surprise leads to an upward revision in the inflation drift. Policy responds by increasing the real interest rate, which depresses consumption demand and inflation and therefore induces downward updates in the drift towards rational expectations. However, sufficiently strong wealth effects impair this process. Higher inflation reduces real debt on impact and leads to a downward revision in long-term debt and tax expectations, leading to net positive wealth effects from holding bonds.[19] Higher consumption demand hinders the downward adjustment of inflation expectations. And as shown in Proposition 1, if wealth effects are sufficiently large there is no convergence.

5 Fiscal Policy and Inflation: Quantitative Evaluation

The idea that more heavily indebted economies constrain monetary policy certainly resonates with public pronouncements of policy makers. But less clear is whether the mechanisms identified by the endowment economy analysis are quantitatively relevant. This section provides an assessment in the context of an empirical medium-scale dynamic stochastic general equilibrium model of the US economy. A core goal of the empirical model is to identify how macroeconomic disturbances drive various objects that are central to the proposed mechanism. Specifically, we want to identify the determinants of movements in perceived wealth and their consequences for aggregate demand. Perceived wealth effects arise from shifting assessments of the value of debt holdings and present discounted value of taxes, which in turn are determined by the mapping of short-run forecast errors into long-run conditional expectations. A comprehensive understanding of the mechanism therefore requires an integrated treatment of how disturbances affects beliefs, perceived wealth effects, and ultimately aggregate demand.

For this reason the empirical model seeks to account for the joint dynamics of both standard macroeconomic time series and also survey data on expectations. The sample period spans both the Great Inflation of the 1970s and the Great Moderation of the 1980s and 1990s. The data from these periods exhibit substantial low-frequency movement in various macroeconomic time series, providing a direct assessment of the consistency of our theory with basic data facts. Our model permits understanding the source of low frequency movement in long-term expectations, and specifically the role of fiscal policy in unanchoring inflation expectations in the 1970s, and the subsequent decline in macroeconomic volatility during the Great Moderation. Furthermore, the model has implications for recent debate on the factors underlying the Great Moderation. Research emphasizes changes in the conduct of monetary policy or changes in the volatility of economic disturbances — often referred to as good policy versus good luck.[20] A notable feature of these analyses is the absence of fiscal variables: to what extent was the Great Moderation the result of good fiscal policy?

[19]The initial increase in net wealth in response to an inflation surprise in shown analytically in Result 2. The appendix also provides plots of the model's impulse response functions.

[20]Important contributions include, inter alia, Clarida, Gali, and Gertler (2000), Lubik and Schorfheide (2004), Sims and Zha (2006), Primiceri (2005), Justiniano and Primiceri (2008) and Fernandez-Villaverde, Guerron-Quintana, and Rubio-Ramirez (2010).

5.1 A Medium-Scale Model

The model is New Keynesian, similar in spirit to Giannoni and Woodford (2004), extended to include multiple-maturity debt. The appendix provides model details.

Firms. There is a continuum of monopolistically competitive firms. Each differentiated good, $Y_t(f)$, is produced according to the linear production function in labor, $N_t(f)$,

$$Y_t(f) = Z_t N_t(f) e^{A_t} \tag{23}$$

where Z_t denotes labor-augmenting technical progress, which evolves deterministically as $Z_t = \gamma Z_{t-1}$, with $\gamma > 1$, and e^{A_t} denotes a zero-mean stationary technology shock with an i.i.d. error term: $A_t = \rho_a A_{t-1} + \sigma_a \epsilon_t^a$.[21] Each firm faces a demand curve as in Kimball (1995)

$$\Psi' \left(\frac{Y_t(f)}{Y_t}; \theta_{p,t} \right) = \Psi'(1) \frac{P_t(f)}{P_t}$$

where $\Psi(\cdot)$ is a concave function with $\Psi(1) = 1$; $\ln(\theta_{p,t}/\theta_p) = \sigma_{\theta_p} \epsilon_t^{\theta_p}$ denotes a mean-zero i.i.d markup shock; P_t the aggregate price index.[22] Equilibrium in the goods market yields $Y_t = C_t + G_t$ where Y_t is aggregate output, C_t is the consumption aggregator and G_t denotes an exogenous government spending shock defined as: $\hat{G}_t = \ln(G_t/G) = \rho_G \hat{G}_{t-1} + \sigma_g \epsilon_t^G + \sigma_{ga} \sigma_a \epsilon_t^a$. The dependence of the spending shock on technology follows Smets and Wouters (2007), and is mainly motivated by empirical fit. Firms solve a Rotemberg-style price-setting problem, choosing a price $P_t(f)$ to maximize the expected discounted value of profits[23]

$$\hat{E}_t^f \sum_{T=t}^{\infty} Q_{t,T} \Gamma_T(f)$$

taking wages, W_t, the aggregate price level and technology as given, with profits defined by

$$\Gamma_t(f) = \frac{P_t(f)}{P_t} Y_t - \frac{W_t}{P_t} N_t(f) - \frac{\Phi_t^p}{2} \left(\frac{P_t(f)}{P_{t-1}(f)} - \bar{\Pi}_t^p \right)^2 \tag{24}$$

and

$$\Phi_t^p = \phi_p C_t; \;\; \bar{\Pi}_t^p = \pi^{1-\iota_p} \pi_{t-1}^{\iota_p}.$$

These final terms ensure adjustment costs are appropriately scaled to the consumption aggregator, given technological progress, and apply only to price movements relative to a price index, which is a weighted combination of the previous-period's and steady-state inflation, with parameters satisfying $\phi_p > 0$ and $0 < \iota_p < 1$. It is assumed that firms value future profits according to the marginal rate of substitution evaluated at aggregate consumption

$$Q_{t,T} = \beta^{T-t} \frac{P_t}{P_T} \frac{\Lambda_T}{\Lambda_t}$$

[21]We normalize all i.i.d disturbances ϵ_t^i to have mean zero and unit variance.

[22]The assumed demand function captures real rigidities affecting the firm pricing decision.

[23]Because we consider a first-order approximation to equilibrium dynamics, this is equivalent to assuming Calvo pricing.

for $T \geq t$, where Λ_t is the marginal value of wealth determined in the household's problem.[24]

Households. A continuum of households i, maximize intertemporal utility

$$\hat{E}_t^i \sum_{T=t}^{\infty} \beta^{T-t} \frac{c_{H,T}(i)^{1-\sigma} \nu \left(N_T(i)\right)}{1-\sigma}$$

where

$$C_{H,t} = \frac{C_t\left(i\right)}{Z_t} - b\frac{C_{t-1}}{Z_{t-1}}$$

with parametric restrictions $\sigma > 1$ and $0 < b < 1$, and where the function $\nu\left(\cdot\right)$ is convex with properties described in the appendix.[25] Households are assumed to have some market power in the supply of differentiated labour inputs, and face demand curve

$$N_t\left(i\right) = \left(\frac{W_t\left(i\right)}{W_t}\right)^{-\theta_{w,t}} N_t$$

where $\theta_{w,t} > 1$ denotes time-varying elasticity of demand across differentiated labor inputs, and evolves according to $\hat{\theta}_t^w = \ln\left(\theta_t^w/\theta^w\right) = \rho_{\theta_w}\hat{\theta}_{t-1}^w + \sigma_{\theta_w}\epsilon_t^{\theta_w}$. Households set their wage rate, subject to quadratic adjustment costs, and supply the quantity of hours demanded by firms at that price.

The household's flow budget constraint is

$$C_t\left(i\right) + \mathbb{W}_t(i) \leq R_t^m \pi_t^{-1} \mathbb{W}_{t-1}(i) + \left(R_{t-1}^s - R_t^m\right) P_{t-1}^s b_{t-1}^s(i) - \frac{\Phi_t^w}{2}\left(\frac{W_t\left(i\right)}{W_{t-1}\left(i\right)} - \bar{\Pi}_t^w\right)^2 + \Gamma_t - T_t$$

defining

$$\Phi_t^w = \phi_w C_t; \;\; \bar{\Pi}_t^w = \left(\pi\gamma\right)^{\iota_w}\left(\pi_{t-1}\gamma_{t-1}\right)^{1-\iota_w}$$

where $\phi_w > 0$ and $0 < \iota_w < 1$. The variables $\mathbb{W}_t(i)$, R_t^s, R_t^m, P_t^s, $b_t^s\left(i\right)$ and T_t are defined as in the endowment economy. Finally, Γ_t denotes profits received from an equal equity share of each differentiated firm. As for the price-setting problem, the adjustment costs attached to wages are scaled to be consistent with balanced growth, and to ensure newly set wages are consistent with recent goods price inflation and productivity growth.

Policy. The central bank implements monetary policy according to the family of interest-rate rules

$$R_t = \left(R_{t-1}\right)^{\rho_i}\left[R\left(P_t/P_{t-1}\right)^{\phi_\pi} X_t^{\phi_x}\right]^{1-\rho_i} e^{m_t} \tag{25}$$

where $\phi_\pi, \phi_x \geq 0$, R the steady-state gross interest rate, and X_t denotes the model-theoretic output gap.[26] Interest-rate policy exhibits inertia and responds to deviations of inflation and output from steady-state levels.[27] The steady-state inflation rate is assumed to be zero;

[24]Given that each agents make identical decisions, this corresponds to the stochastic discount factor of a hypothetical representative agent.

[25]We specify preferences in terms of detrended consumption so that the real return in steady state is not affected by the elasticity of intertemporal substitution of consumption.

[26]This is defined as the ratio between actual output the level of output that would occur under flexible wage and prices, under rational expectations.

[27]The analysis eschews the study of optimal policy to give emphasis to the interaction of monetary policy with various dimensions of fiscal policy. See Eusepi, Giannoni, and Preston (2015) for an analysis of optimal policy in a closely related model.

$m_t = \sigma_m \epsilon_t^m$ denotes a mean-zero i.i.d monetary shock. The flow budget constraint of the government is given by

$$P_t^m B_t^m = B_{t-1}^m \left(1 + \rho P_t^m\right) - P_t S_t \tag{26}$$

where the real structural surplus is

$$S_t = T_t / P_t - G_t. \tag{27}$$

The government levies lump-sum taxes, T_t, according to a rule of the form

$$\frac{T_t}{Z_t P_t} - \bar{\tau} = \rho_\tau \left(\frac{T_{t-1}}{Z_{t-1} P_{t-1}} - \bar{\tau} \right) + \left(1 - \rho_\tau\right) \phi_{\tau_l} \left(l_t - l\right) + \bar{\tau}_t \tag{28}$$

where $\bar{\tau}$ is the normalized steady state level of taxes, $l_t = B_{t-1}^m \left(1 + \rho P_t^m\right) / \left(Z_{t-1} P_{t-1}\right)$ a measure of real government liabilities in period t, with l its steady state value. The policy parameters satisfy $\phi_{\tau_l} \geq 0$ and $0 < \rho_\tau < 1$. Such rules are consistent with empirical work by Davig and Leeper (2006). Finally, the mean-zero tax shock evolves according to $\bar{\tau}_t = \rho_{\bar{\tau}} \bar{\tau}_{t-1} + \sigma_{\bar{\tau}} \epsilon_t^{\bar{\tau}}$.

5.2 Beliefs and Model Solution

As in the simple model, beliefs are specified as a linear econometric model of the form (14), which nests the first-order approximation of the stationary rational expectations equilibrium. The model includes all variables which households and firms have to forecast to make consumption, pricing and wage-setting decisions. These are: inflation, interest rates, taxes, dividends, wages, hours and the quantity of long-term debt. The only uncertainty about the statistical properties of these variables is the mean. As common in the learning literature, assume agents have perfect knowledge of the stationary exogenous shocks: perceived drifts for these variables are zero in every period. Drifts for the endogenous variables are updated according to the rule (17) using a constant gain.

Conditional on the specification of beliefs, we follow the expositional logic of the endowment economy and solve for optimal decisions under the anticipated utility approach — see Preston (2005) and Eusepi and Preston (2016) for discussion. As such the empirical model extends work taking structural models with imperfect knowledge to the data by Orphanides and Williams (2005), Milani (2007) and Slobydan and Wouters (2012a, 2012b) to a richer environment in which agents make optimal decisions. Details of the first-order approximation to the model, and the derivation of the anticipated-utility solution, are relegated to the appendix.

5.3 The Data and State-Space Representation

Model parameters are estimated using nine US time series as observables. Five standard macroeconomic variables are employed: the log-difference of the GDP deflator, the output gap (as measured by Congressional Budget Office), the three-month TBill interest rate, the real hourly compensation growth (measured from nonfarm business sector), and the tax revenue-to-GDP ratio as defined in Traum and Yang (2011).[28] Four additional times series on short- and long-term professional forecasts of the three-month TBill and GDP deflator growth are used to discipline beliefs. To measure short-term forecast we use the mean of the one-quarter-ahead forecasts from the Survey of Professional Forecasters; long-term expectations are measured by the mean of five-to-ten-years-ahead forecasts from Blue Chip Economics. These data permit direct inference on how short-run forecast errors are mapped into long-run beliefs.

The model is estimated over the period 1968Q4 to 2007Q3 using quarterly data.[29] The beginning of the sample coincides with the first available survey forecast of GDP deflator inflation. The end of the sample is chosen to exclude the period when the policy rate is at the zero lower bound period. Handling the modeling complications of the crisis period is beyond the scope of the paper. Short-term forecasts for the TBill are only available starting in 1981Q3, while long-term forecasts are available at bi-annual frequency starting in 1984Q1.

The first-order approximation of the structural equations combined with the specification of beliefs implies the model has a time-invariant linear state-space representation

$$\mathbb{Z}_t = F(\Theta)\,\mathbb{Z}_{t-1} + Q(\Theta)\,\epsilon_t$$

where Θ is a vector of the model parameters and $\mathbb{Z}_t$ is the state vector of the model variables, including the perceived drifts.[30] The measurement equation for the model is defined by

$$\mathbb{Y}_t = \mu_t(\Theta) + H_t(\Theta)\,\mathbb{Z}_t + o_t,$$

where o_t includes four measurement errors associated to the survey forecasts. The vector μ_t contains the long-run mean of the observables. The matrix H_t and vector μ_t are time varying because of missing observations. We estimate the model using Bayesian inference, routinely used to evaluate dynamic stochastic general equilibrium models under rational expectations.[31]

5.4 Parameter Estimates

Calibrated parameters. The long-run mean of inflation and the short-term interest rate in μ are set equal to 2% and 4%. This implies a short-term real interest rate of 2% over the sample, consistent with survey data, as shown by Crump, Eusepi, and Moench (2015). Implicit in this choice is the view that low-frequency movements in inflation, beginning in the late sixties and ending in the mid-nineties, is driven by beliefs. We assume the quarterly growth rate of technical progress to be $\gamma = 1.004$ consistent with the average real GDP per-capita growth over the sample. The household's discount factor is $\beta = 0.99$. Given

[28]In terms of the model, this measure of output gap is defined by detrended output: Y_t/Z_t. Tax revenues are defined as the sum of federal personal current tax, federal taxes on corporate income and federal contributions to social insurance. Together with GDP and inflation, these data are from the National Income and Product Accounts released by the Bureau of Economic Analysis. The compensation data are released from the Bureau of Labor Statistics.

[29]We include a training sample of 4 quarters, starting in the first quarter of 1968.

[30]Details are discussed in the appendix.

[31]The parameters' posterior distribution is computed using the Metropolis-Hastings algorithm. Details are in the appendix.

technical progress, this implies a steady-state real rate of 5.6%, which differs to the mean short-term rate in the observation equation. In the model, steady-state returns on short- and long-term bonds are the same: $R^m = R$. This equality fails to hold in the data: our chosen discount factor roughly matches a mean nominal interest rate on government debt of about 7%.[32] The choice reflects our focus on measuring the wealth effects from holding bonds which are directly linked to the steady-state discount rate, as shown by equation (9) in section 3.[33] Regarding fiscal policy, the average maturity of debt in sample is 5.5 years giving $\rho = 0.97$; the debt-to-output ratio is set to 30%, in terms of annualized quarterly GDP, giving $\delta = 1.2$; and the spending-to-output ratio is $G/Y = 0.16$.[34] Finally, two parameters not well identified by the data are fixed. The steady-state elasticity of demand for labor is $\theta^w = 5$, implying a steady-state markup of 25%. The Frisch elasticity of labor supply, denoted by ϕ_n, is 0.6, consistent with micro-evidence.

Prior Distributions. Tables 1 and 2 provide details on the priors. The priors for the exogenous shock processes are the same across variables. The persistence of the autocorrelated processes has a beta distribution with mean 0.5 and standard deviation of 0.2; the standard deviation of the innovations, including measurement errors, has an inverse-gamma distribution with mean 0.1 and standard deviation of 2.[35] The priors for the parameters of the monetary policy reaction function are based on the Taylor rule, while the parameters of the fiscal policy rule are consistent with a passive fiscal regime. Based on Hall (1988) and Ravina (2011), the inverse intertemporal elasticity of substitution of consumption, σ, has a gamma distribution with mean 2 and a fairly large standard deviation of 0.6, while the degree of habit persistence has a beta prior with mean 0.35. Turning to price and wage setting, the parameters ξ_p and ξ_w, determined by the adjustment cost parameters in the Rotemberg price-setting environment, have the same interpretation as the probability of not resetting prices and wages in a Calvo setup. The prior mean implies an average duration of about half a year. As shown in the appendix, these parameters determine both the slope of the wage and price Phillips curve, and, also, the rate at which agents discount the future when making price and wage decisions — see also Preston (2005). For this reason, these parameters can be identified separately from the sources of strategic complementarity, or real rigidity. Therefore, the slope of the price Phillips curve, defined by the parameter κ, is estimated separately; it has a beta prior distribution with mean 0.3 and standard deviation of 0.15. The parameters capturing price and wage indexation, ι_p and ι_w, have means of 0.5. Following Slobodyan and Wouters (2012a), the constant gain coefficient has a gamma distribution with mean 0.035 and standard deviation of 0.03.

Posterior Distributions. Tables 1 and 2 also show the mean, the mode and 95 per-

[32] This is the mean over the sample from the monthly statement of the public debt of the US from the Treasury Department.

[33] Because the counterfactuals consider substantially different debt burdens, a concern might be that such high steady state real interest rates overstate any identified effects. For this reason, the appendix reports the results for an estimated model with $\beta = 0.995$, which is consistent with an average term premium (defined as the difference between the average interest rate paid on the debt and the three-month Tbill) of about 2% over the Great Moderation: the results are very close to our baseline model. Note, however, that higher debt burdens might reasonably be thought to be associated with higher equilibrium real interest rates, leading to the use of $\beta = 0.99$ as the baseline value.

[34] This value is chosen to respect the steady state link between debt, surplus and taxes.

[35] These are the last four standard deviations in Table 2.

centiles of the posterior distribution of the parameters. Overall, the data are informative. The estimated persistence of the shocks is lower than usually found in estimated DSGE models.[36] This reflects the role of learning in soaking up low-frequency variation in the data. The estimated intertemporal elasticity of substitution, σ^{-1}, is remarkably low, roughly between 0.1 and 0.2. The price and wage stickiness parameters, ξ_w and ξ_p, are both consistent with price durations of over one year in terms of a Calvo model. In addition, the estimated slope of the Phillips curve is very flat, implying a high degree of real rigidity. The learning gain $\bar{g}$ is precisely estimated between 0.034 and 0.045: a short-term forecast error of 1% leads to about 4 basis point revision in the long-term drift. To further help interpretation, the estimated gain implies that an observation that is 10 years old receives a weight of about 20%. The estimated monetary policy rule displays a response to inflation and the output gap that is not too different from the priors, save a high degree of interest smoothing. Considerable inertia is also shared by the tax rule. The price markup $\Phi_p = \theta_p / (\theta_p - 1)$, which identifies the degree of preference non-separability in steady state, is estimated to be substantially higher relative to the prior, while the habit parameter is estimated closer to its prior.

Stability. Model parameters are estimated under the restriction of stability under learning. Given the constant gain learning assumption, this implies that the data generating process is stationary. However, Proposition 1 shows that high levels of government debt of intermediate maturity can generate instability. The appendix provides various results on expectational stability, which verify the implications of the Proposition for the richer empirical model, and show the dependency of these conditions on various features of the model specification. In particular the results are derived under different assumptions about the learning process: constant gain learning and least square learning where agents learn about all parameters in their vector auto-regression model, rather than just means. Furthermore, while the estimated low intertemporal elasticity of substitution enhances the destabilizing role of wealth effects on consumption, a high degree of price rigidity promotes stability.

6 Fiscal Policy and the Transmission of Shocks

The remaining sections of the paper explore various implications of the model. While an exhaustive study of the properties of the learning model relative rational expectations is merited, focus is here given to the implications of fiscal policy for model dynamics, and specifically the challenges that high-debt economies pose for the conduct of monetary policy, and the goal of price stability. The discussion is developed in three steps. First, impulse response functions are studied to underscore that impulse and propagation mechanisms of the model are fundamentally different under learning dynamics. These differences are driven by the public debt being perceived as net wealth. Second, armed with this understanding, various model predictions are studied, focusing on the role of identified shocks in explaining the evolution of expectations and wealth effects on aggregate demand. Third, the model is used to generate some counterfactual predictions to better understand the interactions of monetary and fiscal policy.

[36] See for example Smets and Wouters (2007), Justiniano, Primiceri and Tambalotti (2010), and Del Negro, Giannoni and Shorfiede (2014).

6.1 A Useful Decomposition

To facilitate understanding the basic mechanisms of the model, we express perceived wealth in terms of a set of forecast errors, defined as the difference between the subjective beliefs of agents and the beliefs implied by model-consistent expectations — that is, the beliefs that would be held if the true data generating process was known. By construction, because the model is Ricardian under full information, model-consistent expectations imply zero net wealth effects in every period. As for the endowment economy, aggregate consumption demand has a net wealth component given by

$$n_{w,t} = \left(\beta^{-1} - 1\right) \times \left\{ \left(\tilde{b}^m_{t-1} - \delta\hat{\pi}_t + \delta\beta\rho\hat{P}^m_t \right) + \beta\hat{E}_t \sum_{T=t}^{\infty} \beta^{T-t} \left[\delta \left(\hat{R}^m_{T+1} - \hat{\pi}_{T+1} \right) - \tilde{\tau}_T \right] \right\}.$$

Adding and subtracting model-consistent expectations for each term in this expression provides

$$\begin{aligned} n_{w,t} &= \beta\delta \left[\sum_{T=t}^{\infty} \beta^{T-t} \left(\hat{E}_t r_{T+1} - \tilde{E}_t r_{T+1} \right) - \tilde{E}_t \sum_{T=t}^{\infty} \beta^{T-t} \left(\hat{R}^m_{T+1} - \hat{R}_T \right) \right] \\ &\quad -\beta \sum_{T=t}^{\infty} \beta^{T-t} \left(\hat{E}_t \tilde{\tau}_T - \tilde{E}_t \tilde{\tau}_T \right) \end{aligned} \qquad (29)$$

where $r_t = \hat{R}_t - E_t\hat{\pi}_{t+1}$ is the ex-ante short-term real interest rate and $\tilde{E}_t$ denotes model-consistent expectations. Wealth effects emerge from three sources of forecast error. The first term measures the difference in expectations of the present discounted value the short-term real rate; the second term defines the *negative* of the present discounted value of excess returns from holding long-term bonds using model-consistent expectations (note that expected returns from holding long- and short-term bonds are equalized via arbitrage only under subjective beliefs); and, finally, the third term is the *negative* of the difference in expected taxes.

The decomposition makes clear a lower expected path of taxes, or a higher expected path for the real rate, relative to model-consistent expectations, produces positive wealth effects. Both these terms capture the impact of beliefs on the perceived present discounted value of taxes. Higher expected real rates, imply a lower present discounted value of taxes. In contrast, changes in expected returns have the opposite effects on net wealth: bond prices that are too low relative to a model-consistent valuation lead to negative net wealth effects, because the market value of debt is low relative to the present discounted value of taxes; these effects are measured by positive expected excess returns under model consistent expectations, as the true data generating process implies a predictable decline of long-term interest rates to steady state.

This difference between subjective and model-consistent beliefs highlight a fundamental property of the expectations formation process. Model-consistent expectations satisfy mean reversion as the true data-generating process is stationary with a mean corresponding to the rational expectations equilibrium. In contrast, because agents must infer the long-run conditional expectation of each variable, shifting assessments of the conditional mean lead to revision of the *entire anticipated path* of a given variable, leading them to systematically over predict the consequences of surprise increases in macroeconomic time series, and under-predict falls. This property of beliefs in infinite-horizon decision problems is central to model dynamics, and renders perspicuous the earlier claim, based on Eusepi and Preston (2011), that constant dynamics under learning generate the most important quantitative implications.

6.2 Impulse and Propagation Mechanisms

This section studies how different shocks drive wealth effects from holdings of the public debt. While the simple endowment economy might suggest the perceived wealth effects attached to different disturbances can be analytically characterized, in general these effects will depend on a range of model features. It is ultimately an empirical matter, with the consequences of different shocks for perceived wealth effects being identified in estimation. For brevity we focus on a monetary shock and a price markup shock, leaving all other impulse responses for remaining model shocks to the appendix.

Price markup shock. Figure 1 illustrates the mean impulse responses to a price markup shock in our baseline economy (solid lines), and also in an otherwise identical economy, but with an average debt-to-output ratio of 200% (dashed lines). The high-debt scenario informs subsequent analysis of the model. Beliefs are assumed to be at rational expectations equilibrium at the time of the disturbance. Consider the top four panels. A positive supply shock in a low-debt economy implies higher inflation, while the output gap declines in response to a steeper real interest rate path. This is the standard transmission mechanism of monetary policy in a Ricardian economy. Counterbalancing the restraining influence of higher real interest rates is a positive wealth effect on consumption demand. This additional source of demand prolongs the period of higher interest rates, leading to a protracted period of weak demand.

The final three panels identify the source of wealth effects using the above decomposition. Agents expect lower taxes and a higher path for the real interest rate relative to model-consistent expectations. As the real rate increases and taxes decline in response to the shock, agents revise their long-run assessment of these variables accordingly. For example, the top two panels show how inflation and nominal interest rate beliefs respond to the shock — agents expect inflation and interest rates to have increased permanently. In the case of taxes, beliefs are revised downwards, leading to a permanently lower anticipated tax burden. In contrast, model-consistent expectations correctly predict *mean reversion* in these economic variables. Muting these two positive contributions to net wealth, is a smaller negative contribution from expected excess returns. The steeper path for the nominal rate causes bond prices to be low relative to the model-consistent valuation of debt.

On net tax expectations play a dominant role in generating positive wealth effects. Worth underscoring is that three factors determine the level of taxes, movements in which induce expectations effects. Higher inflation and lower bond prices (higher expected nominal rates) lower the market value of outstanding debt in real terms, and, therefore, lower taxes directly through the assumed tax policy rule. Counterbalancing this, from the flow budget constraint of the government, higher expected nominal interest rates lead to more debt issuance and therefore higher taxes. While generally the net effects depend on the parameters characterizing fiscal policy, the first two components dominate in response to a markup shock.

The wealth effects are small in an low-debt economy but they alter significantly the transmission mechanism of the shock in high-debt economies. Here the mean response of the output gap flips in equilibrium as the positive wealth effects on aggregate demand are only gradually counteracted by tighter monetary policy. While the mechanics of adjustment are the same, the wealth effects arising from projected declines in taxes, and later, rising projected real rates, are sufficiently large to offset the typical decline in aggregate demand in response to the negative supply shock. Perceived wealth effects completely undermine the stabilizing influence of higher interest rates operating through intertemporal substitution motives. The figure suggests in high-debt economies shocks tend to have larger and more persistent effects.

Monetary policy shock. Figure 2 shows the mean impulse response to a contractionary monetary policy shock. Both inflation and the output gap fall in response to the shock. As with the price markup shock the substitution effects reducing aggregate demand are partially off-set by positive wealth effects. These are induced by only one out of the three components of net wealth: the steeper expected path of the real rate. In fact, low inflation and high debt issuance associated with the nominal rate increase, tend to raise taxes, and, concomitantly, tax beliefs, over the medium term.[37] This produces negative effects on consumption demand since agents now over-estimate the present discounted value of taxes. Similarly, the steep increase in the path of the nominal rate produces positive expected excess returns to long-term bonds, with negative impact on consumption demand. In a high-debt economy the short-term drop in the output gap is ameliorated to some degree, given the re-weighting of substitution and wealth effects. The effects are, however, more persistent than in a low-debt economy.

In summary, wealth effects generally have opposite effects on aggregate demand when compared to the standard intertemporal substitution channel of monetary policy. The economic response to shocks is altered and magnifies the propagation mechanism. As a result, monetary policy is less effective in stabilizing high-debt economies as we show in the next section.

6.3 Expectations and Wealth Effects

This section details some basic predictions of the estimated model. Figure 3 shows selected macroeconomic variables over the sample period. The two top panels display the evolution inflation and interest rates, and, for each of these variables, the five-to-ten-year-ahead expectations from both survey forecasts (red diamonds) and model-implied forecasts (black solid line).[38] Long-term inflation expectations drifted up to about 7% in the late 1970s, and gradually reverted back toward the true unconditional mean of 2% in the late 1990s. Similarly, long-term interest-rate forecasts exhibit considerable drift over the sample. The model accounts for these patterns in long-term expectations as being determined by revisions in estimated drifts $\hat{\omega}_t^\pi$ and $\hat{\omega}_t^i$ (blue solid line) in the forecasting models. Hence a contribution

[37]Even though taxes dip in the first periods, debt issuance increase, boosting agents' beliefs about long-run debt and therefore long-run taxes.

[38]Notice the model does a good job in fitting the survey, as shown by the small variance of the estimated observation errors in Table 2.

of the learning model is to provide an account of the Great Inflation that does not rely on an exogenously specified inflation target disturbance, as done in Cogley and Sbordone (2008) and Del Negro, Giannoni, and Schorfheide (2015), among others.

As anticipated by the impulse response functions, wealth effects are relatively unimportant to aggregate dynamics. The middle-left panel illustrates the evolution of both consumption less wealth, $c_t - n_{w,t}$, and net wealth, $n_{w,t}$. It is clear non-Ricardian effects have played only a minor role in determining the evolution of output and inflation over the sample, including the Great Inflation. This is not to say imperfect knowledge is unimportant in explaining the data — drifting beliefs are clearly central to inflation and interest-rate dynamics. However, non-Ricardian demand effects induced by imperfect knowledge of the fiscal regime, are fairly inconsequential.

The remaining panels in Figure 3 plot the components of net wealth (black solid line) as defined by the above decomposition and compares them with the overall level of net wealth, $n_{w,t}$ (red solid line). Expected taxes play a dominant role in explaining movements in wealth. Their present discounted value relative to model-consistent expectations is positive until the early 1980s, when taxes were under predicted, and then turns negative until the mid-2000s. While we do not have survey evidence documenting this, Laubach (2009) discusses the evolution of five-years-ahead deficit and debt projections from the Congressional Budget Office. Consistent with our model, the paper shows large under-predictions in the 1970s, and over-predictions in the early 1990s.

Looking at the individual components, net wealth from movements in the real rate (relative to model-consistent expectations) mimics the fluctuations in the policy rate. Expansionary policies in place during the 1970s created negative wealth effects that were reversed during the Volcker disinflation. Finally, the last panel on the right shows positive excess returns from holding long-term bonds throughout the sample, yielding negative wealth effects. These are explained by interest rates, and interest-rate expectations, that were generally above their unconditional mean over the sample. For example, in 1980, agents expected the short-term rate to remain around 9%: the equilibrium bond price reflected those views. However, model-consistent bond price expectations imply current bond prices are too low, as short-term rates are expected to revert to their unconditional mean of 4%, yielding positive expected excess returns. This partially offsetting behavior of the three components of wealth is an additional reason for its small role in affecting consumption demand.

Figure 4 shows the historical contribution of each of three types of shocks (demand, supply and monetary shocks) to the variables described above. Supply shocks are here interpreted as the combined effects of the three supply-side disturbances: price markup, wage markup and technology shocks. For the reasons explicated in the endowment economy, tax shocks satisfy Ricardian Equivalence and explain no variation in the plotted series. The contribution of estimated initial conditions is also shown. To assist interpretation, the shock decomposition is conducted on annual data. Broadly, the historical account of the data agrees with the narrative found in Smets and Wouters (2007). Excessively loose monetary policy and large positive supply shocks account for much of the rise in inflation and short-term interest rates during the 1970s. Short-term forecast errors, driven primarily by surprise monetary and supply shocks, led to consistent upwards revision of long-term beliefs about inflation and interest rates. While the recession in 1974 is mainly driven by supply shocks, the large drop in the output gap observed in the early 1980 is largely due to tight monetary policy during the Volcker disinflation. During the mid 1990s the joint increase in output and further stabilization in inflation expectations is driven by negative supply shocks. Finally, net wealth is positive over the 1970s, initially reflecting the predominance of positive supply shocks and later tight monetary policy (recall the impulse response functions discussed earlier). From the mid 1980s, perceived net wealth contributed negatively to aggregate demand, reflecting positive demand shocks and negative supply shocks.[39]

7 Wealth Effects in a High-Debt Economy

The model predicts that wealth effects are a relatively unimportant source of demand in the historical sample. However, in many countries, including the United States, the stance of fiscal policy has changed radically over the course of the recent financial crises, raising the question of whether one ought always to expect fiscal policy to place few constraints on the conduct of monetary policy. Indeed, the impulse response functions suggest high debt economies fundamentally alter the impulse and propagation mechanisms of the imperfect knowledge economy. And this suggests fiscal policy might present challenges to central banks committed to price stability.

To assess the consequences of a substantial change in the fiscal position of the US economy, consider two different sets of counterfactual exercises, which assume the economy is subject to the same sequences of disturbances identified in estimation.[40] Figure 5 plots "volatility frontiers" corresponding to different assumptions about the *size* and *maturity* of government debt. The left panels show the relationship between the average duration of debt and the standard deviation of inflation and output gap that would be observed in an economy with a debt-to-output ratio of 120% (Italy, for example) given the identified disturbances. The right panel describes an economy with a 200% debt to-output-ratio (Japan, for example). Consistent with theoretical results, intermediate maturities of debt lead to substantial volatility in both the output gap and inflation relative to our baseline economy (red line). Moreover, high-debt economies not only create more volatility in terms of median outcomes (solid black lines), but also substantially increased uncertainty as reflected in the widening of 95 percent posterior probability outcomes. The volatility of the output gap is affected considerably more than the volatility of inflation, reflecting a very flat price Phillips curve. An interesting feature of these figures is that policy always satisfies the requirements for expectations stability. Despite this, the dynamic properties of the model are fundamentally altered.

Figure 6 shows the evolution of several key variables under two further counterfactual experiments. The left panel shows an economy with 200% debt-to-output ratio and a maturity of debt corresponding to the baseline calibration. In this economy the output gap moves substantially, and so do interest-rate expectations. The effects are less dramatic for inflation, again reflecting the flat Phillips curve. The 1974 recession, driven by positive supply shocks,

[39] Similarly to an expansionary monetary shock, a positive spending shock produces negative wealth effects. See the impulse responses in the appendix.

[40] The counterfactuals assume beliefs are characterized by the same constant gain implied by the posterior distribution. Furthermore, initial beliefs, part of the unobserved state inferred in estimation, are scaled appropriately: for example, if estimated initial long-run inflation beliefs are above steady state by 1 percent, then same percentage deviation is maintained in the counterfactual.

disappears in the counterfactual: as shown in the impulse responses, the response of output gap to a price markup shock is reversed in a high-debt economy. Negative wealth effects in the mid-1980s drive the policy rate below the zero lower bound. The economy experiences very low inflation (and deflation for some realizations). Inflation would be substantially lower if the model took appropriate account of the zero lower bound constraint on the nominal interest rate, which is ignored by the simulations. Moreover, the economy again flirts with the zero lower bound in the mid-2000s — the fears of deflation expressed at the time by economic commentators would have been realized in a high-debt economy. The counterfactual clearly shows that a monetary policy regime which successfully stabilizes inflation, inflation expectations and economic activity, may lose effectiveness when the fiscal regime shifts from low- to high-debt levels. Importantly, this policy ineffectiveness arises even though the fiscal policy regime ensures taxes are adjusted to back outstanding debt.

Finally, the right panel in Figure 6 shows the same counterfactual but with an average debt duration of 14 years. The role of wealth effects decreases substantially in this economy. Despite the high debt burden, monetary policy retains its power to control inflation. This simulation emphasizes that the choice of the maturity of debt can have important implications for monetary policy.

Robustness of the Gain. The policy exercises above assume expectations formation to be invariant to the policy regime. In particular, the constant gain, if chosen in some optimal way, should respond to a change in policy. For example a fiscal regime leading to higher short-term volatility could lead to a lower gain, as agents revise their assessment of the signal-to-noise ratio. Conversely, the gain could be updated upwards if higher volatility is associated with more volatile long-term fundamentals. While a treatment of the optimal gain is beyond the scope of this paper[41], the appendix shows a counterfactual where higher steady-state debt is associated with a lower gain ($\bar{g} = 0.02$): this economy continues to display large fluctuations albeit a bit reduced from the baseline. In addition, drift movement occur at somewhat lower frequencies: for example the zero lower bound is reached later with a lower constant gain.

8 Discussion

Some implications of the empirical results are now discussed. The proposed theory is also related to various other literatures that argue the importance of debt to a proper understanding of inflation dynamics.

Policy Implications. The counterfactual experiments using the empirical model demonstrate the conduct of fiscal policy was clearly relevant to the success of the Volcker Disinflation and the subsequent Great Moderation. If fiscal policy in the US had been characterized by higher average levels of debt, then volatility would have been higher than observed. Hence good fiscal policy also appears to be central the stability of the 1980s and 1990s.

More generally, the results have relevance for contemporary policy debate. Take Japan for example. It has displayed significantly less monetary control than the US, having been confronted with the zero lower bound for the past two and half decades. The model ac-

[41] Marcet and Nicolini (2003) introduce a framework where the constant gain responds to a change in policy regime. For an alternative approach where near-rational expectations are not invariant to the policy regime see Adam and Woodford (2012).

counts for the difference as being due to high public indebtedness in Japan. Furthermore, it explains why certain (conventional and unconventional) policy interventions might have produced disappointing results. Expansionary monetary and fiscal policies in a high-debt economy, when viewed through the lens of the model, would be expected to create negative wealth effects, restraining aggregate demand and creating unintended economic volatility. In line with our model predictions, these effects do not require large movements in long-term inflation expectations to be important, which is consistent with the Japanese experience.

Policy design and adaptive learning. These results build on a now large literature on learning dynamics and inflation control. Bullard and Mitra (2002), Evans and Honkapohja (2003) and Preston (2005, 2006) consider the stability properties of interest-rate rules in a New Keynesian model in which one-period-ahead expectations matter and there is no public debt.[42] In models with one-period debt Evans and Honkapohja (2007) and Eusepi and Preston (2012) explore the interactions of fiscal and monetary policy, characterizing learning analogues to the seminal insights of Leeper's (1991) rational expectations analysis. A specific implication is the standard account of monetary policy, with active monetary policy and passive fiscal policy, is shown to be always stable under learning, regardless of the size of debt if interest rates are adjusted in response to current inflation.[43] The present paper advances these contributions, demonstrating that the maturity structure itself is a critical determinant of inflation control in models of imperfect knowledge.

The Fiscal Theory of the Price Level. The fiscal theory of the price level — see Leeper (1991), Sims (1994), Woodford (1996) and Cochrane (2001) — asserts a distinct mechanism by which debt determines inflation. In contrast to the unpleasant monetarist arithmetic of Sargent and Wallace (1981), the connection between debt and inflation is not determined causally by printing money — though money balances might adjust because of equilibrium considerations. Rather, the theory contends that certain choices of fiscal policy can render future structural surpluses insufficiently responsive to outstanding debt. The only way intertemporal solvency of government accounts can be restored is through adjustments in the price level to ensure consistency between the real value of current outstanding debt and the real present discounted value of structural surpluses. Here fiscal policy determines inflation, while monetary policy maintains the value of the public debt. This theory predicts that debt has monetary consequences.

A striking difference of our work is that the fiscal regime affects inflation dynamics even monetary policy satisfies the Taylor principle and taxes respond sufficiently to debt to guarantee intertemporal solvency. This property has much in common with regime switching models of policy. Starting with Davig and Leeper (2006) there has been a concerted effort to understand the consequence of shifts in policy regime for macroeconomic dynamics. The central idea is that while there are periods in which policy is conducted according to conventional wisdom, with monetary policy providing a nominal anchor, there may also be periods in which fiscal policy determines the price level, with monetary policy stabilizing the level of the public debt. To the extent that there is non-zero probability weight on this second regime, debt will have monetary consequences, even during periods when policy is conducted

[42]Preston (2005) and Preston (2006) use a model of anticipated utility employed here.

[43]Eusepi and Preston (2012) shows that when monetary policy rules respond to inflation expectations instability can occur in more heavily indebted economies. See also the appendix for a related result.

according to the first regime.

These theories have been invoked by Sims (2011b), Bianchi and Ilut (2017) and Bianchi and Melosi (2017) to explain the surge in inflation in the 1970s, when monetary policy has been characterized as passive. The large role of fiscal policy found in these studies contrast with our results. We offer two explanations. First, these papers allow explicitly for an active fiscal regime in the 1970s, while fiscal policy is passive throughout the sample in this paper. Importantly, it is the fiscal regime that captures low-frequency movements in inflation. Second, the inflationary consequences of wealth effects from fiscal policy decline with lower levels of debt in our framework, while this is not true in the fiscal theory of the price level.

Also related to our paper is Sims (2011a). In contrast to our analysis, Sims proposes that agents make model consistent forecasts except for inflation. Conditional expectations of inflation are assumed to depend on debt. This is a reduced-form description of beliefs that would arise in a formal model of policy regime change discussed above. Like our paper, it does not require explicit characterization of alternative regimes. Unlike our paper, it is somewhat less general, restricting the possible influence of alternative regimes to inflation expectations alone.[44] Nonetheless, Sims demonstrates, consistent with the analysis of Eusepi and Preston (2012) and this paper, that tighter monetary policy can lead to bursts of future inflation in the medium term — even when monetary and fiscal policy have conventional assignments. Sims (2011a) refers to this as "stepping on a rake" — see also Sims (2011b).

9 Conclusions

This paper provides fiscal foundations of inflation based on imperfect knowledge and learning. It defines an economic environment where holdings of the public debt are perceived as net wealth, giving scope for the scale and composition of debt to be relevant to inflation dynamics. Both characteristics of debt place constraints on monetary control. High debt and moderate maturity economies require more aggressive monetary policy to deliver expectations stability.

An estimated version of the model reveals perceived net wealth does not play a key role in the run-up of inflation in the 1970s, or in the subsequent period of economic stability. This reflects the relatively low levels of public debt through the entire period. The analysis shows that had the US experienced a fiscal burden similar to current levels in Japan, the Great Moderation would not have occurred, and monetary policy would have been constrained at the zero lower bound for prolonged periods. Fiscal policy matters for inflation control.

[44] As shown in section 6.2, in our framework the relation between debt and expected inflation depends on the specific shock.

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10 Appendix: Proof of the Proposition

The local stability of the ODE in (22) is determined by the eigenvalues of the matrix

$$T - I = \begin{bmatrix} \Gamma_\pi - 1 & -\frac{\sigma}{\phi_\pi} \\ -\left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\delta\Gamma_\pi + \frac{(1-\rho)\beta\rho}{1-\beta\rho}\delta\phi_\pi & \left(\beta^{-1} - (1-\rho)\,\phi_\pi\right)\delta\frac{\sigma}{\phi_\pi} - 1 \end{bmatrix},$$

where

$$\Gamma_\pi = -\left(1 - \sigma\delta\left(\beta^{-1} - 1\right)\right)\frac{\beta - \phi_\pi^{-1}}{1-\beta} - \left(\frac{(1-\rho)\,\beta\rho}{1-\beta\rho} + \frac{\beta\rho^2}{1-\beta\rho}\right).$$

It is immediate to verify that the both eigenvalues are negative. The determinant of $T - I$ is $\left(1 - \phi_\pi^{-1}\right)/\left(1-\beta\right)$ and it is positive under the assumed $\phi_\pi > 1$. The trace is negative provided

$$\phi_\pi > \left(1 + (1-\beta)\left(1 - \sigma\delta \times \frac{(1-\rho)\,\rho\beta}{1-\rho\beta}\right)\right)^{-1}.$$

	Prior distribution			Posterior distribution			
	Distr.	Mean	St. Dev.	Mode	Mean	5 percent	95 percent
σ	Gamma	2.000	0.600	6.922	7.147	5.642	8.748
b	Beta	0.350	0.100	0.499	0.501	0.448	0.554
ξ_w	Beta	0.500	0.050	0.757	0.743	0.652	0.814
ι_w	Beta	0.500	0.150	0.337	0.392	0.189	0.623
ξ_p	Beta	0.500	0.050	0.755	0.738	0.674	0.798
ι_p	Beta	0.500	0.150	0.526	0.544	0.475	0.613
Θ_p	Normal	1.250	0.120	1.592	1.620	1.479	1.763
κ	Beta	0.300	0.150	0.003	0.003	0.002	0.004
ϕ_π	Normal	1.500	0.150	1.522	1.623	1.490	1.767
ρ_i	Beta	0.500	0.100	0.849	0.857	0.835	0.877
ϕ_x	Normal	0.120	0.050	0.077	0.094	0.069	0.131
ρ_τ	Beta	0.700	0.100	0.839	0.835	0.768	0.897
ϕ_{τ_l}	Gamma	0.070	0.020	0.043	0.047	0.027	0.071
g	Gamma	0.035	0.030	0.039	0.039	0.034	0.045

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm.

Table 1: **Prior and Posterior Distribution of Structural Parameters**

	Prior distribution			Posterior distribution			
	Distr.	Mean	St. Dev.	Mode	Mean	5 percent	95 percent
ρ_{θ_w}	Beta	0.500	0.200	0.891	0.870	0.791	0.921
ρ_g	Beta	0.500	0.200	0.934	0.931	0.912	0.950
$\rho_{\bar{\tau}}$	Beta	0.500	0.200	0.061	0.073	0.019	0.151
ρ_a	Beta	0.500	0.200	0.865	0.855	0.821	0.882
σ_{θ_w}	Inv.-Gamma	0.100	2.000	0.162	0.186	0.141	0.253
σ_{θ_p}	Inv.-Gamma	0.100	2.000	0.201	0.201	0.180	0.224
σ_g	Inv.-Gamma	0.100	2.000	0.510	0.526	0.438	0.623
σ_m	Inv.-Gamma	0.100	2.000	0.195	0.197	0.179	0.218
$\sigma_{\bar{\tau}}$	Inv.-Gamma	0.100	2.000	2.046	2.088	1.898	2.295
σ_a	Inv.-Gamma	0.100	2.000	1.441	1.418	1.046	1.844
$\sigma_{g\gamma}$	Beta	0.500	0.200	0.468	0.480	0.368	0.600
$\sigma_{o,\pi^{SR}}$	Inv.-Gamma	0.100	2.000	0.179	0.184	0.161	0.208
$\sigma_{o,R^{SR}}$	Inv.-Gamma	0.100	2.000	0.058	0.059	0.052	0.068
$\sigma_{o,R^{LR}}$	Inv.-Gamma	0.100	2.000	0.047	0.057	0.030	0.092
$\sigma_{o,\pi^{LR}}$	Inv.-Gamma	0.100	2.000	0.045	0.049	0.035	0.067

Note: The posterior distribution is obtained using the Metropolis-Hastings algorithm.

Table 2: **Prior and Posterior Distribution of Shock Processes**

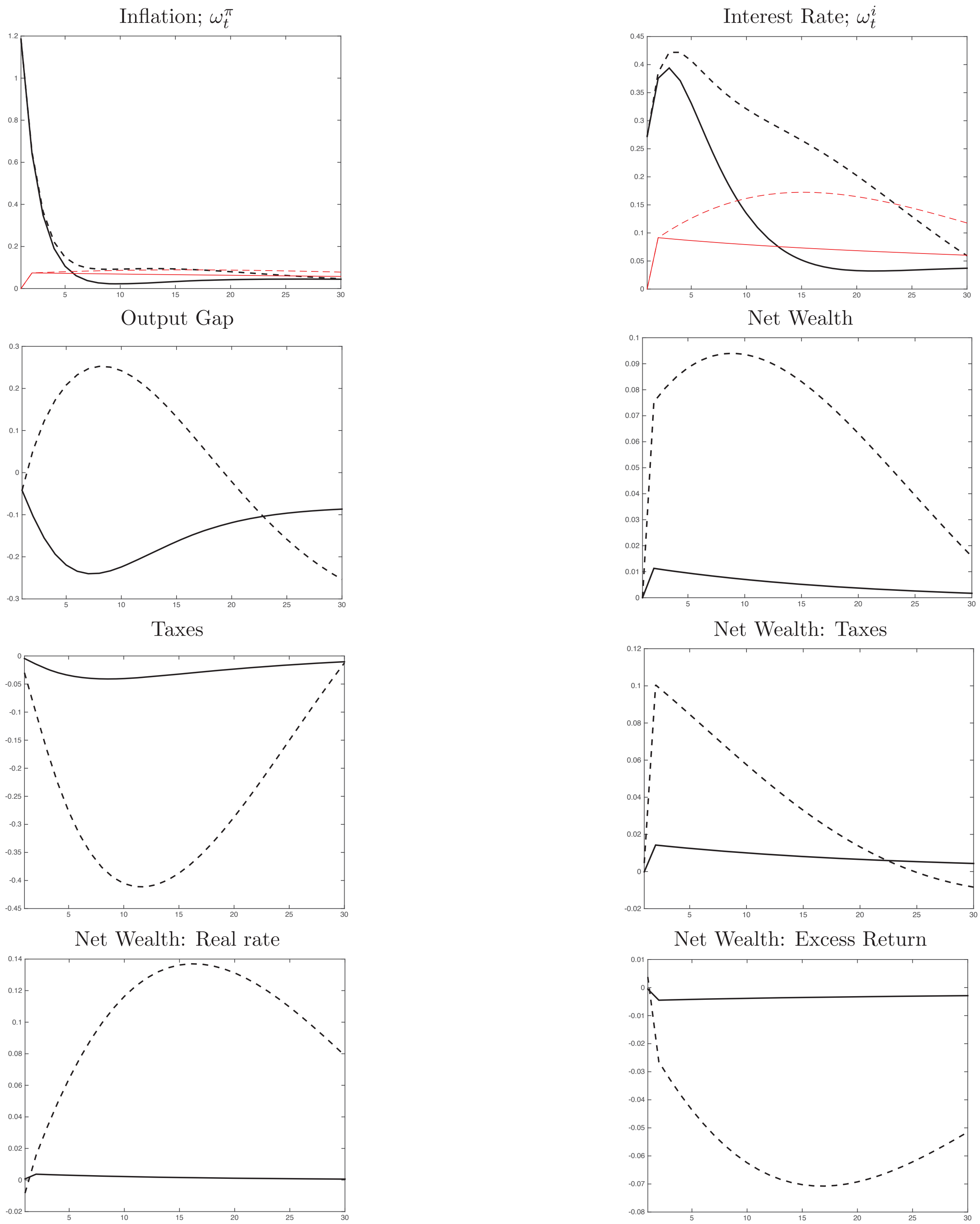

Figure 1: **Mean Impulse Response to a Price Markup Shock**

Solid lines denote the baseline economy with Debt-to-output ratio of 30%. Dashed lines correspond to an economy with debt-to-output ratio of 200%. Red lines measure inflation and interest rate estimated drifts.

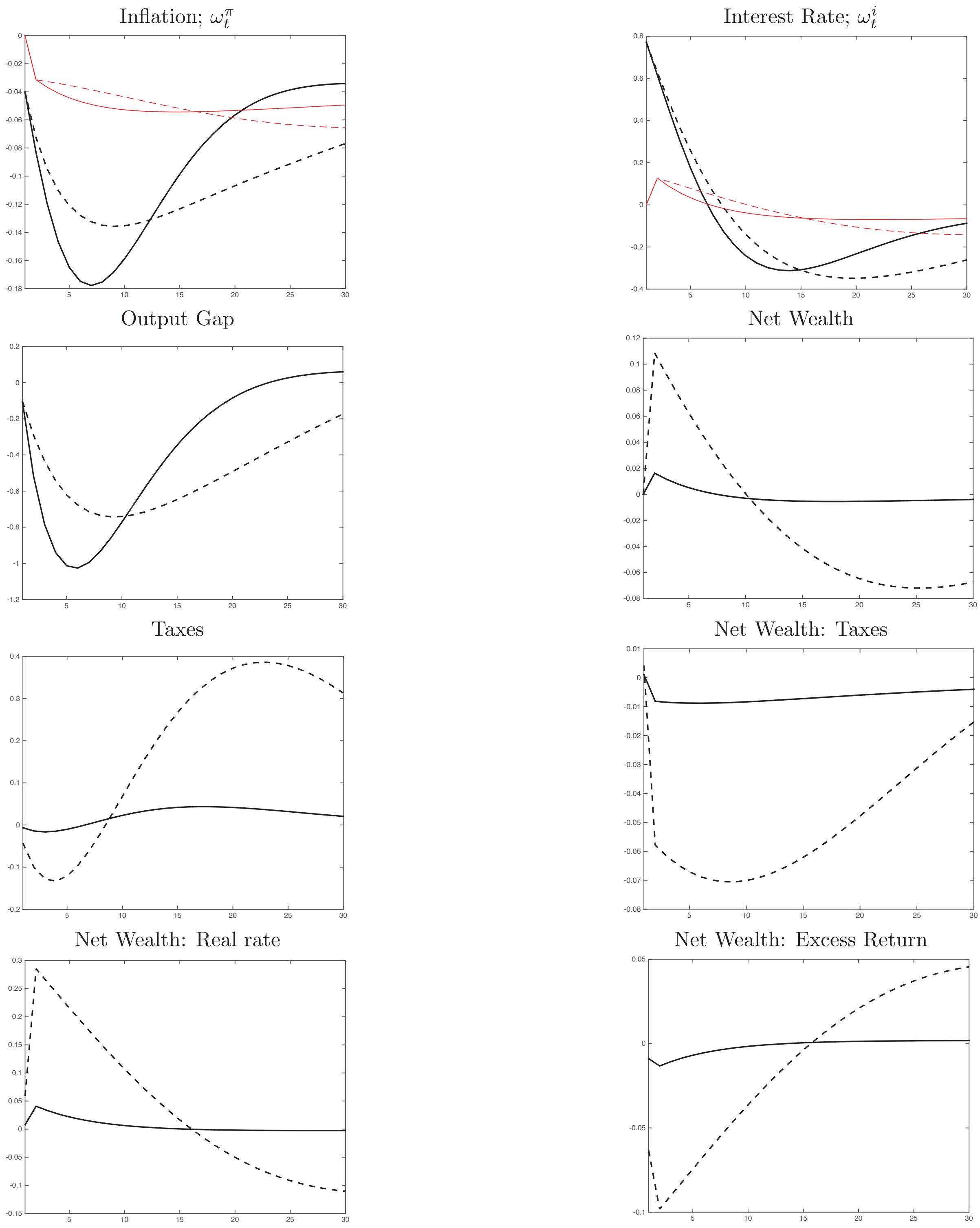

Figure 2: **Mean Impulse Response to a Monetary Policy Shock**

Solid lines denote the baseline economy with Debt-to-output ratio of 30%. Dashed lines correspond to an economy with debt-to-output ratio of 200%. Red lines measure inflation and interest rate estimated drifts.

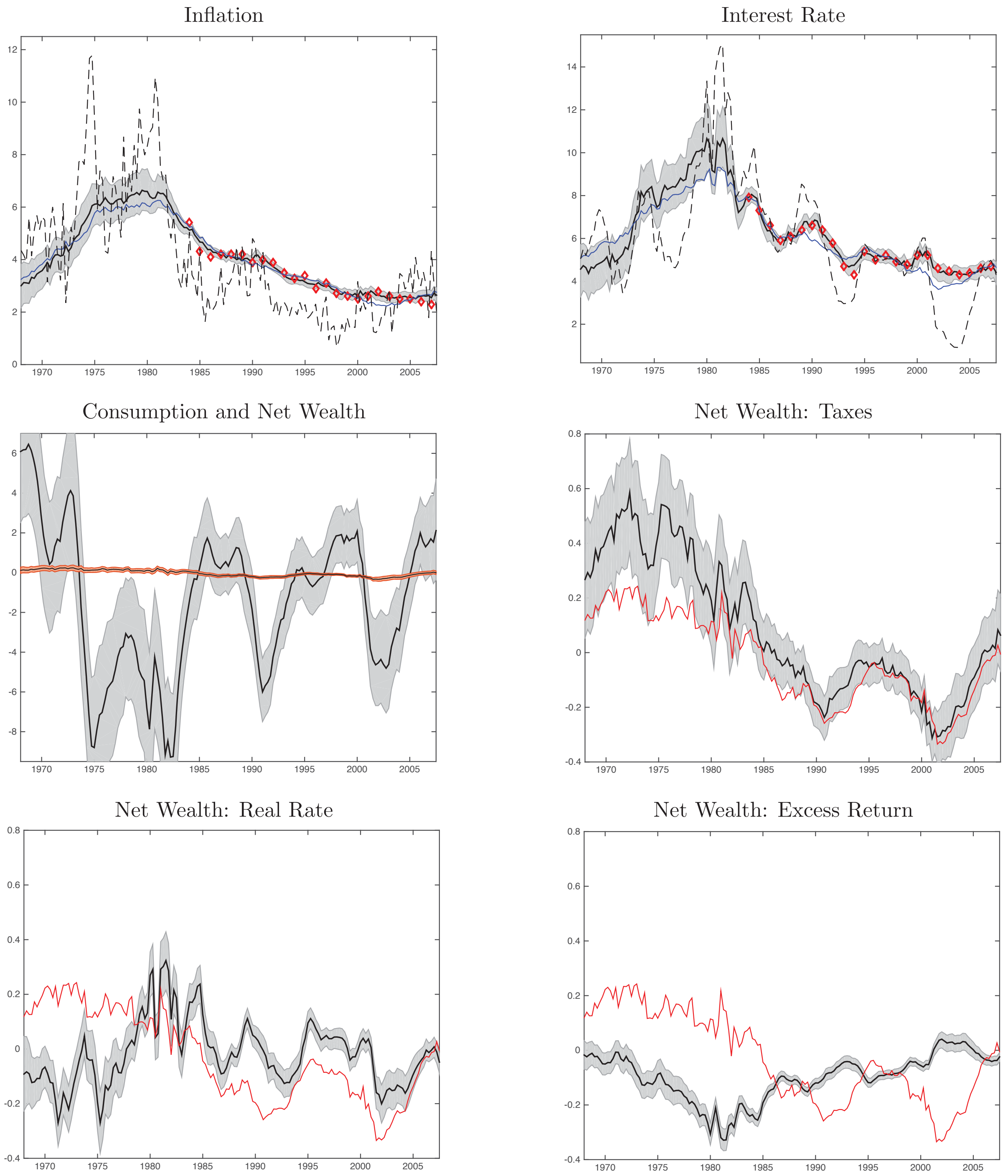

Figure 3: **Model Predictions**

The top figures show the predicted evolution of long-term expectations for inflation and nominal interest rate. Median predictions are denoted by the solid black line, while the grey area measures the 95% credible interval; the red diamonds denote 5-10 survey forecasts from Blue Chip Economics; the dashed black line denotes actual variables. The other panels show the evolution of consumption net of wealth (grey), net wealth (red), and its three subcomponents.

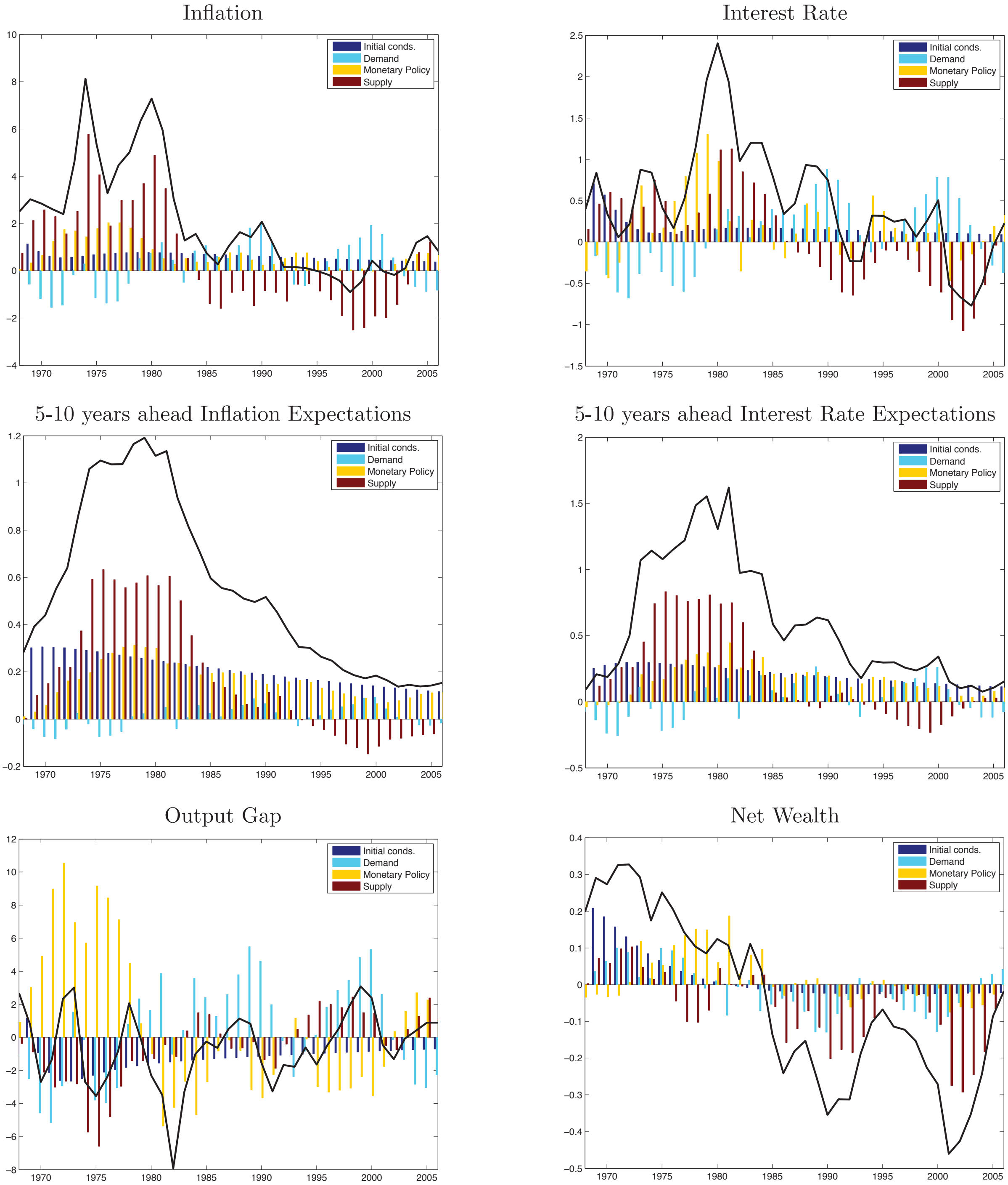

Figure 4: **Shock Decomposition**

The panels show the decomposition of selected variables calculated at the posterior mode. Data are plotted at an annual frequency; inflation is expressed in term of a four-quarter average; interest rate; output gap, net wealth and expectations are the fourth-quarter realizations (not annualized).

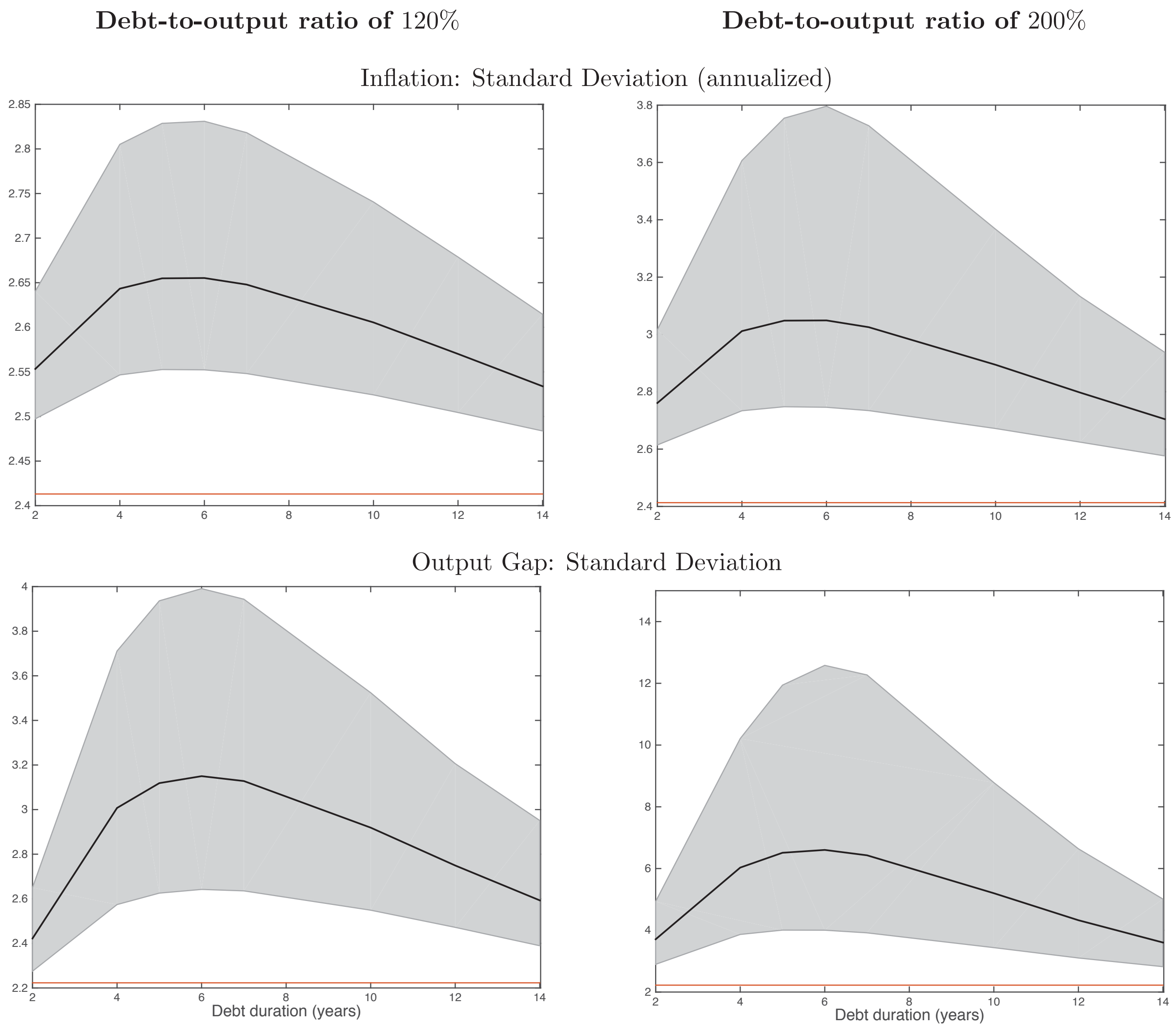

Figure 5: **Volatility Frontiers**

The left panels show the volatility of inflation and output gap with a debt-to-output ratio of 120%, for different average durations of debt. The right panels show an economy with debt-to-output ratio of 200%. The red line denotes the sample volatility. The frontiers are computed using the parameters' posterior distribution; the grey area includes the 95% posterior intervals, while the black solid line describes the median.

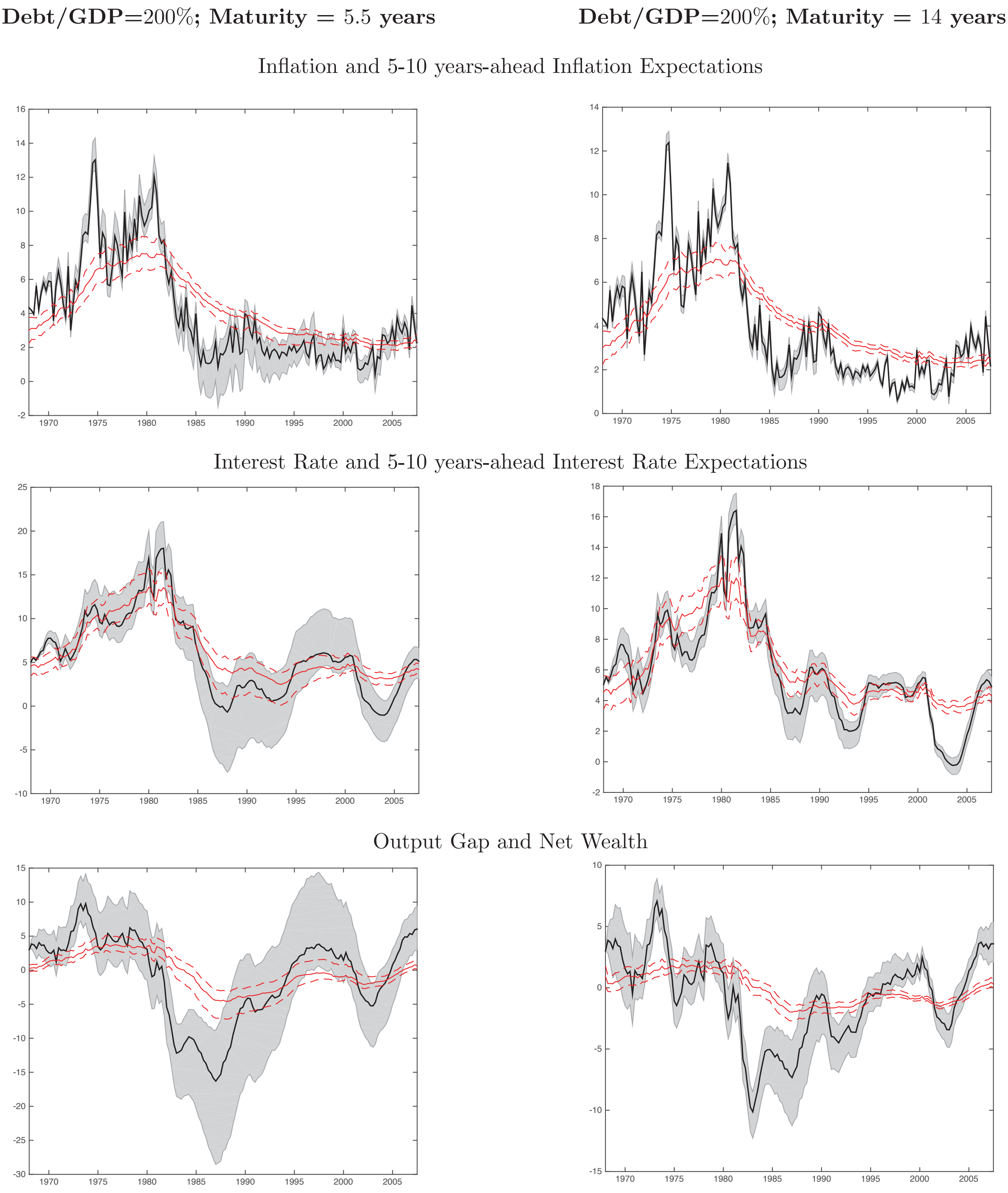

Figure 6: **Counterfactuals**

The panels show the evolution of selected variables in two counterfactual economies. Inflation, interest rate and output gap are denoted by solid black lines; expectations and net wealth are shown in red solid lines. The 95th posterior intervals are defined by the grey area and the dashed red lines respectively. The left panels show an economy with 200% debt-to-output ratio and baseline average maturity of debt. The right panels show an economy with 200% debt-to-output ratio and 14-years average maturity of debt.