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Three Great American Disinflations

Abstract

In this paper, we examine three famous episodes of disinflation (or deflation) in U.S. history, including episodes following the Civil War, World War I, and the Volcker disinflation of the early 1980s. We derive measures of policy predictability for each of these episodes that attempt to quantify the extent to which each deflation was anticipated by economic agents. We use our measures to help account for the disparate real effects observed across episodes, and in turn relate them to the policy actions and communication strategy of the monetary authority. We then proceed to account for the salient features of each episode within the context of a stylized SDGE model. Our model simulations indicate how a more predictable policy of gradual deflation could have helped avoid the sharp post-WWI depression. But our simulations also suggest that securing the benefits of gradualism requires a supporting institutional framework and communication strategy that allows the private sector to make reliable inferences about the course of policy.

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1 Introduction*

How should monetary policy be conducted to unwind a protracted episode of inflation? This is an old question in monetary economics, and the answer clearly depends on a number of important considerations. These include:

1. The monetary regime being followed – whether there is a credible nominal anchor like under the classical gold standard or a fiat regime without one. Agents reactions to an inflationary episode would differ considerably between these regimes. In the first case, they would understand that inflation is temporary (e.g., as during a war, Bordo and Kydland, 1996) and that policymakers, once the emergency has been perceived as over, would follow the requisite policies to unwind it. In the latter case, expectations would be much less sanguine (Bordo and Schwartz, 1999).

2. The type of central bank institutions in place. A long-standing central bank such as the Bank of England before 1914, with relatively well understood and clear objectives and operating procedures, with a history of credible disinflations under similar circumstances (Meltzer 2003, chapter 2) would elicit a better response from economic agents than one such as the early Federal Reserve which had not yet established the procedures or track record in conducting monetary policy (Erceg and Levin, 2003).

3. The presence and degree of nominal rigidities in both wages and prices. Even in an environment of credible and well understood policies, disinflation could still be costly (Clarida et al, 1999).

In this paper, we address these issues by making a comparison of three famous disinflations in U.S. monetary history. We examine the post-Civil War Resumption period of 1866-79, the post World War I disinflation of 1920-22; and the Volcker disinflation of 1979-82. Each of these episodes had features incorporating the three considerations above.

In the first period, the policy objective was to exit the Greenback fiat money regime, based on

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the issue of fiat money to finance the war, and roll back prices sufficiently to return the U.S. to the Gold Standard at the pre-war price of gold of $20.67. The commitment to return to gold parity was viewed by agents as credible, and the U.S. Treasury (the monetary authority at the time) was strongly committed to it. Resumption occurred January 1, 1879, and was accompanied by a mild 13 year fairly predictable deflation with little disruption in the real economy. We interpret this episode as one with limited nominal rigidity, a credible commitment, and transparent policy objectives.

In the second episode, 1920-22, the United States had not left the gold standard, but the price level had doubled from its pre-war level due in part to inflationary finance of the war. The recently founded Federal Reserve was clearly committed to rolling back the wartime runup in prices, but embarked on a disinflation that was unpredictable in its timing, and unclear about its long-run target for the price level. As a result, agents repeatedly underestimated the extent of the price decline. This resulted in large output losses. We interpret this episode as one characterized by both a lack of transparency in monetary policy, and the presence of nominal rigidity.

Finally, in the third period, the disinflation that began in 1979 was associated with considerable output losses. We characterize this episode as incorporating both elements of a lack of credibility and transparency, as well as displaying the presence of some nominal rigidity.

We analyze these episodes using an extension of the DGE model in Erceg and Levin (2003). The model assumes Taylor-style nominal price and wage contracts and also assumes that agents can't perfectly observe shifts in the monetary policy regime. Our analysis highlights the importance, in explaining a high sacrifice ratio, of the lack of policy transparency comparing 1920-22 with the Resumption episode and both the absence of credibility and transparency in 1979-82.

The rest of the paper proceeds as follows. In Section 2, we describe the three episodes focusing on institutional background, implementation of policy, and the macroeconomic outcomes. Section 3 provides evidence on the evolution of expectations in the episodes based on bond spread yields, commodity futures, survey evidence, and historical narratives. Section 4 develops the model. We emphasize the wage and price-setting environment and consider different types of contracts (Calvo vs. Taylor), alternative monetary policy strategies, and expectations formation. Section 6 matches the model to the salient features of the three episodes. Section 7 reports a number of counterfactual policy experiments which highlight the importance of transparency, speed of implementation, and credibility. Special consideration is given to the role of nominal inertia. Section 8 concludes with some lessons for policy.

2 Historical Background

For our purposes in this paper, it will be useful to understand the history of the episodes in at least some detail. Our discussion here will highlight the differences across the three disinflations that motivate the analysis of monetary policy in the next section.

We first put each episode in context. To do so, we describe the run-up in inflation that preceded each episode and the monetary institutions charged to implement the disinflation. Next, we describe how policy was implemented across the three episodes. Finally, we discuss the evolution of aggregate output, employment, and prices around the period of the disinflation.

2.1 Institutional Considerations

The face of monetary policy varies across our three episodes. In the first episode, the Congress legislated policy, as there existed no independent central bank. After World War I, the 5-year-old American central bank was the monetary policy arm of the Federal Government. However, the Federal Reserve was not even institutionally independent of the U.S. Treasury and so remained under some political control. Finally, by the late 1970s, the central bank was nominally independent of the U.S. Treasury, even if it was not wholly insensitive to politics.

2.1.1 1866-1879

The U.S. had left the gold standard in 1862 and issued fiat money, or greenbacks, in order to finance its war with the Confederacy. The Union government issued around $450 million worth of greenbacks over the next two years; the supply of greenbacks would remain at about that level until 1866. At the time, this was an enormous increase, equal to about 10 percent of pre-war national income. Such a large injection of paper currency caused a steep decline in the value of greenbacks relative to gold. The greenback price of gold rose more than 150 percent before it began to fall after the summer of 1864. The reversal in the price of gold was likely due to the government's decision to keep the supply of notes constant and to the influence of the Union's military successes in the second half of 1864 on agents' expectations of the price of gold.

The decision to return to the pre-war price of gold – $20.67 per standard ounce – was a political decision agreed to by Congress and the President and executed by the Treasury. In April 1866, Congress passed and President Johnson signed an act that instructed the Treasury to retire the supply of greenbacks. Within two years, though, Congress and the President suspended the contraction in the face of strong public protest (Friedman and Schwartz, 1963, pgs. 44-45). By the middle of 1867, the wholesale price level had dropped just over 12 percent in 3 quarters, and by the end of that year, the Treasury had retired some 20 percent of the greenback supply and overseen a similar decline in the supply of publicly-held currency (see Mitchell, 1903; Friedman and Schwartz, 1963, pg. 24 and Friedman and Schwartz, 1970, Table 1). However, when President Grant delivered his first inaugural in March 1869, he promised to renew the march toward resumption. The important difference was that he would preside over a much more gradual deflation.

2.1.2 1919-1922

The U.S. government suspended the gold standard de facto shortly after it entered World War I and began an enormous arms build-up that fueled inflation. President Wilson ordered the suspension and placed an embargo on the export of gold in order to protect the country's stock. In the absence of the embargo, high inflation likely would have triggered large outflows of gold: GNP prices rose almost 40 percent while the U.S. was at war, which was equal to the cumulative increase in prices observed in the 15 years earlier. Wartime inflation had its roots in an almost

20-fold increase in federal government expenditure from the time the U.S. entered the war in April 1917 to the armistice in November 1918 (see Firestone, 1960, Table X). Twenty percent of this increase was financed by money creation by the country's young central bank, the Federal Reserve System (Rockoff, 2004).

When the war ended, the embargo was lifted, and the Treasury and the Federal Reserve had to negotiate monetary policy in order to protect the standard. The Federal Reserve's Board of Governors included 5 appointees and two ex-officio members, the Secretary of Treasury and the Comptroller of the Currency. The System's most potent policy instrument was the discount rate charged by the System's Reserve Banks to its member commercial banks on short-term loans. The Reserve Banks could request an adjustment in its discount rate, but the Board had to approve. This gave the Secretary of the Treasury a disproportionate influence over monetary policy, since the five appointees to the Board were reluctant to cross the Treasury. Faced with a 25-fold increase in gross public debt after the War (see Meltzer, 2003, pg. 84), the Secretary refused to support an increase in discount rates despite an acceleration in inflation into double digits in 1919. However, the Treasury's reputation was strongly linked to the success of the gold standard. In particular, U.S. law required the Treasury to ensure a stock of monetary gold equal to at least 40 percent of the supply of base money, and by November 1919, that legal minimum was in sight. The Treasury supported Board action to raise the discount rate.

2.1.3 1981-1983

As of 1979, the Federal Reserve had been in operational control of U.S. monetary policy for about 25 years, even if it remained sensitive to the political climate. The Accord of 1951 between the central bank and the Treasury had ceded monetary policy to the Federal Reserve. For a dozen years after the Accord, the Federal Reserve generally maintained a low, steady level of inflation. But beginning in the middle of the 1960s, the Federal Reserve permitted inflation to accelerate. By the time President Carter appointed in 1979 a well-known inflation "hawk", Paul Volcker, to run the Federal Reserve, (GNP) price inflation had reached 9 percent.

The Federal Reserve's first attempt to reign in inflation in 1979 failed, in part because of a lack of political support. Volcker initially tightened policy dramatically. The sudden deceleration in output growth and the rise in unemployment to a two-year high motivated a change in course. Reluctantly, the Volcker FOMC imposed credit controls and let the fed funds rate decline; this was a move that Carter Administration had publicly supported. Financial market participants saw the decline in the fed funds rate in the middle of 1980 as an about-face and a sign that the FOMC was not committed to disinflate (Blanchard, 1984). As a result, the earlier tightening failed to convince price and wage setters that inflation was going to fall, and GNP prices rose almost 10 percent in 1980.

2.2 Policy Actions

Because of institutional differences, the implementation of monetary policy varied across our episodes. In the post-Civil War episode, Congressional legislation marked the beginning of the deflation, which was explicitly scheduled to proceed slowly. Deflation was accomplished by the Treasury's management of the supply of fiat currency in circulation. After World War I, the Executive Branch and the Congress delayed the deflation for a year before giving the Federal Reserve the authority to act. In this case, policy took the form of fairly sudden increases in the discount rate charged by the System to member commercial banks. Under Volcker, the FOMC raised the federal funds rate to unprecedented heights and kept the real funds rate at a high level for roughly two years.

2.2.1 1866-1879

Post-Civil War monetary policy evolved as a series of Congressional Acts, Supreme Court rulings, and Presidential decisions. In 1869, Congress passed, and President Grant signed, the Public Credit Act. This was the crucial bill that pledged the Federal Government to repay its debt in specie within 10 years. The Act sent a strong signal of the Congress's and the President's intentions, since the Government would not want to honor its debt at the then-elevated price of gold. At the same time, the Act promised a gradual approach to resumption. The Supreme Court also weighed in around this time. It initially ruled that the issuance of greenbacks was unconstitutional before it over-ruled itself a year later by just one vote. The decisions indicated that if the Court were involved in the future, at least a near-majority of its members would attempt to use the power of the Court to endorse resumption. Later in the decade, faced with pressure to postpone or even renege on resumption, President Grant vetoed the so-called Inflation Bill that proposed to expand the greenback supply. The issue of going back to gold was legally sealed one year later by a Congressional Act that set the date of resumption: January 1, 1879.

From an operational perspective, the U.S. treasury followed a policy of keeping the monetary base nearly constant: the issuance of National Bank notes was roughly offset by the retirement of greenbacks. With real money demand growing with the progressive expansion in economic activity, this policy induced the gradual deflation shown in Figure 1. The gradual deflation successfully returned the U.S. to the gold standard, which would remain the law of the land until the Great Depression some 50 years later.

2.2.2 1919-1922

The Treasury freed the Federal Reserve to act in November 1919, and the Board raised the System-wide average discount rate by about 2.5 percentage points within 8 months (see Figure 3). The tightening was not completely unanticipated, as private agents believed that the Government would defend its gold stock. Nevertheless, as we argue below, the highly persistent rise in nominal rates in the face of rapidly shifting expectations about inflation (i.e., towards the expectation of deflation) represented a much tighter policy stance than agents had anticipated. The increase in the discount rate was associated with a marked fall in the growth rate of Reserve Bank credit extended to commercial banks, with the growth rate turning sharply negative in 1921. The effects of the sharp contraction in System credit was perhaps exacerbated by the System's use of moral suasion to influence the lending decisions of commercial banks.

2.2.3 1981-1983

In October 1979, newly-appointed Federal Reserve Chairman Paul Volker announced a major shift in policy aimed at rapidly lowering the inflation rate. Volker desired the policy change to be interpreted as a decisive break from past policies that had allowed the inflation rate to rise to double digit levels (Figure 4). The announcement of the policy change was accompanied by a sizeable increase in the federal funds rate. But while the roughly 7 percentage point rise in the nominal federal funds rate between October 1979 and April 1980 (see Figure 4) was the largest increase over a sixth month period in the history of the Federal Reserve System, this tight monetary stance was temporarily abandoned in mid-1980 as economic activity decelerated sharply.

The Federal Reserve embarked on a new round of monetary tightening in late 1980. The federal funds rate rose to 20 percent in late December, implying an ex post real interest rate of about 10 percent. Real ex post rates were allowed to fall only slightly from this extraordinarily high level over the following two years. Feldstein (1993) argued that newly-elected President Reagan's support of Volcker's policy was significant in giving the Federal Reserve the political mandate it needed to keep interest rates elevated for a prolonged period. However, while Volcker's policy did not face much initial opposition in Congress (Kettle), widespread dissatisfaction emerged as the economy moved into a deep recession in 1982.

2.3 Macroeconomic outcomes

The real effects of disinflationary policy were much more severe in the latter two episodes than the first. After the Civil War, policy proceeded gradually, and the real effects seem to have been minimal. The post-World War I deflation was sharp and so was the contraction in output, although it was fairly brief. The recession of 1981-82 was not as deep as after World War I, but it was protracted and large enough to cause a considerable increase in unemployment.

2.3.1 1866-1879

The 1869 and 1875 Acts of Congress seem to have been received as credible commitments by the Government to deflate. The greenback price of gold fell markedly within a year of the signing of the 1869 Act. Throughout the 1870s, the GNP price index (Figure 1) declined smoothly and almost uninterruptedly. Despite the 30 percent decline in prices, real output growth was reasonably robust throughout the decade, averaging about 4 to 5 percent per year. These observations on prices and output are consistent with a credible commitment to deflate. Such a policy would have induced private agents to set contracts in anticipation of a restrained monetary policy and thereby avoid declines in real output. Therefore, we would argue that beginning in 1869, agents were most probably making plans conditioning on the expectation of resuming convertibility within a decade.

2.3.2 1919-1922

In contrast to the gradual deflation of the 1870s, the Federal Reserve presided over a sharp decline in prices and output after World War I. While prices rose substantially after the armistice, the aggregate price level (measured by the GNP deflator in Figure 3) began to plunge in mid-1920, falling by 25 percent from its peak by early 1921. Commodity prices exhibited an even sharper decline, falling roughly 50 percent from their mid-1920 peak. The price decline was associated with a nearly coincident decline in real activity. Real GDP declined 20 percent from its late 1919 peak, with an even sharper decline in manufacturing (not shown). But as noted by Friedman and Schwartz, the relatively short-lived nature of the depression is as striking as its magnitude, with a robust expansion returning output to its pre-deflation level by early 1922.

2.3.3 1981-1983

The monetary tightening that began in 1979 had little initial effect on inflation (Figure 4), even though activity contracted sharply in the first half of 1980 in response to the higher real interest rates and the implementation of credit controls. After some retreat from tight money policies between the spring and fall of 1980, the renewed round of tightening that began in late 1980 proved much more durable. The tight monetary policies succeeded in reducing the inflation rate from about 10 percent in early 1981 to about 4 percent in 1983. The cost was a sharp and very prolonged recession, with the CBO measure of the output gap expanding to 9 percent of GDP by mid-1982 (n.b. the plot shows the output gap by rescaling relative to its 1980 level, when the CB0's measure of the gap was already about 3 percent). The unemployment rate (not shown) hovered at 10 percent until late 1983, and the output gap remained significantly negative. Thus, monetary tightening under Volcker was associated with both a large and highly persistent downturn in economic activity.

3 Policy Predictability: Evidence from Forecast errors

In the previous subsection, we argued that the aggregate data are consistent with the hypothesis that the post-Civil War deflation was largely anticipated. Here, we provide further evidence that supports our hypothesis. We then contrast this episode with policy after World War I and in 1981-82, arguing that monetary policy in the latter two episodes was less transparent. The discussion in the section motivates the theoretical work that follows on the effect of credibility and transparency on the sacrifice ratio of a disinflation.

Data on expectations after the Civil War are derived from two sources. The first is Calomiris (1985, 1993). He shows data suggesting that agents' forecast errors of greenback appreciation (i.e., price deflation) were fairly small. The forecast of greenback appreciation is computed as the difference between greenback-denominated railroad bonds and a gold-denominated U.S. Treasury bond. In Figure 1, we plot Calomiris' data and observe that the forecast errors were quite small, typically less than one percentage point on average.

We investigated the robustness of Calomiris' results to the use of different railroad yields. Our exercise considers three bonds from different major railroads that all mature within two years of the U.S. gold bond, and follows them through our sample period of 1869-78. Given the gold-denominated Treasury bond used in Calomiris, we can compute four series of forecast errors. The results are summarized in Figure 2. The figure shows an average error – across time and railroads – of about -0.8 percentage points. The average error over the same period in the Calomiris data is about -0.2 percentage points. Interestingly, the forecast errors are fairly small even during the latter half of the 1870s, a period of particularly large price declines.

We can reinforce our message regarding the post-Civil War deflation with commodity futures data. We collected data on the longest-to-maturity futures contract that were fairly regularly available, and that means we alternate between 4 and 5 months contracts. Of course, each commodity is subject to specific demand and supply shocks, so we concentrate on the broad patterns observable across time and commodities.

Forecast errors in the 1870s in general were not that large and were not persistently negative (i.e., agents did not repeatedly underestimate future deflation). The data are plotted in Figure 1 (lower right quadrant). The actual (or realized) prices are taken from the NBER's macro history database when available, and otherwise, from annual reports of the Chicago Board of Trade (the futures prices were reported in The Chicago Tribune). Over the period from 1871 through 1878, agents' errors were relatively small in absolute terms. The average absolute error across commodities and time was around 10 percentage points. Moreover, the errors were not consistently negative, suggesting that agents did not repeatedly underestimate the deflation.

In contrast, in the post-World War I deflation, commodity price forecast errors turned consistently negative shortly after monetary policy was tightened in early 1920, and reached 50 percentage points or higher (Figure 3). The futures data on corn and oats are from the Annual Reports of the Chicago Board of Trade, as in Hamilton (1992). Cotton futures traded on the New York commodity futures exchange, and their data is recorded in the Commercial and Financial Chronicle. Figure 3 shows large negative forecast errors among all three around the same time, namely, from May 1920 through October or November of the same year. Agents do not seem to have anticipated the initial deflation after World War I, although it did not take them too long to learn the future path of policy. The average forecast errors over the 1920-21 tightening period over roughly three times as large as the commodity price forecast errors derived from the post-Civil War data.

The forecast errors after World War I can be traced to a lack of transparency in monetary policy. Most importantly, the Board was very reluctant to publicly discuss a price-level target, even though several members had the deflation of the aggregate price level in mind as they made policy. The Board's only trained economist, Adolph Miller, publicly doubted that "the American public would sanction or tolerate a discount [rate] policy . . . avowedly based upon price indexes . . . It would be regarded as tantamount to . . . a credit and price despotism" (1921). We suspect that Miller's skepticism had its roots in an episode several years earlier, when labor unions demanded that the Federal Reserve stabilize sectoral prices (Harris, 1933, pg. 86-89).

The absence of an explicit price-level target meant that it was easier for agents to misinterpret the intentions of the System. For instance, the Board reassured the public that it would pursue a gradual reduction in the credit extended to firms in order to minimize the costs to real output. In January 1920, the head of the Federal Reserve System, William Harding, told an audience that "first consideration will be given to the industrial and commercial requirements of the country" and, therefore, "the process will necessarily be a gradual one" (Harding, 1920). It seems as if agents interpreted this to mean that the deflation of aggregate prices would also be gradual, when in fact the Board apparently was ready to tolerate a sharp decline prices and even output so long as the level of credit did not fall precipitously.

Lastly, we can contrast the forecast errors from the post-Civil War episode with the data on observed expectations in the 1981-82 tightening. Figure 4 largely summarizes our case for the Volcker disinflation. We plot professional forecasters' one-year-ahead inflation expectations and the realized level of inflation four quarters later. We also include in the figure data on 10-year average inflation expectations. The one-year-ahead forecasts are the median projections of GNP price inflation from the Survey of Professional Forecasters. The long-run expectations are form the semiannual Blue Chip survey. Both series tell the same story: agents' forecasts were persistently too high. Based on one-year-ahead forecasts, we find that the average forecast error over this period equaled -2 percentage points.

There are two important points to make in regards to the credibility and transparency of the Volcker disinflation. First, the FOMC never announced a long-run inflation objective, so agents had to infer its intentions. Kettl (1986) observed that President Reagan and Treasury Secretary Regan both criticized the Federal Reserve in January 1982 for the sudden surge in the money supply, arguing that it sent the wrong signal to financial markets. Second, the Committee probably enjoyed much less credibility than the Treasury after the Civil War and the Federal Reserve after World War I. The Volcker disinflation followed a decade and a half in which monetary policy allowed inflation to rise to double digits, and even the current FOMC committee had to re-establish the credibility it had lost when it aborted the disinflation begun in late 1979 (see Blanchard, 1984). Moreover, credibility was weakened by mounting Congressional opposition. In the first quarter of 1982, Chairman of the Joint Economic Committee Henry Reuss even threatened the "political dismemberment of the Federal Reserve System" unless the FOMC lowered the fed funds rates (Kettl, pg. 181).

4 The Model

We utilize the same basic model to analyze each of the three historical episodes, aside from differences in the characterization of monetary policy. Thus, we incorporate nominal rigidities by assuming that labor and product markets each exhibit monopolistic competition, and that wages and prices are determined by staggered nominal contracts of fixed duration (Taylor-style contracts).[1] We also include various real rigidities emphasized in the recent literature, including habit persistence in consumption, and costs of changing the rate of investment. Given that our characterization of monetary policy differs across episodes, we defer our characterization to Section

[1] Staggered contracts of fixed duration were originally considered by Phelps and Taylor (1977) and Taylor (1980). Lucas (1986) and King and Wolman (1999) analysed DGE models with staggered price contracts of fixed duration, while Levin (1989) analyzed a DGE model with staggered wage contracts of this type.

6 (in which we analyze results in each episode).

4.1 Firms and Price Setting

Final Goods Production As in Chari, Kehoe, and McGratten (2000), we assume that there is a single final output good Y_t that households use either for consumption or investment. The final output good is produced using a continuum of differentiated intermediate goods $Y_t(f)$. The technology for transforming these intermediate goods into the final output good is constant returns to scale, and is of the Dixit-Stiglitz form:

$$Y_t = \left[\int_0^1 Y_t\left(f\right)^{\frac{1}{1+\theta_p}} df \right]^{1+\theta_p} \tag{1}$$

where $\theta_p > 0$.

Firms that produce the final output good are perfectly competitive in both product and factor markets. Thus, final goods producers minimize the cost of producing a given quantity of the output index Y_t, taking as given the price $P_t\left(f\right)$ of each intermediate good $Y_t(f)$. Moreover, final goods producers sell units of the final output good at a price P_t that is equal to the marginal cost of production:

$$P_t = \left[\int_0^1 P_t\left(f\right)^{\frac{-1}{\theta_p}} df \right]^{-\theta_p} \tag{2}$$

It is natural to interpret P_t as the aggregate price index.

Intermediate Goods Production A continuum of intermediate goods $Y_t(f)$ for $f \in [0,1]$ is produced by monopolistically competitive firms, each of which produces a single differentiated good. Each intermediate goods producer faces a demand function for its output good that varies inversely with its output price $P_t\left(f\right)$, and directly with aggregate demand Y_t :

$$Y_t\left(f\right) = \left[\frac{P_t\left(f\right)}{P_t} \right]^{\frac{-(1+\theta_p)}{\theta_p}} Y_t \tag{3}$$

Each intermediate goods producer utilizes capital services $K_t\left(f\right)$ and a labor index $L_t\left(f\right)$ (defined below) to produce its respective output good. The form of the production function is

Cobb-Douglas:

$$Y_t(f) = K_t(f)^{\alpha} L_t(f)^{1-\alpha} \tag{4}$$

Firms face perfectly competitive factor markets for hiring capital and the labor index. Thus, each firm chooses $K_t(f)$ and $L_t(f)$, taking as given both the rental price of capital R_{Kt} and the aggregate wage index W_t (defined below). Firms can costlessly adjust either factor of production. Thus, the standard static first-order conditions for cost minimization imply that all firms have identical marginal cost per unit of output. By implication, aggregate marginal cost MC_t can be expressed as a function of the wage index W_t, the aggregate labor index L_t, the aggregate capital stock K_t, and total factor productivity X_t, or equivalently, as the ratio of the wage index to the marginal product of labor MPL_t:

$$MC_t = \frac{W_t L_t^{\alpha}}{(1-\alpha) K_t^{\alpha} X_t} = \frac{W_t}{MPL_t} \tag{5}$$

$$MPL_t = (1-\alpha) K_t^{\alpha} L_t^{-\alpha} X_t \tag{6}$$

We assume that the prices of the intermediate goods are determined by staggered nominal contracts of fixed duration. For a firm which resets its contract price during period t, $P_{t+j}(f) = P_t(f)$ for each period j in which the contract remains in effect. As discussed below, we assume that price contracts lasted for only two quarters during the post Civil War and post WWI deflations, while lasting four quarters during the Volcker disinflation. Each firm that is allowed to reset its contract price $P_t(f)$ chooses a value which maximizes its discounted profits over the life of the contract, subject to its product demand curve (3):

$$\mathbb{E}_t \sum_{j=0}^{3} \psi_{t,t+j}((1+\tau_p) P_t(f) Y_{t+j}(f) - MC_{t+j} Y_{t+j}(f)) \tag{7}$$

The operator $\mathbb{E}_t$ represents the conditional expectation based on information through period t. The firm's output is subsidized at a fixed rate τ_p.(this allows us to eliminate the monopolistic competition wedge by setting $\tau_p = \theta_p$).

4.2 Households and Wage Setting

We assume a continuum of monopolistically competitive households (indexed on the unit interval), each of which supplies a differentiated labor service to the production sector; that is, goods-producing firms regard each household's labor services $N_t(h)$, $h \in [0,1]$, as an imperfect substitute for the labor services of other households. It is convenient to assume that a representative labor aggregator (or "employment agency") combines households' labor hours in the same proportions as firms would choose. Thus, the aggregator's demand for each household's labor is equal to the sum of firms' demands. The labor index L_t has the Dixit-Stiglitz form:

$$L_t = \left[\int_0^1 N_t(h)^{\frac{1}{1+\theta_w}} \, dh \right]^{1+\theta_w} \tag{8}$$

where $\theta_w > 0$. The aggregator minimizes the cost of producing a given amount of the aggregate labor index, taking each household's wage rate $W_t(h)$ as given, and then sells units of the labor index to the production sector at their unit cost W_t:

$$W_t = \left[\int_0^1 W_t(h)^{\frac{-1}{\theta_w}} \, dh \right]^{-\theta_w} \tag{9}$$

It is natural to interpret W_t as the aggregate wage index. The aggregator's demand for the labor hours of household h – or equivalently, the total demand for this household's labor by all goods-producing firms – is given by

$$N_t(h) = \left[\frac{W_t(h)}{W_t} \right]^{-\frac{1+\theta_w}{\theta_w}} L_t \tag{10}$$

The utility functional of a typical member of household h is

$$\widetilde{\mathbb{E}}_t \sum_{j=0}^{\infty} \beta^j \{ \frac{1}{1-\sigma} \left(C_{t+j}(h) - \varkappa C_{t+j-1}(h) \right)^{1-\sigma} + \tag{11}$$

$$\frac{\chi_0}{1-\chi} (1 - N_{t+j}(h))^{1-\chi} + \frac{\mu_0}{1-\mu} \left(\frac{M_{t+j}(h)}{P_{t+j}} \right)^{1-\mu} \} \tag{12}$$

where the discount factor β satisfies $0 < \beta < 1$. The dependence of the period utility function on consumption in both the current and previous period allows for the possibility of habit persistence in consumption spending (e.g., Christiano, Eichenbaum, and Evans, 2001). In addition, the period utility function depends on current leisure $1 - N_t(h)$, and current real money balances. $\frac{M_t(h)}{P_t}$(although we will assume that the weight on real balances is arbitrarily small, and hence ignore real balances in our subsequent analysis).

Household h's budget constraint in period t states that its expenditure on goods and net purchases of financial assets must equal its disposable income:

$$
\begin{gathered}
P_t C_t(h) + P_t I_t(h) \\
MB_{t+1}(h) - MB_t(h) + \int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h) \\
e_t P^*_{B,t} B_{F,t+1}(h) - e_t B_{F,t}(h) \\
= W_t(h) N_t(h) + \Gamma_t(h) + TR_t(h) - T_t(h) \\
R_{Kt} K_t(h) - 0.5\phi_K P_t K_t(h)\left(\frac{I_t(h)}{K_t(h)} - \delta\right)^2 \\
-\frac{1}{2}\psi_I P_t \frac{(I_t(h) - I_{t-1}(h))^2}{I_{t-1}(h)}
\end{gathered}
\tag{13}
$$

The household purchases the final output good (at a price of P_t), which it chooses either to consume $C_t(h)$ or invest $I_t(h)$ in physical capital. Investment in physical capital augments the household's (end-of-period) capital stock $K_{t+1}(h)$ according to a linear transition law of the form:

$$
K_{t+1}(h) = (1 - \delta) K_t(h) + I_t \tag{14}
$$

Financial asset accumulation of a typical member of household h consists of increases in nominal money holdings $(MB_{t+1}(h) - MB_t(h))$ and the net acquisition of bonds. We assume that agents within a country can engage in frictionless trading of a complete set of contingent claims, with the term $\int_s \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h)$ representing net purchases of state-contingent domestic bonds. As noted above, $\xi_{t,t+1}$ represents the price of an asset that will pay one unit of domestic currency in a particular state of nature in the subsequent period, while $B_{D,t+1}(h)$ represents the quantity of such claims purchased by a member of household h at time t. Thus, the gross outlay on new state-contingent domestic claims is given by integrating over all states at time $t+1$, while $B_{D,t}(h)$ indicates the value of existing claims given the realized state of nature.

Each member of household h earns labor income $W_t(h) N_t(h)$, and receives gross rental income of $R_{Kt} K_t(h)$ from renting its capital stock to firms. Each member also receives an aliquot share $\Gamma_t(h)$ of the profits of all firms, receives a lump-sum transfer of $TR_t(h)$ from the government and pays a lump-sum tax of $T_t(h)$ (so that the difference may be regarded as a net transfer). Finally, we assume two types of costs associated with adjusting the capital stock. First, there is a cost associated with changing the net stock of physical capital, as in the standard q-theory literature; specifically, these costs depend on the square of the deviation of the investment-to-capital ratio from its steady state level level of δ. Second, it is also costly to change the level of gross investment from the previous period, so that the acceleration in the capital stock is penalized. The quadratic functional form follows the specification in Christiano, Eichenbaum, and Evans (2001).

In every period t, each member of household h maximizes the utility functional (11) with respect to its consumption, investment, (end-of-period) capital stock, money balances, and holdings of contingent claims, subject to its labor demand function (10), budget constraint (13), and transition equation for capital (14). Households also set nominal wages in staggered contracts that are analogous to the price contracts described above. In particular, we assume that wage contracts last four periods (during every episode), and that the households are divided into four cohorts of equal size. In each period, the households in one cohort renegotiate their wage contracts. Thus, for a typical member of household h which resets its contract wage $W_t(h)$ during period t, $W_{t+j}(h) = W_t(h)$ for $j = 1, 2, 3$.

4.3 Fiscal Policy and the Aggregate Resource Constraint

The government's budget is balanced every period, so that total lump-sum taxes plus seignorage revenue are equal to output and labor subsidies plus the cost of government purchases:

$$M_t - M_{t-1} + \int_0^1 T_t(h)\,dh = \int_0^1 \tau_p P_t(f)\,Y_t(f)\,df + \int_0^1 \tau_w W_t(h)\,N_t(h)\,dh + P_t G_t \tag{15}$$

where G_t indicates real government purchases. We assume that log of real government spending (g_t) follows a first order autoregression of the form:

$$g_t = \varphi_G g_{t-1} + \epsilon_t \tag{16}$$

Finally, the total output of the service sector is subject to the following resource constraint:

$$Y_t = C_t + I_t + G_t \tag{17}$$

5 Solution and Calibration

To analyze the behavior of the model, we log-linearize the model's equations around the non-stochastic steady state. Nominal variables, such as the contract price and wage, are rendered stationary by suitable transformations. We then compute the reduced-form solution of the model for a given set of parameters using the numerical algorithm of Anderson and Moore (1985), which provides an efficient implementation of the solution method proposed by Blanchard and Kahn (1980).

5.1 Parameters of Private Sector Behavioral Equations

The model is calibrated at a quarterly frequency. Thus, we assume that the discount factor $\beta = .993$, consistent with a steady-state annualized real interest rate $\overline{r}$ of about 3 percent. We assume that the subutility function over consumption is logarithmic, so that $\sigma = 1$, while we set the parameter determining the degree of habit persistence in consumption $\varkappa = 0.6$ (in the range of the empirical estimate of Smets and Wouters 2003). The parameter χ, which determines the curvature of the subutility function over leisure, is set equal to 4, implying a Frisch elasticity of labor supply of 1/2. This is somewhat lower than if preferences were logarithmic in leisure, but well within the range of most empirical estimates. The scaling parameter χ_0 is set so that employment comprises one-third of the household's time endowment, while the parameter μ_0 on the subutility function for real balances is set an arbitrarily low value (so that variation in real balances has a negligible impact on other variables).

The capital share parameters $\alpha = 1/3$. The quarterly depreciation rate of the capital stock $\delta = 0.025$, implying an annual depreciation rate of 10 percent. The price and wage markup parameters $\theta_P = \theta_W = 1/3$. We set the cost of adjusting investment parameter $\phi_I = 1$, which is somewhat smaller than the value estimated by Christiano, Eichenbaum, and Evans (2001) using a limited information approach; however, the analysis of Erceg, Guerrieri, and Gust (2005) suggests that a lower value in the range of unity may be better able to capture the unconditional volatility of investment within a similar modeling framework. The parameter determining the cost of adjusting the level of the capital stock is simply set to zero, i.e., $\phi_K = 0$. As noted above, price contracts are assumed to last two quarters in the post Civil War and post-WWI episodes – as suggested by the very rapid price level declines experienced during those periods – while lasting four quarters during the Volcker disinflation. Wage contracts are assumed to last four quarters in each episode. The share of government spending of total expenditure is set equal to 10 percent, while the autoregressive parameter of the government spending shock is set close to unity ($\varphi_G = 0.999$).

6 Model Simulations

6.1 The Post Civil War Deflation

While Congressional legislation was directed at inducing a progressive decline in the dollar price of gold, we make the simplifying assumption that the government instead targeted a gradual decline in the general price level. This allows us to abstract from the considerable complication of modeling the gold market explicitly. Moreover, it seems reasonable given that the real price of gold was fairly stable during the 1870s.

In this vein, we characterize the government (the monetary authority during this period) as adopting a target price level p_t^* (in logs). Given the legislative mandate to achieve this price level target gradually, we model it as following an AR(1) in the growth rate:

$$\Delta p_t^* = \varphi_P \Delta p_{t-1}^* + e_t \tag{18}$$

We assume that the monetary authority follows a simple instrument rule to achieve its price level target of the form:

$$i_t = \gamma_i i_{t-1} + (1-\gamma_{i)} \left[\overline{r} + \gamma_\pi \pi_t + \gamma_G(\pi_t - \pi_t^*) + \gamma_P(p_t - p_t^*) + \gamma_y \ln(y_t \,/\, y_{t-1}) \right] \tag{19}$$

This rule posits the nominal interest rate i_t as responding to the deviation of the price level from its target value, i.e., the "price level gap" $(p_t - p_t^*)$, as well as to the level of inflation π_t, the inflation gap $(\pi_t - \pi_t^*)$, and output growth. This rule is perhaps less descriptive of actual policy during the 1870s than a rule specified in terms of the monetary base. But it is easy to show that money-based rules designed to target the same price level path p_t^* can be re-expressed in essentially the same form as (19). Given that this simple rule seems to provide a useful framework for describing the latter two episodes, and that it allows us to abstract from somewhat peripheral considerations about the form of the money demand function, we opt to use it as a benchmark description of monetary policy during each episode.

The green dashed line in Figure 5 presents our benchmark characterization of the post Civil War deflation period in response to an announced changed in the price level target path p_t^* (the innovation is a fall in e_t in (19). We assume that the coefficient φ_P that determines the speed of price level target adjustment given a policy shock.is set equal to 0.95, implying very gradual adjustment with a half-life of nearly four years. This induces a correspondingly slow and steady decline in the price level of nearly 3 percent per year, close to what occurred over the historical episode. Given that the reaction function rule is calibrated so that *real* (ex post) interest rates respond modestly to price level target gaps (i.e., $\gamma_\pi = 1, \gamma_P = .04$), and with some delay ($\gamma_i = .7$), the policy shock only induces a small initial rise in the real interest rate (we assume that the coefficients on the inflation gap and output gap are zero, except for during the Volcker disinflation episode). As a result, while the immediate effects of the shock elicit a small and short-lived output decline, activity rebounds quickly to potential.

Thus, our simulation results show that despite the presence of nominal rigidities (including in the form of four quarter wage contracts), monetary policy can engineer a substantial deflation with low output costs. The key qualifications are that the deflation must be gradual, and agents clear about the policy objectives. These features clearly obtain in our benchmark case, and account for the small forecast errors depicted. This logic is familiar from earlier work by Taylor (1983) and Ball (1995). As suggested by the latter analysis, even the small output costs in our benchmark case could be reduced by assuming that the policymaker has some explicit preference for stabilizing output. This is illustrated in the figure for responses which are derived under a full commitment targeting rule that maximizes an ad-hoc policymaker loss function. This loss function is assumed to depend on the deviation of the price level from its target path four years in the future (which accounts for gradualism), and also has a substantial weight on the output gap. In this case, output never falls more than 1/3 percent below steady state, even though prices are reduced by 30 percent over four years.

Finally, the figure also considers an alternative case in which policy engineers a much sharper deflation that causes the price level to plummet more than 20 percent within two years of the policy shift (the solid blue line). Clearly, this alternative policy is consistent with a much sharper rise in real interest rates, and vastly larger output contraction than in our benchmark. Interestingly, while our model would account for fairly similar effects as in this alternative if the target path were adjusted much more abruptly, this simulation is derived by simply assuming that the coefficient on inflation in the monetary rule is set equal to zero ($\gamma_\pi = 0$), while continuing to assume the same gradualist target path as in our benchmark. In this alternative case, agents' perceptions that nominal interest rates will remain relatively high in future periods despite an anticipated decline in the price level contributes to a substantial rise in ex ante real interest rates (by contrast, in our benchmark the perception that future nominal rates will fall when inflation is low contributes to a much smaller rise in real rates). This emphasizes that the behavior of nominal interest rates – which initially behave very similarly in the benchmark and alternative cases – is an inadequate guide to interpreting the "tightness" of policy, a point emphasized frequently by Friedman and Schwartz.

6.2 The Post World War I Deflation

We continue to characterize policy during the post WWI period as choosing a price level target, with the nominal interest rate the instrument of policy. There are a number of important features of the episode that we would like to capture in our benchmark calibration that we think are crucial to understanding the monetary nature of the downturn. These empirical features include: i) the substantial runup in prices in the aftermath of the war (as seen in Figure 3, the price level rose over 20 percent between early 1919 and its peak in mid-1920), ii) the subsequent precipitous price level decline of nearly 30 percent between mid-1920 and early 1921, iii) the pattern of price level forecast errors suggested by both the commodity futures data and narrative accounts, which alternate between positive in 1919 and negative in 1920, iv) the high persistence of the nominal interest rate despite an enormous fall in inflation, and v) the sharp but short-lived contraction in real activity.

These features motivate both our specification of the shocks, and the particular form of the interest rate reaction function. With regard to the latter, we assume that nominal interest rates (rather than ex post real rates) adjust to deviations of the price level from target, as in the alternative simulation considered above (i.e., $\gamma_\pi = 0$, $\gamma_i = .7$, $\gamma_P = .04$). This helps account for observation iv). We also assume that price level target adjustments are immediate rather than gradual ($\varphi_P = 0$), and that there are a sequence of innovations to the price level target that account for both the initial runup in prices, and subsequent decline. The latter assumption allows the model to rationalize the persistent pattern of variation evident in the commodity price forecast errors. Specifically, we assume that there are a sequence of equally-sized shocks that collectively push up the inflation target by 20 percent in the first three quarters of 1919; these are followed by a sequence of equally-sized negative shocks beginning in 1920:2 that reduce the inflation target by 30 percent over three quarters. Finally, we also allow for a sequence of government spending shocks in 1919 that are calibrated to match the roughly 10 percentage points of GDP decline in the government spending share that occurred following the armistice. These shocks have little bearing on our explanation of the deflation episode, though they do allow the model to provide a better account of why output remained flat in 1919 despite enormous monetary stimulus.

Simulation results for our benchmark case are shown by the solid blue lines in Figure 6. The model evidently accounts quite well for the observed sharp fall in the price level. From a specification standpoint, the dramatic price decline would be difficult to rationalize in a model that incorporated significant structural persistence into the price-setting process; in our framework, two period Taylor contracts providing a better account of the rapid price decline than would four quarter contracts. The model also does remarkably well in accounting for the quantitative magnitude of the output decline of around 15 percent, and quite rapid recovery in 1921. The output decline is attributable to a sizeable and fairly persistent rise in the real interest rate. The large and persistent rise in the real interest rate despite little movement in the nominal interest rate in our simulation reflects both that agents came to expect large price declines, and that policy would maintain high nominal rates even in this deflationary environment. This seems a reasonable description of policy during that period. As observed by Meltzer, the Federal Reserve kept interest rates very high even when defense of the Gold standard was no longer in question (so that traditional Gold standard rules would implied rate cuts). Finally, given the calibration of the shocks, the model reproduces the pattern evident in the commodity price forecast errors, including large negative errors in 1920.

Thus, our simulation results suggest that the high costs of the 1920-21 deflation reflect that the Federal Reserve attempted to engineer an extremely rapid deflation, *and* that it was perceived as following a monetary policy stance in which future nominal rates were expected to remain high (at least for a few quarters) in the face of deflation. Accordingly, it is of interest to consider the counterfactual simulation depicted by the dotted green line in Figure 7, which shows a case in which the central bank is assumed to change its target path level incrementally, and to follow a rule in which the nominal interest rate also responds to ex post inflation. (i.e., $\gamma_\pi = 1$, $\gamma_i = .7$, $\gamma_P = .04$). Given our setting of $\varphi_P = .8$, the target path adjusts within just a few years, rather than roughly a decade as in the calibration for the post Civil War period. It is clear that allowing for a somewhat more gradual pace of adjustment, in concert with a policy rule that reacts to inflation, greatly ameliorates the output costs of deflation relative to the benchmark. But it is important to emphasize that "gradualism isn't enough" for reducing the output costs. In particular, merely allowing the target path to adjust at the slower pace assumed in Figure 7 would induce an output downturn nearly as large as under the benchmark (not shown for expositional reasons). Thus, it is important that policy is conducted in a way that ensures that agents expect that interest rates in future periods will be adjusted in a way that precludes very high ex ante real rates.

Figure 7 also shows the case of a full commitment optimal policy rule that is derived under the assumption of a policymaker loss function that depends on the price level target gap four years ahead, and on output growth. Clearly, it is possibly to devise a policy that allows for fairly rapid adjustment of the price level (i.e., a 30 percent price decline spread over about three years), while implying minimal output losses. This policy is consistent with very little increase in the real interest rate, and very small forecast errors.[2]

[2] The fall in output in the longer-term reflects the massive decline in government spending. The lower gov-

6.3 The Volcker Disinflation

A striking feature of the Volcker disinflation period was the fact that inflation forecast errors were extremely persistent. Erceg and Levin (2003) argued that this may have reflected a high level of uncertainty about the central bank's inflation target. In this paper, we take a similar stylized approach to characterizing uncertainty about inflation target of the central bank by assuming that agents cannot differentiate permanent from transitory shocks to the target, and update expectations using the Kalman filter.

In particular, agents regard the central bank as following an interest rate reaction function of the form (19), and are assumed to know all of the parameters of the reaction function. But while agents can infer the current value of the inflation target from knowledge of the central bank's reaction function, they cannot directly observe the underlying components of π_t^*. Thus, agents must solve a signal extraction problem in order to forecast the future path of the inflation target, which in turn influences the outcome of their current decisions (e.g., in setting new wage and price contracts).

In our baseline specification, we formulate the signal extraction problem by assuming that the central bank's inflation target is the sum of a constant steady state rate of inflation $\bar{\pi}$ and two zero-mean stochastic components:

$$\pi_t^* = \bar{\pi} + (\pi_{pt} - \pi) + \pi_{qt} = H\xi_t \tag{20}$$

where $H = [1 \;\; 1 \;\; 1]$ and $\xi_t = [\bar{\pi} \quad (\pi_{pt} - \bar{\pi}) \quad \pi_{qt}]$'. The time-varying components are determined by the following first-order vector autoregression:

ernment spending raises consumption, which depresses labor supply. In the absence of the government spending shock, output would remain close to zero (potential) under our specification of the optimal rule.

$$\begin{bmatrix} \pi_{pt+1} - \bar{\pi} \\ \pi_{qt+1} \end{bmatrix} = \begin{bmatrix} \rho_p & 0 \\ 0 & \rho_q \end{bmatrix} \begin{bmatrix} \pi_{pt} - \bar{\pi} \\ \pi_{qt} \end{bmatrix} + \begin{bmatrix} \upsilon_1 & 0 \\ 0 & \upsilon_2 \end{bmatrix} \begin{bmatrix} \varepsilon_{pt+1} \\ \varepsilon_{qt+1} \end{bmatrix} \tag{21}$$

or

$$\xi_{t+1} = F\xi_t + Q\varepsilon_{t+1}$$

For simplicity, we assume that the highly persistent component $(\pi_{pt} - \bar{\pi})$ has an autoregressive root ρ_p arbitrarily close to unity, while the transitory component π_{qt} has a much smaller autoregressive root ρ_q. Thus, while we assume the central bank's inflation target eventually returns to its steady state value of $\bar{\pi}$, the shock ε_{pt} drives the inflation target away from steady state for a very prolonged period. On the other hand, the shock ε_{qt} has a more temporary effect on the target. Given that the inflation target innovations ε_{pt} and ε_{qt} are assumed to be mutually uncorrelated with unit variances (and are not correlated with any other shocks), the Kalman filter can be used to obtain an optimal solution to the signal-extraction problem.

We first consider the effects of the shock under perfect observability of the central bank's inflation target. Perfect observability corresponds to the case where agents observe both the permanent and transient components of the inflation target separately. Hence, they correctly interpret the reduction in the inflation target as a permanent shock, and have perfect foresight about the path of π_t^*. As seen in the upper left panel of Figure 8, a perfectly observed reduction in the inflation target induces a rapid disinflation. Given an immediate fall in the inflation target from 10 percent to 4 percent, actual inflation also falls from 10 percent to 4 percent within a year, so that the inflation response does not persist beyond the contract length. The upper right panel shows the output gap. Output contracts substantially in the period in which the shock occurs, but even rebounds somewhat *above* baseline after a couple of quarters. The initial output contraction occurs because the estimated monetary policy rule implies a sharp initial jump in the ex ante real interest rate. However, given that inflation expectations are anchored by the new lower target, progress in reducing inflation allows nominal and real interest rates to fall quickly, and output to rebound. The lower left panel of Figure 8 shows that a disinflation is consistent with a slight fall in the nominal interest rate upon announcement of the plan.

We now turn to the case of imperfect observability. Under our assumption that shocks to the transient component of the inflation target are iid ($\rho_q = 0$), the expected future inflation target $\mathbb{E}_t\pi^*_{t+j}$ (j>0)depends only on a constant ($\bar{\pi}$) and the expectation of the highly persistent component of the target ($\mathbb{E}_t(\pi_{pt+j} - \bar{\pi})$). The latter evolves according to a first order autoregression of the form:

$$\mathbb{E}_t(\pi_{pt+1} - \bar{\pi}) = \rho_p \mathbb{E}_{t-1}(\pi_{pt} - \bar{\pi}) + \left[\frac{1}{1 + (\frac{v_2}{v_1})^2}\right](\pi^*_t - \bar{\pi} - \rho_p \mathbb{E}_{t-1}(\pi^*_t - \bar{\pi})) \tag{22}$$

Thus, agents update their assessment of the persistent component of the inflation target by the product of the forecast error innovation and a constant coefficient. This coefficient, or "noise-to-signal" ratio, depends inversely on the ratio of the variance of the transient to permanent component $(\frac{v_2}{v_1})^2$.

We estimate the ratio $(\frac{v_2}{v_1})$ by choosing the value that minimizes the difference between historical four quarter-ahead expected inflation (taken from survey data) and the corresponding expected inflation path implied by our model. In particular, we minimize the loss function:

$$Loss = \sum_{j=0}^{20} \left[\mathbb{E}_{t+j}(\pi^4_{t+3+j}(survey\ data)\text{-}\mathbb{E}_{t+j}(\pi^4_{t+3+j}(\mathrm{mod}\, el)\right]^2 \tag{23}$$

The estimation period is 1980:4-1985:4 (21 quarters). The model expectation in (23) is the expected rate of four-quarter inflation that agents project at each date, given the historical path of both the highly persistent and transient components of the inflation target. The highly persistent component is assumed to shift only because of a one-time shift in 1980:4 (of six percentage points), while the historical path of the transient component π_{qt} is determined by the residuals in the estimated monetary policy rule.[3] Our estimation routine yields a point estimate of $(\frac{v_2}{v_1}) = 7.1$. In terms of equation (22), this means that the coefficient on the forecast error innovation is about 0.13; thus, about half of the six percentage point reduction in the (unobserved) persistent component of the inflation target in 1980:4 is incorporated into agents'expectations by a year later.

The learning problem about the inflation target plays a critical role in allowing our model to account the broad features of the Volker disinflation episode discussed earlier, including sluggish inflation adjustment, a persistently negative output gap, and an initial rise in the nominal interest rate. Returning to the upper left panel of Figure 8, inflation exhibits much greater persistence in the case of imperfect observability. Inflation declines in roughly exponential fashion, with about 50 percent of the fall in inflation to its long-run steady state level (of four percent) completed after four quarters, and about 75 percent after eight quarters. Our model's predicted path for inflation in the six quarters following the shock is in fact very close to what was observed in the Volker disinflation. The slow inflation decline in our model reflects that current inflation is partly anchored by expectations about the future inflation target. Even if the current target that agents "back out" of the monetary policy rule is low, expectations about the longer-term path of the inflation target adjust slowly in response to a disinflation shock

In contrast to the sharp but transient output decline that occurs under perfect observability, the output gap exhibits a substantial and persistent fall under imperfect observability (upper right panel). Because current inflation decreases slowly, the post-shock policy rule requires high ex ante real interest rates for a sustained period. The output gap averages around minus four percent in the first year following the disinflation shock, and only gradually narrows as progress in reducing the inflation gap allows the central bank to lower interest rates. The model accounts for a sacrifice ratio of 1.6 in the 21 quarters following the disinflation shock (1980:4–1985:4), close

[3] Only a small fraction of an innovation in the monetary policy residual is expected to be permanent. Thus, it makes little difference to our parameter estimate whether the model expectation in (23) incorporates the historical path of the transient component of the inflation target in addition to the highly persistent component.

to our empirical estimate of 1.5 in the Volker disinflation, and broadly in line with the estimates reported by Ball for a wide sample of disinflation episodes.

Unlike the model with perfect observability – which predicts a fall in the nominal interest rate after the announcement of a disinflation program – our model is consistent with a substantial initial rise in the nominal interest rate (upper panel) of roughly 300 basis points. This reflects that inflation is much more sluggish with imperfect observability, implying a larger inflation gap, while output exhibits a smaller initial contraction than under perfect observability.

[INCOMPLETE - include simulations contrasting a gradual deflation under imperfect information and full information]

7 Conclusions

In this paper, we have examined three famous episodes of deflation (or disinflation) in U.S. history, including episodes following the Civil War, World War I, and the Volcker disinflation of the early 1980s. Our model simulations indicate how a more predictable policy of gradual deflation could have helped avoid the sharp post-WWI depression, although we also stress the importance of adopting a monetary policy that agents would perceive as allowing future nominal interest rates to decline while expectations remained deflationary. More generally, securing the benefits of gradualism requires a supporting institutional framework and communication strategy that allows the private sector to make reliable inferences about the course of policy

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Figure 1. The Post Civil War Deflation, 1869–1879

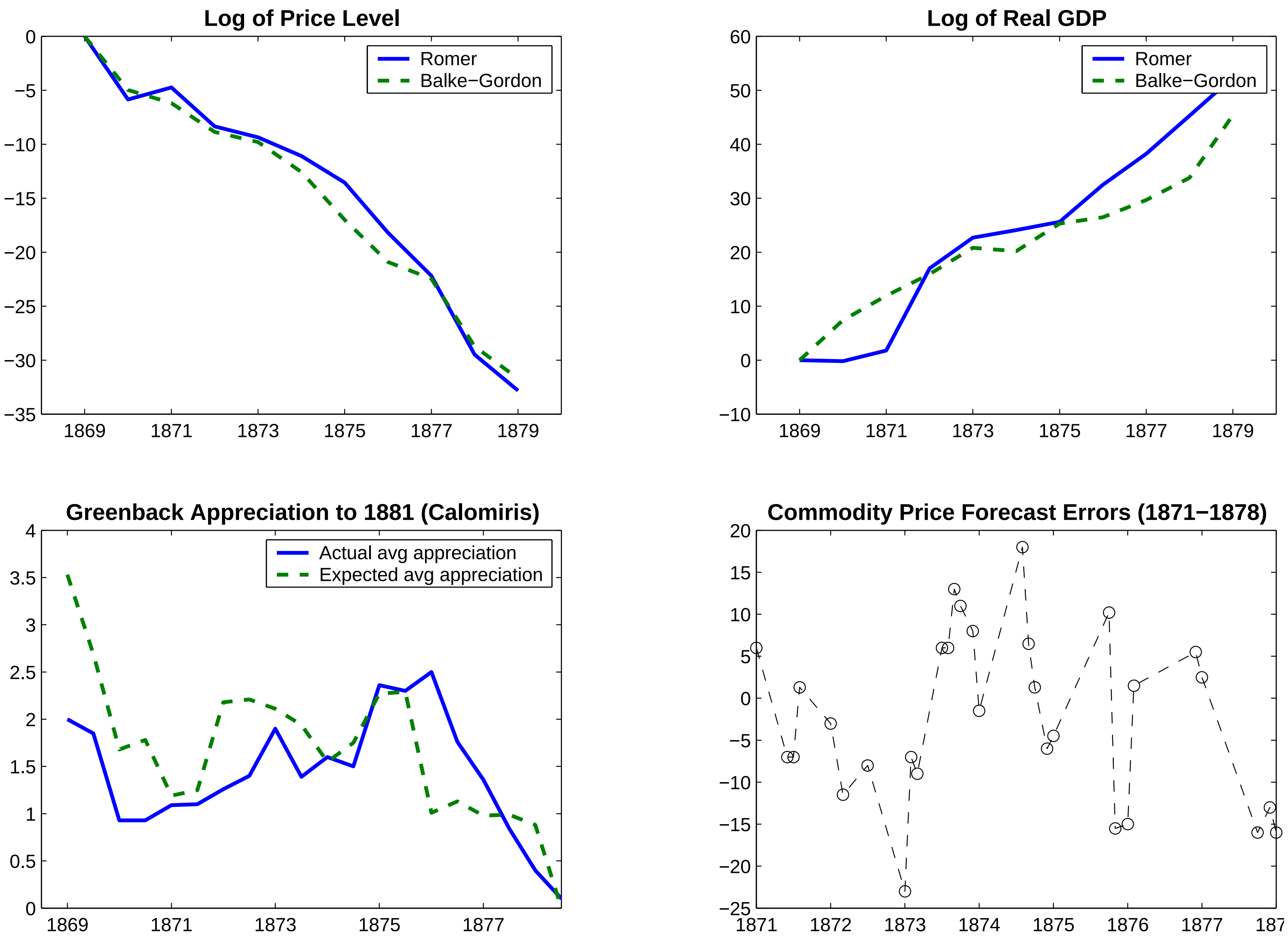

Figure 2. Long−term Greenback Appreciation Forecast Errors

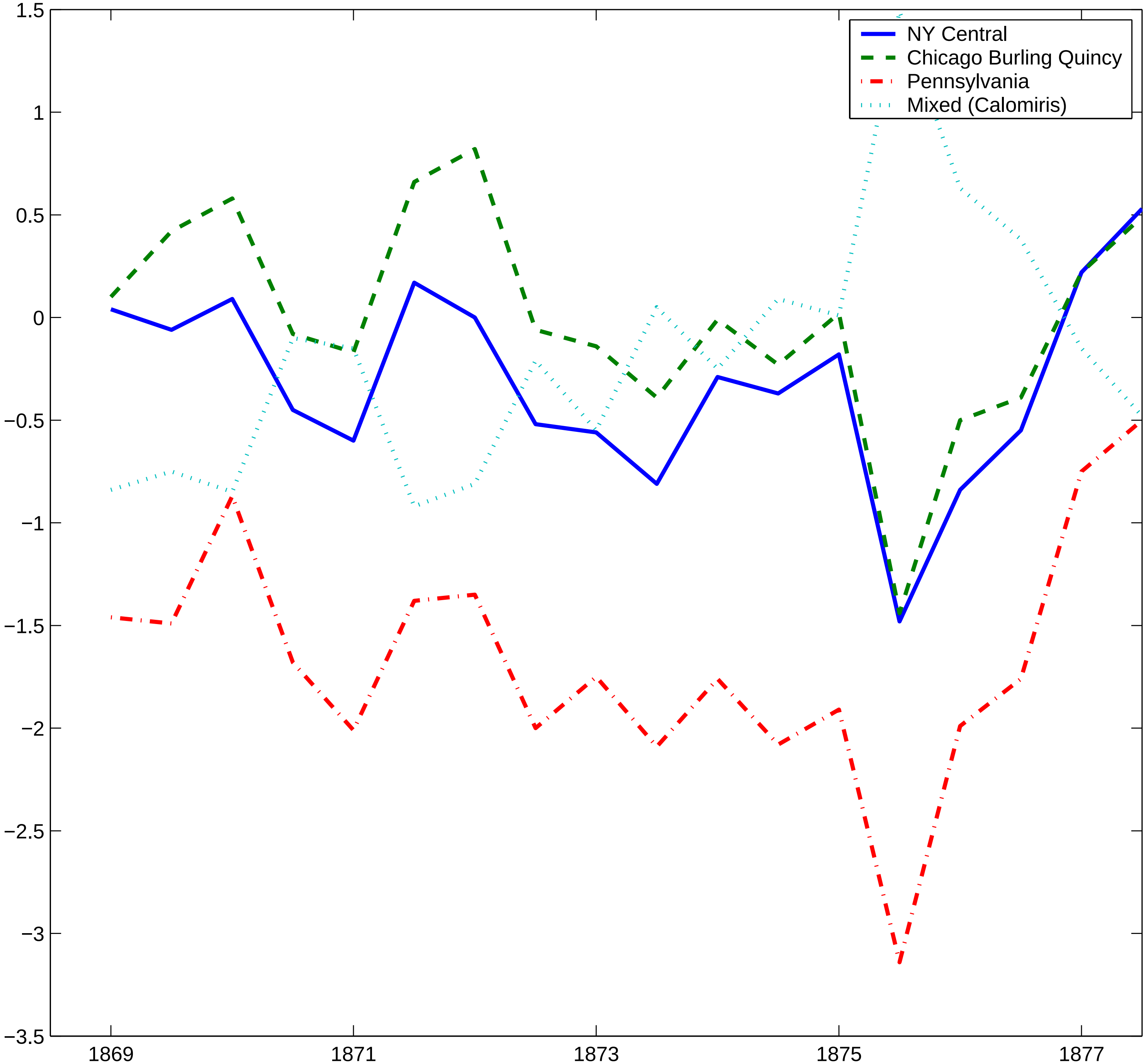

Figure 3. Inflation and Deflation after WWI, 1919−1922

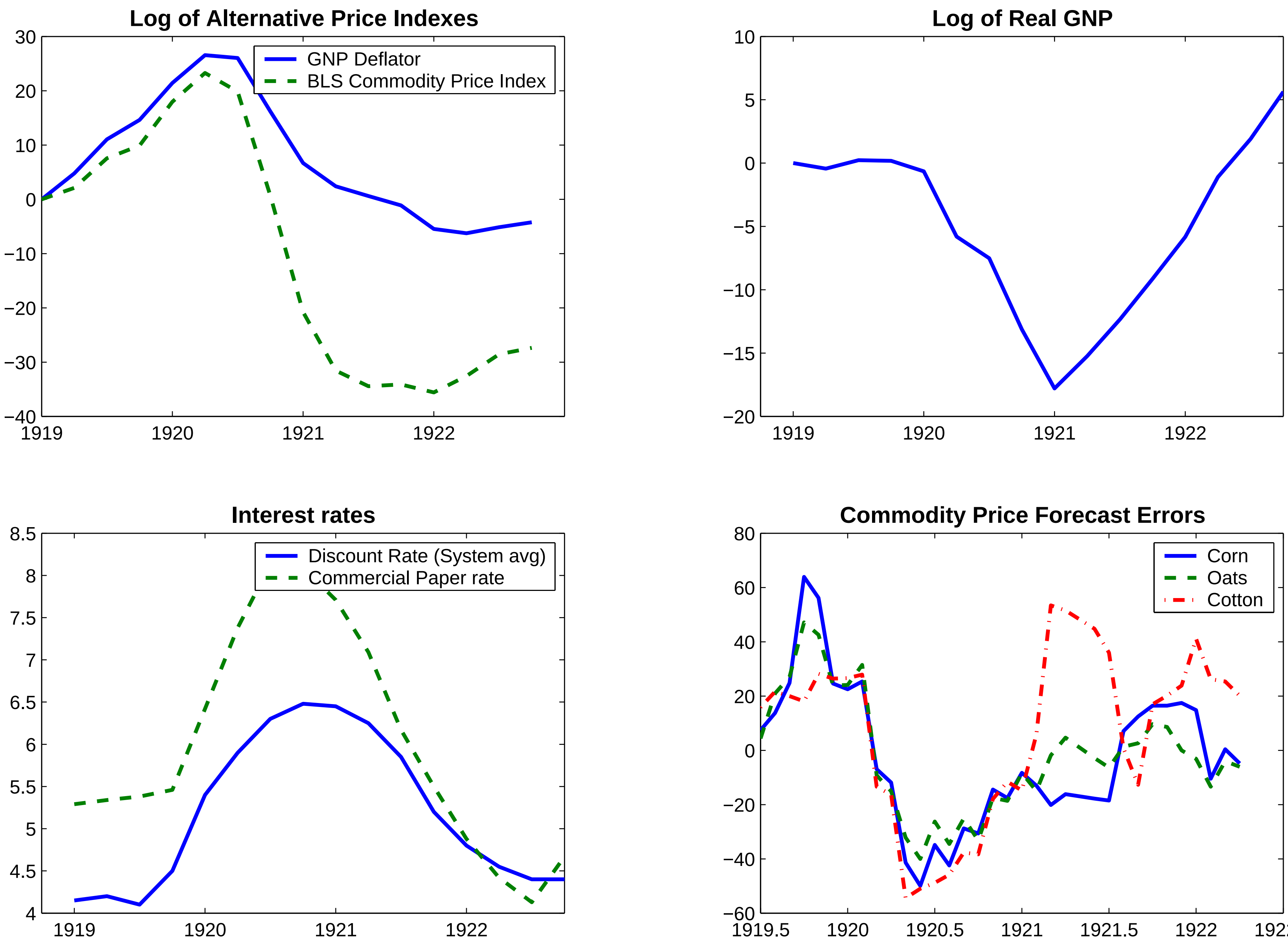

Figure 4. Macroeconomic Indicators under Volcker: 1979−1985

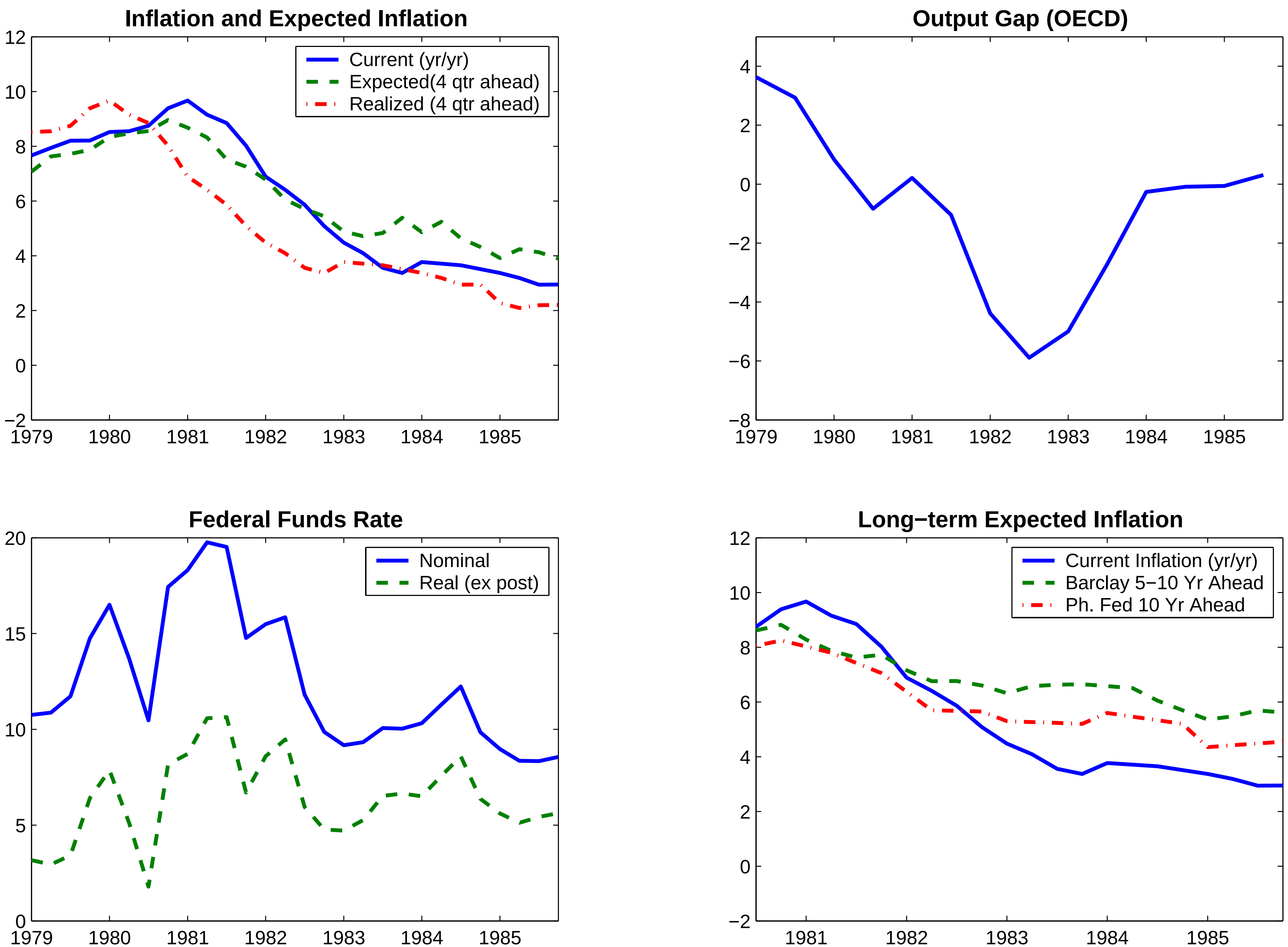

Figure 5. 1869−1879 episode: Slow Deflation

phii=1,sigma=1,phic=.6,gampi=.04,gamirs=.7,gamy=0,gampi1=0,rho1=.95,16 qtr adj under opt

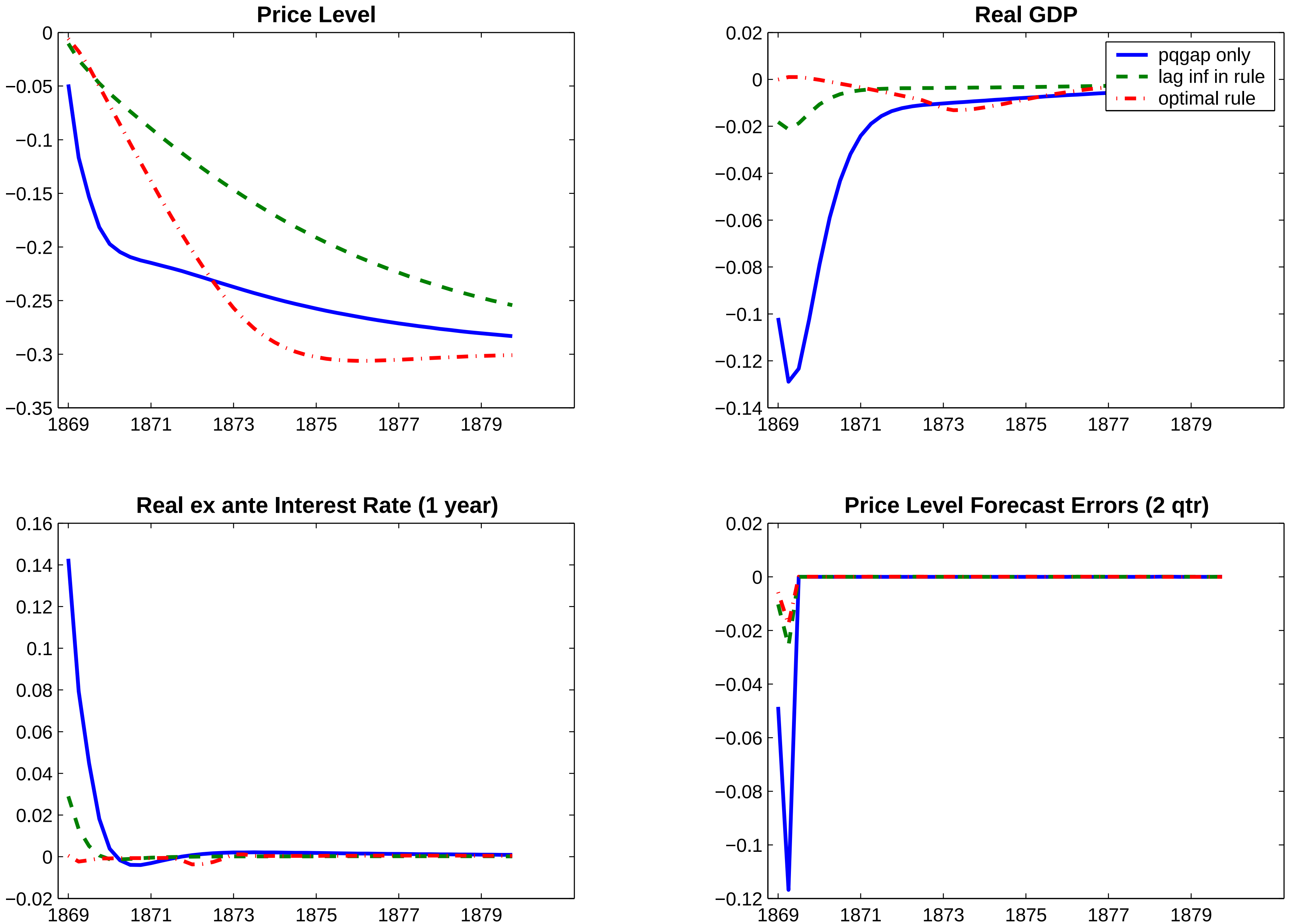

Figure 6. Baseline calibration of 1920−1922 episode: Perfect Foresight

phii=1,sigma=1,phic=.6,gampi=.04,gamirs=.7,gamy=0,gampi1=0,rho1=0,2 qtr price

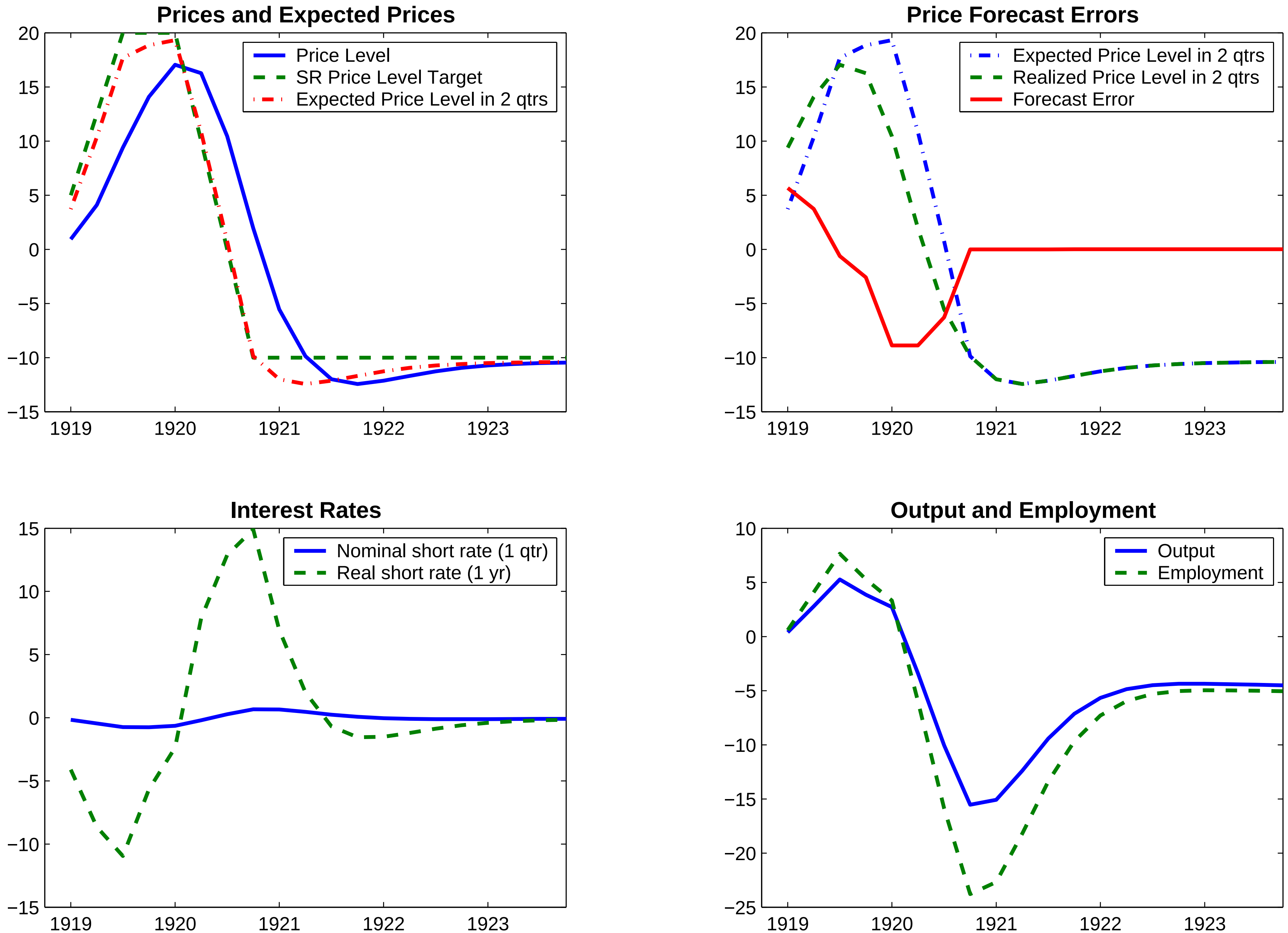

Figure 7. 1920−1922 episode: Slower Deflation

phii=1,sigma=1,phic=.6,gampi=.04,gamirs=.7,gamy=0,gampi1=0,rho1p=1,rho1t=0,sig1p=.005,2 qtr price