Contents lists available at ScienceDirect

Research in Economics

journal homepage: www.elsevier.com/locate/rie

Policy credibility and alternative approaches to disinflation

Michael Bordo^a, Christopher Erceg^{b,*}, Andrew Levin^c, Ryan Michaels^d

^a Rutgers University and NBER, USA

^b Federal Reserve Board, Mail Stop 20, 20th and C Streets NW, Washington, DC 20051, USA

^c Dartmouth University and NBER, USA

^d Federal Reserve Bank of Philadelphia, USA

ARTICLE INFO

Article history: Received 13 April 2017 Accepted 28 May 2017 Available online 21 July 2017

Keywords: Monetary policy regimes Transparency Credibility Sacrifice ratio

ABSTRACT

This paper examines how central bank credibility affects the merits of a "gradualist" versus "cold turkey" approach to disinflation in a DSGE model in which private agents use optimal filtering to infer the central bank's nominal anchor. Our analysis is applied to two episodes of sharp and deliberate monetary tightening in the United States – the post-WWI deflation and the Volcker disinflation. For a policy regime with relatively high credibility, our analysis highlights the benefits of a gradualist approach; thus, the aggressive tightening that occurred in 1920–21 did not seem warranted. In contrast, for a policy regime with relatively low credibility (such as the Federal Reserve in late 1980), an aggressive policy stance can play an important signalling role by making the policy shift more evident to private agents.

© 2017 University of Venice. Published by Elsevier Ltd. All rights reserved.

1. Introduction

It has long been recognized that episodes of deflation or disinflation may have costly implications for the real economy, and much attention has been devoted to assessing how policy should be conducted to reduce such costs. Prominent classical economists, including Hume, Thornton, and Ricardo, advocated that a deflation should be implemented gradually, if at all; in a similar vein a century later, Keynes (1925) and (Fisher, 1920) discussed the dangers of trying to quickly reverse the large runup in prices that occurred during and after World War I.

While the modern literature has provided substantial empirical evidence to support the case that deflations or disinflations are often quite costly, there is less agreement about the underlying factors that may have contributed to high real costs in some episodes, or that might explain pronounced differences in costs across episodes.¹ Indeed, disagreement about the factors principally responsible for influencing the costs of disinflation helped fuel contentious debates about the appropriate way to reduce inflation during the 1970s and early 1980s. Many policymakers and academics recommended a policy of gradualism–reflecting the view that the costs of disinflation were largely due to structural persistence in wage and price setting–while others recommended aggressive monetary tightening on the grounds that the credibility of monetary policy in the 1970s had sunk too low for gradualism to be a viable approach.

In this paper, we examine two notable episodes of *deliberate* monetary contraction: the post-WWI deflation, and the Volcker disinflation. One contribution of our paper is to draw on these episodes to illuminate the key factors that influence

* Corresponding author:

E-mail address: ercegc@frb.gov (C. Erceg).

http://dx.doi.org/10.1016/j.rie.2017.05.007







¹ For example, see Gordon (1982), Taylor (1983), Ball (1994a), and Goncalves et al. (2009).

^{1090-9443/© 2017} University of Venice. Published by Elsevier Ltd. All rights reserved.

the costs of a monetary contraction. A second contribution is to evaluate the ability of a variant of the New Keynesian model that has performed well in fitting certain features of post-war U.S. data to account for these historical episodes. Finally, our methodological contribution is to develop a theoretical framework that can provide a signalling-based rationale for adopting an aggressive policy to stabilize inflation under certain conditions.

Our paper begins by providing an overview of the two historical episodes. The price level fell by over 20% during the deflation that began in 1920, and real activity plummeted. We interpret these outcomes as attributable to the Federal Reserve's abrupt departure from the expansionary policies that had prevailed until that time; fortunately, because the ultimate policy objective was clear (reducing prices enough to raise gold reserves), the downturn was fairly short-lived.² The Volcker disinflation succeeded in reducing inflation from double digit rates in the late 1970s to a steady 4% by 1983, though at the cost of a severe and prolonged recession. We argue that the substantial costs of this episode on the real economy reflected the interplay both of nominal rigidities, and the lack of policy credibility following the unstable monetary environment of the previous 15 years.

We next attempt to measure policy predictability during each of the episodes. For the earlier period, we draw on narrative accounts from Harvard's Monthly Survey of Business Conditions (described below), as well as evidence from commodity futures. This evidence supports our interpretation that the abruptness and severity of the monetary tightening took agents by surprise, but that conditions rapidly stabilized once it was clear that the Federal Reserve had achieved its objective of reducing prices and bolstering gold reserves. For the Volcker period, we utilize direct measures of survey expectations on inflation to construct inflation forecast errors, and show that forecast errors were large and extremely persistent, suggesting a high degree of uncertainty about the Federal Reserve's policy objectives.

We then examine whether a relatively standard DSGE model is capable of accounting for these episodes. The model that we employ is a slightly simplified version of the models used by Christiano et al. (2005a) and Smets and Wouters (2003). Thus, our model incorporates staggered nominal wage and price contracts with random duration, as in Calvo (1983) and Yun (1996), and incorporates various real rigidities including investment adjustment costs and habit persistence in consumption. The structure of the model is identical across periods, aside from the characterization of monetary policy. In particular, we assume that the monetary authority targets the price level in the earlier episode, consistent with the authorities desire to reinstate or support the Gold standard; by contrast, we assume that the Federal Reserve followed a Taylor-style interest rate reaction function in the Volcker period, responding to the difference between inflation and its target value. Moreover, we assume that agents had imperfect information about the Federal Reserve's inflation target during the Volcker episode, and had to infer the underlying target through solving a signal extraction problem.

We find that our simple model performs remarkably well in accounting for the two episodes. Notably, the model is able to track the sharp but transient decline in output during the 1920s, as well as generate a substantial recession in response to the monetary tightening under Volcker. More generally, we interpret the overall success of our model in fitting these episodes as reflecting favorably on the ability of the New Keynesian model – augmented with some of the dynamic complications suggested in the recent literature – to fit important business cycle facts. Even so, our analysis underscores a key role for imperfect information in accounting for the range of outcomes.

Our model's implication that imperfect credibility about the Federal Reserve's inflation target played a key role in the macroeconomic impact of the Volcker disinflation echoes earlier work by Ball (1995), Erceg and Levin (2003), and Goodfriend and King (2005). But a novel feature of this paper is that the signal extraction problem is formulated so that the speed at which the private sector learns about a shift in the central bank's inflation target depends on how aggressively the central bank responds to inflation. Intuitively, a more aggressive monetary rule makes it easier for agents to differentiate a true shift in the inflation target from a more transient departure from the rule (i.e., " noise" in the reaction function). Such a signalling role improves the tradeoff locus associated with adopting an aggressive policy in an environment with imperfect information. This contrasts with an environment of full credibility and complete information, in which the mere announcement of a lower inflation target suffices to reduce inflation through an expectations channel; in this setting, there is little gain to trying to reduce inflation even faster by compressing the economy.

Applying this framework to critique policy during the historical episodes, we argue that a more predictable policy of gradual deflation could have helped avoid the sharp post-WWI downturn. However, the strong argument for gradualism under a transparent and credible monetary regime is less compelling if the monetary regime lacks credibility, as in the Volcker disinflation period. Volcker's aggressive policies may have induced inflation expectations to adjust more quickly than would have a more gradualist approach, allowing inflation to move more quickly to target, and shortening the duration of the recession.

The rest of the paper proceeds as follows. Section 2 describes the episodes, while Section 3 examines empirical evidence on the evolution of expectations during each episode. Section 4 outlines the model, and Section 5 describes the calibration. Section 6 matches the model to the salient features of the two episodes, and considers counterfactual policy experiments. Section 7 concludes.

² An earlier version of this paper titled "Three Great American Disinflations" also examined the deflation following the U.S. Civil War. This episode was notable insofar as the public resolve to pursue a gradual deflation beginning in 1869 was successful in reducing the price level significantly with relatively modest output losses (output growth was robust until the worldwide financial panic of 1873).

2. Historical background

2.1. The post-WWI episode

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% while the U.S. was at war, which was equal to the cumulative increase in prices over the previous 15-year period. Wartime inflation had its roots in a roughly twenty-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 A3).³

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 Gold standard.⁴ The Federal Reserve's Board of Governors included five appointees and two ex-officio members, the Secretary of Treasury and the Comptroller of the Currency. This governance structure 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 (Meltzer, 2003), the Secretary refused to support an increase in discount rates despite an acceleration in inflation into double digits in 1919.⁵ However, the Treasury's reputation was strongly linked to the success of the gold standard. In particular, U.S. law required the Federal Reserve to ensure a stock of monetary gold equal to at least 40% of the supply of base money. By November 1919, sizeable gold outflows put the legal minimum in sight, and the Treasury finally supported Board action to raise the discount rate.

Once freed to act, the Board raised the System-wide average discount rate over 2% points between late 1919 and mid-1920 (see Fig. 1). Although an eventual tightening of policy was anticipated insofar as private agents believed that the government was committed to defending the Gold standard, both the timing and severity of the contraction were a surprise. The highly persistent rise in nominal rates in the face of rapidly shifting expectations about inflation (i.e., towards deflation) represented a much tighter policy stance than agents had anticipated. As seen in Fig. 1, the aggregate price level plunged 20% between mid-1920 and mid-1921, and commodity prices declined much more precipitously. Output also declined very abruptly, especially in manufacturing. The FRB's index of industrial production fell more than 30% between mid-1920 and early 1921, while manufacturing employment showed a commensurate decline (both series are plotted at quarterly frequency). But the short-lived nature of the depression appears equally striking, as a robust expansion pushed output back to its pre-deflation level by early 1922.

The deflation of 1920 was recognized both by contemporary observers and by later historians as a dramatic event in U.S. monetary history. Fisher (1934) was strongly critical of the Federal Reserve's role in engineering a "disastrous deflation" for which "millions of workers were thrown out of work." Friedman and Schwartz (1963) observed that the price decline was "perhaps the sharpest in the entire history of the United States" and characterized the output contraction as "one of the severest on record."

The industrial production and manufacturing employment measures shown in Fig. 1 indicate a much more severe recession than would be suggested from annual data for the aggregate economy.⁶ First, the magnitude of the downturn is obscured by its relatively transitory nature, particularly since the decline in output and employment began in mid-1920 and ended partway through the following year; indeed, Friedman and Schwartz argued that this recession was so abrupt that "annual data provide a misleading indicator of its severity." Second, the fluctuations in real GNP were dampened by the stability of real agricultural output (which comprised a substantial fraction of aggregate output) and hence this measure is somewhat less relevant for gauging the effects of monetary policy during this period.⁷

The U.S. authorities' commitment to supporting the Gold Standard after WWI seems beyond doubt. By the 1920s, the Gold standard was entrenched as both a national and international norm, and even countries that had experienced much larger wartime inflations expected to return to gold. The high credibility of the monetary regime ultimately served an important role in allowing the economy to recover quickly once it was clear that prices had fallen enough. But influential Federal Reserve policymakers including Benjamin Strong believed that it was of foremost importance to reverse quickly most of the price level increase that had occurred since the U.S. entry into the war; while they acknowledged this might cause a substantial output contraction, they believed the recessionary effects would be transient and did not warrant dragging out the deflation (Meltzer, 2003). Thus, policymakers kept nominal interest rates at elevated levels even as prices fell dramatically. This departure from traditional gold standard rules – which would have prescribed cutting interest rates in the face of a massive deflation and sizeable gold inflows – helped create a depression in activity through its effect on real interest rates.

³ While the war was primarily financed through higher taxes and the issuance of government bonds, money creation by the Federal Reserve System also played a significant role (Rockoff, 2005).

⁴ Unlike the Civil war period, in which the dollar was allowed to float, the official price of gold remained fixed during WWI. Thus, the task facing policymakers was to ensure that gold reserves were sufficient to support free convertibility after the lifting of the embargo.

⁵ 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.

⁶ While government statistics indicate a very sharp recession–with real GNP in 1921 nearly 15% lower than in the previous year, the analysis of Romer (1988, 1989) and Balke and Gordon (1989) indicates that real output declined by roughly 3 to 6 percent over the period from 1919 through 1921.

⁷ For example, the National Industrial Conference Board estimated that nonagricultural employment contracted nearly 10 percent from 1919 to 1921 (Balke and Gordon, 1986; Beney, 1936).





2.2. The Volcker disinflation

As of 1979, the Federal Reserve had been in operational control of U.S. monetary policy for over 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 and steady inflation rate. But beginning in the mid-1960s, the Federal Reserve permitted inflation to rise to progressively higher levels. 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%.

Two months after taking office in August 1979, Volcker announced a major shift in policy aimed at rapidly lowering the inflation rate. Volcker 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 (Fig. 2). The announcement was followed by a series of sizeable hikes in the



Fig. 2. The Volcker disinflation.

federal funds rate: the roughly 7 percentage point rise in the nominal federal funds rate between October 1979 and April 1980 represented the largest increase over a sixth month period in the history of the Federal Reserve System. However, this tight monetary stance was temporarily abandoned in mid-1980 as economic activity decelerated sharply. Reluctantly, the FOMC imposed credit controls and let the funds rate decline – moves that the Carter Administration had publically supported. The FOMC's policy reversal and acquiesence to political pressure was widely viewed as a signal that it was not committed to achieving a sustained fall in inflation (Blanchard, 1984). Having failed to convince price and wage setters that inflation was going to fall, GNP prices rose almost 10% in 1980.

The Federal Reserve embarked on a new round of monetary tightening in late 1980. The federal funds rate rose to 20% in late December, implying an expost real interest rate of about 10%. Real expost rates were allowed to fall only slightly from this extraordinarily high level over the following two years. 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, and provided some shield from growing opposition in Congress; cf. Feldstein (1993). This second and more durable round of tightening succeeded in reducing the inflation rate from about 10% in early 1981 to about 4% in 1983, but at the cost of a sharp and very prolonged recession. The OECD's measure of the output gap expanded by 6% between mid-1980 and mid-1982, and the unemployment rate (not shown) hovered at 10% until mid-1983.

While policymakers in the Gold standard environment examined in the earlier episode had the advantage of a transparent and credible long-run nominal anchor, the Volcker disinflation was conducted in a setting in which there was a high degree of uncertainty about whether policymakers had the desire and ability to maintain low inflation rates. But notwithstanding that Federal Reserve policy during the 1970s and early 1980s merits some criticism for a lack of transparent objectives, it seems unlikely that simple announcements about long-run policy goals (e.g., an inflation target of 3%) would have carried much weight given the poor track record of the preceding two decades. Thus, it seems arguable that Volcker's FOMC had little hope of harnessing inflation expectations in a way that could facilitate lower inflation without sizeable output costs.

3. Policy predictability: empirical evidence

There is considerable evidence about the predictability of monetary policy in the post-WWI period. One very useful source is Harvard's Monthly Survey of General Business Conditions, which appeared as a monthly supplement to the Review of Economics and Statistics beginning in 1919. Harvard's Monthly Survey (HMS) interpreted recent financial and macroeconomic developments, and also made projections about the future evolution of output, prices, and short-term interest rates. While projections about individual macroeconomic series were primarily qualitative, the HMS did make some explicit forecasts about the likely duration of the business downturn during the course of 1920–21.

Drawing on the surveys from the first half of 1920, the HMS forecasters correctly predicted that the post-war inflation would be followed by a period of monetary retrenchment, and appeared to have a fairly clear understanding of the channels through which the monetary tightening would operate. In particular, they argued that the Federal Reserve's imposition of higher discount rates beginning in late 1919 would precipitate a fall in commodity prices, followed by a decline in consumer prices, wages, and business activity; but drawing on historical experience, they expected that lower prices would allow monetary easing, and promote a vigorous recovery within about a year.

The HMS forecasters turned out to be surprised by the severity of the monetary tightening, and by the associated magnitude of the price and output decline. At the onset of the tightening, the HMS commented that "both the Treasury and the Federal Reserve Board have embarked on a policy of orderly deflation," and projected in April 1920 that "it does not seem probable ... that liquidation in the near future will cause prices to fall below the level of a year ago and perhaps not below the level of November 1918," suggesting an anticipated fall in commodity prices of only 15–20%.⁸ But in the wake of a 40% decline in commodity prices by early 1921 and depression in business activity, (Bullock, 1921) observed that he and the other HMS forecasters "had not expected a (monetary) reaction of such acute severity. We had looked for a return [of commodity prices] to some such level as had prevailed in the few months following the armistice, and as late as July expected nothing so drastic as the events of the last half of the year." Moreover, the HMS forecasters were forced to revise their optimistic initial predictions (made in the spring of 1920) that recovery would occur within a year as the sharp nature of the downturn became more apparent. The HMS attributed the severity of the downturn in part to persistently high interest rates, as interest rates remained elevated for a longer duration than in previous cyclical downturns dating back to the 1890s.⁹ Nevertheless, given the enormous price contraction by early 1921, the HMS forecasters were confident that prices would soon stabilize (as in fact occurred by late 1921), and that an eventual easing of monetary conditions would facilitate a rebound in real activity.

Commodity price forecast errors provide complementary evidence that prices fell more quickly and by a greater magnitude than expected by private agents. Fig. 1 (lower right panel) shows commodity price forecast errors for three individual commodities – corn, oats, and cotton – measured as the realized price of each commodity minus the "forecast" implied by the futures price.¹⁰ 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% points or higher in absolute value terms. Forecast errors, though noisy, are generally much smaller after early 1921. This seems consistent with our intepretation that after a markedly lower price level was achieved, the policy environment became much more predictable, as agents expected the aggregate price level to remain roughly stable.

Turning next to the Volcker disinflation, there is considerable survey data available on inflation expectations at different horizons. Fig. 2 plots the median projection of four quarter ahead GNP price inflation from the Philadephia Federal Reserve's

⁸ The HMS drew on two different measures of commodity prices: a Bureau of Labor Statistics index of wholesale commodity prices, and an alternative index produced by the trade publication Bradstreet's. Using the BLS measure apparently favored by HMS researchers, commodity prices were about 19% higher in March 1920 than in March 1919, and about 15% higher than in November 1918 (using Bradstreet's, commodity prices were 15% higher than in March 1919, and 9% higher than in November 1918).

⁹ Given that the HMS forecasters saw the adjustment of retail prices to lag that of commodity prices, retail prices were expected to fall through much of 1921 (e.g., Bullock (1921)), suggesting that ex ante real interest rates were expected to remain at very elevated levels.

¹⁰ 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, with the data recorded in the Commercial and Financial Chronicle.

Survey of Professional Forecasters. The average inflation forecast error at a one year horizon (the gap between realized inflation over the subsequent year, the dash-dotted line, and the forecast, the dashed line) averaged about 2 percentage points in absolute terms over the 1981–84 period. Importantly, the inflation forecast errors show little tendency to die out, reflecting that inflation was consistently lower than what agents projected. The lower right panel of Fig.2 also contrasts the relatively quick decline in current inflation 5–10 years ahead, and by the 10 year ahead median inflation projection of the Survey of Professional Forecasters). Taken together, the survey data suggests that inflation expectations were very slow to react to the decline in realized inflation, which we interpret as strong evidence that private agents doubted the ability or desire of policymakers to maintain low inflation rates. This interpretation is consistent with that of Goodfriend (1993) and Goodfriend and King (2005), who argued that the slow adjustment of inflation expectations was a primary factor accounting for the high nominal interest rates on long-term bonds that prevailed through most of the 1980s.

4. The model

We utilize the same basic model to analyze each of the two historical episodes, aside from differences in the characterization of monetary policy. The model can be regarded as a slightly simplified version of the model utilized by Christiano et al. (2005a), and Smets and Wouters (2003). Thus, our model incorporates 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 random duration (following Calvo (1983) and Yun (1996)). 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 this discussion to Section 6 (when we present simulation results for each episode).

4.1. Firms and price setting

Final Goods Production As in Chari et al. (2000), we assume that there is a single final output good Y_t that 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:

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

$$P_t = \left[\int_0^1 P_t(f)^{\frac{-1}{\theta_p}} df\right]^{-\theta_p}$$
(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 $P_t(f)$, and directly with aggregate demand Y_t :

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

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

$$Y_t(f) = K_t(f)^{\alpha} L_t(f)^{1-\alpha}$$
(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 , and the aggregate capital stock K_t , or equivalently, as the ratio of the wage index to the marginal product of labor MPL_t :

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

Note that the aggregate stock of capital is simply the sum of the capital stocks held by individual firms, i.e., $K_t = \int_0^1 K_t(f) df$, and similarly for the aggregate stock of labor.

We assume that the prices of the intermediate goods are determined by Calvo–Yun style staggered nominal contracts. In each period, each firm faces a constant probability, $1 - \xi_p$, of being able to reoptimize its price $P_t(f)$. The probability that any firm receives a signal to reset its price is assumed to be independent of the time that it last reset its price. If a firm is not allowed to optimize its price in a given period, we follow Yun (1996) by assuming that it simply adjusts its price by the steady state rate of inflation Π (i.e., $P_t(f) = \pi P_{t-1}(f)$). Finally, the firm's output is subsidized at a fixed rate τ_p (this allows us to eliminate the monopolistic competition wedge in prices 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:

$$L_t = \left[\int_0^1 N_t(h)^{\frac{1}{1+\theta_w}} dh\right]^{1+\theta_w}$$
(6)

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 :

$$W_t = \left[\int_0^1 W_t(h)^{\frac{-1}{\theta_w}} dh\right]^{-\theta_w}$$
(7)

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

$$N_t(h) = \left[\frac{W_t(h)}{W_t}\right]^{-\frac{1+2w}{\phi_w}} L_t$$
(8)

The utility functional of a typical member of household h is

$$\mathbb{E}_{t} \sum_{j=0}^{\infty} \beta^{j} \{ \frac{1}{1-\sigma} \left(C_{t+j}(h) - \varkappa C_{t+j-1} \right)^{1-\sigma} + \frac{\chi_{0}}{1-\chi} (1-N_{t+j}(h))^{1-\chi} + \frac{\mu_{0}}{1-\mu} \left(\frac{M_{t+j}(h)}{P_{t+j}} \right)^{1-\mu} \}$$
(9)

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 external habit persistence in consumption spending (e.g., Smets and Wouters (2003)). In addition, the period utility function depends on current leisure $1 - N_t(h)$, and current real money balances $\frac{M_t(h)}{P_t}$.

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:

$$P_{t}C_{t}(h) + P_{t}I_{t}(h) + \frac{1}{2}\psi_{l}P_{t}\frac{(l_{t}(h) - l_{t-1}(h))^{2}}{l_{t-1}(h)} + M_{t+1}(h) - M_{t}(h) + \int_{s}\xi_{t,t+1}B_{D,t+1}(h) - B_{D,t}(h)$$

$$= (1 + \tau_{W})W_{t}(h)N_{t}(h) + R_{Kt}K_{t}(h) + \Gamma_{t}(h) - T_{t}(h)$$
(10)

Thus, 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. The total cost of investment to each household h is assumed to depend on how rapidly the household changes its rate of investment (as well as on the purchase price). Our specification of such investment adjustment costs as depending on the square of the change in the household's gross investment rate follows Christiano et al. (2005a). 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:

$$K_{t+1}(h) = (1-\delta)K_t(h) + I_t(h)$$
(11)

In addition to accumulating physical capital, households may augment their financial assets through increasing their nominal money holdings $(M_{t+1}(h) - M_t(h))$, and through the net acquisition of bonds. We assume that agents can engage in frictionless trading of a complete set of contingent claims. The term $\int_{S} \xi_{t,t+1} B_{D,t+1}(h) - B_{D,t}(h)$ represents net purchases of state-contingent domestic bonds, with $\xi_{t,t+1}$ denoting the state price, and $B_{D,t+1}(h)$ the quantity of such claims purchased at time *t*. Each member of household *h* earns labor income $(1 + \tau_W)W_t(h)N_t(h)$ (where τ_W is a subsidy that allows us to offset monopolistic distortions in wage-setting), 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, and pays a lump-sum tax of $T_t(h)$ (this may be regarded as taxes net of any transfers).

In every period *t*, each member of household *h* maximizes the utility functional (9) with respect to its consumption, investment, (end-of-period) capital stock, money balances, and holdings of contingent claims, subject to its labor demand function (8), budget constraint (10), and transition equation for capital (11). Households also set nominal wages in Calvostyle staggered contracts that are generally similar to the price contracts described above. Thus, the probability that a household receives a signal to reoptimize its wage contract in a given period is denoted by $1 - \xi_w$, and as in the case of price contracts this probability is independent of the date at which the household last reset its wage. However, we specify a dynamic indexation scheme for the adjustment of the wages of those households that do not get a signal to reoptimize which implies that their wages adjust at the average level of wage inflation in the previous period (i.e., full dynamic indexation). As discussed by Christiano et al. (2005a), dynamic indexation of this form introduces some element of structural persistence into the wage-setting process. Our asymmetric treatment of wage-setting compared with price-setting is motivated by the empirical analysis of Levin et al. (2005). These authors estimated a similar model using U.S. data over the 1955:1–2001:4 period, and found evidence in favor of nearly full indexation of wages, but not of prices (hence our specification of prices as purely forward-looking).

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:

$$M_t - M_{t-1} + \int_0^1 T_t(h)dh = \int_0^1 \tau_p P_t(f) Y_t(f)df + \int_0^1 \tau_w W_t(h) N_t(h)dh + P_t G_t$$
(12)

where G_t indicates real government purchases. We assume that government spending is a fixed share of output in our analysis. The total output of the service sector is subject to the following resource constraint:

$$Y_t = C_t + I_t + G_t \tag{13}$$

The monetary policy reaction function differs across regimes, and will be described below.

4.4. The log-linearized equations

4

In the log-linear approximation to the model that we use below, price inflation evolves according to a standard New Keynesian Phillips Curve which links current price inflation π_t to real marginal cost mc_t and expected future inflation:

$$\pi_t = \beta \pi_{t+1|t} + \kappa_{mc} m c_t. \tag{14}$$

The parameter κ_{mc} determining the sensitivity of inflation to marginal cost depends on the mean price contract duration $\frac{1}{1-\xi_p}$ according to $\kappa_{mc} = \frac{(1-\xi_p)(1-\beta\xi_p)}{\xi_p}$. Real marginal cost in turn depends on the gap between the product real wage w_t^r and the marginal product of labor mpl_t :

$$mc_t = w_t^r - mpl_t = w_t^r + n_t - y_t.$$

$$\tag{15}$$

The final equality follows from the definition of the mpl_t and the Cobb–Douglas form of the production function:

$$y_t = \alpha k_t + (1 - \alpha) n_t. \tag{16}$$

The household's first order condition for holding bonds implies a (log-linearized) consumption Euler equation linking the marginal utility of consumption λ_{ct} to the future marginal utility of consumption and to the real interest rate, which is the difference between the central bank's policy rate i_t and expected inflation:

$$\lambda_{ct} = \lambda_{ct+1|t} + i_t - \pi_{t+1|t},\tag{17}$$

The marginal utility of consumption varies inversely with current consumption c_t , but rises with past consumption due to habit persistence:

$$\lambda_{ct} = -\frac{1}{\sigma(1-\varkappa)} (c_t - \varkappa c_{t-1}).$$
(18)

Taken together, these equations imply that a rise in the real interest rate depresses consumption, though habit damps the near-term effects.

The Calvo-style wage contracting structure with dynamic indexation implies a wage-setting equation of the form:

$$\omega_t - \omega_{t-1} = \beta(\omega_{t+1|t} - \omega_t) + \kappa_{\omega}(\mathsf{mrs}_t - w_t^r).$$
⁽¹⁹⁾

Thus, wage inflation rises if the current and future disutility from working (the mrs_t) exceeds the real wage, where the mrs_t varies directly with hours worked and inversely with the marginal utility of consumption, so that $mrs_t = \hat{\chi}n_t - \lambda_{ct}$. The parameter κ_w is given by $\kappa_w = \frac{(1-\xi_w)(1-\beta\xi_w)}{\xi_w}(\frac{1}{1+\hat{\chi}\frac{1+\theta_w}{\vartheta_w}})$, and hence depends both on the mean wage contract duration $\frac{1}{1-\xi_w}$

and also on strategic complementarities in wage-setting that reflect the degree of substitution between the different types of labor input and the Frisch elasticity of labor supply $\hat{\chi}$. The real wage evolves according to the identity:

$$w_t^r = w_{t-1}^r + \omega_t - \pi_t.$$
(20)

Turning to investment, the change in investment depends on current and future Tobin's q according to:

$$i_t - i_{t-1} = \beta(i_{t+1} - i_t) + \frac{1}{\psi_l} q_t.$$
⁽²¹⁾

Tobin's q varies directly with the path of the expected return to capital r_{kt+1+j} and inversely with the path of real interest rates $i_t - \pi_{t+1|t}$ (j > 0) with both of these factors discounted by the rate of time preference and depreciation rate of capital:

$$q_t = \beta(1-\delta)q_{t+1|t} - \beta(i_t - \pi_{t+1|t}) + (1-\beta(1-\delta))r_{kt+1}.$$
(22)

The capital stock evolves according to:

$$k_{t+1} = (1-\delta)k_t + \delta i_t \tag{23}$$

Finally, with government spending a constant fraction of output, the aggregate resource constraint may be written as:

$$(1 - g_y)y_t = c_y c_t + i_y i_t.$$
(24)

where g_y is the steady state share of government spending in output, c_y the consumption share, and i_y the investment share.

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 $\beta = .9925$, consistent with a steady-state annualized real interest rate \bar{r} of about 3%. 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 $\kappa = 0.6$ (similar to 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 10, implying a Frisch elasticity of labor supply of 1/5. This is considerably lower than if preferences were logarithmic in leisure, but within the range of most estimates from the empirical labor supply literature. 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 share of government spending of output g_y is set equal to 12%.

The capital share $\alpha = 1/3$. The quarterly depreciation rate of the capital stock $\delta = 0.02$, implying an annual depreciation rate of 8%. The price and wage markup parameters are given by $\theta_P = \theta_W = 1/5$. We set the cost of adjusting investment parameter $\phi_I = 2$, which is somewhat smaller than the value estimated by Christiano et al. (2005b) using a limited information approach; however, the analysis of Erceg et al. (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. We assume that price contracts last three quarters, while nominal wage contracts last four quarters. The calibration of contract duration is in the range typically estimated in the literature.¹¹

6. Model simulations

6.1. The post-WWI deflation

We now turn to using our model to characterize the severe monetary recession that began in 1920. As discussed above, the salient feature was a precipitous and largely unexpected decline in the price level of about 20% over a period of less than two years, and a sharp but fairly short-lived contraction in activity. Despite obvious difficulties in characterizing policy

¹¹ See Nakamura and Steinsson (2013) for an extensive survey on price-setting. Bils et al. (2016) find that wages are adjusted about once a year.

during this turbulent period, many of the prominent features of the policymaking framework can be summarized in a simple instrument rule of the form:

$$i_t = \gamma_i i_{t-1} + \gamma_P (p_t - p_t^*)$$
 (25)

This rule posits the nominal interest rate i_t as responding to the price level gap $(p_t - p_t^*)$, as well as to its own lag (a constant term is suppressed for simplicity). This specification has two salient features. First, policy rates are driven exclusively by the difference between the current price level and its target p_t^* . This specification is intended to capture the belief of key Federal Reserve policymakers that continued adherence to the Gold standard hinged on rolling back the rise in the U.S. price level that had occurred following the U.S. entry into the war. While it was recognized that real activity might suffer in the short-run, it was regarded of paramount importance to reduce prices enough to faciliate an adequate buildup of gold reserves. The second key feature of (25) is that nominal rates do not respond to inflation (either ex post or ex ante). As shown below, this helps account for the empirical observation that nominal rates remained high despite an enormous decline in the price level in 1920–21.

The price level target is assumed to follow an exogenous random walk, so that any shift in the target is perceived as permanent. The shock we consider involves a 20% cumulative reduction in p_t^* that begins in 1920q1. While private agents are assumed to observe the underlying price level target, we assume that the shock is phased-in over three quarters, in part to match the modest persistence suggested by the commodity price forecast errors discussed in Section 3. Finally, we set $\gamma_i = .5$ to allow for a modest degree of interest rate smoothing, and $\gamma_P = .12$ in order to allow our model to do reasonably well in matching the rise in nominal interest rates that occurred in the historical episode.

Simulation results for our benchmark case are shown by the solid black lines in Fig. 3.¹² The model simulation generates a large decline in the price level beginning in 1920 that is similar in magnitude to that observed. The sharpness of this price decline is well-captured by our modelling framework, in which prices are determined by Calvo-style contracts without dynamic indexation. The speed of the price decline would be much more difficult to rationalize in a model that incorporated dynamic price indexation or other forms of intrinsic inflation persistence.

The model implies a pronounced output decline that is followed by a rapid recovery, which is similar to the pattern observed historically. The output decline in our model simulation is attributable to a sizeable and fairly persistent rise in the real interest rate. The substantial rise in real long-term interest rates despite little movement in the nominal interest rate reflects both that agents came to expect large price declines, and that policy would maintain high nominal rates even in a deflationary environment.¹³

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. Consistent with our historical analysis, the Federal Reserve used, in effect, the blunt instrument of a severe recession to push down prices, rather than operating more gradually. Accordingly, it is of interest to consider the counterfactual simulation depicted by the dashed blue lines, 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 (but is otherwise identical to equation (25)). Clearly, while allowing for nominal rates to decline with inflation would have induced a more gradual convergence in prices to target, it would have greatly ameliorated the output costs.

It may seem surprising that the peak output decline even in the counterfactual is as high as 5%, given that the deflation is stretched out over more than a four year period. This raises the more general issue of how quickly a deflation can be implemented without causing substantial fallout on the real economy. This question has a close parallel in earlier work by Taylor (1983) and Ball (1994b; 1995), but with the important difference that these authors assessed how the output costs depended on the horizon over which the *inflation rate* was changed, rather than the *price level*. While Taylor and Ball found that a disinflation could be implemented over a short horizon of roughly two years or less with minimal output losses, our results suggest that a considerably longer horizon is required to implement a change in the price level. The difference reflects that while the staggered contracts framework implies little endogenous persistence in the inflation rate – so that it is relatively easy for inflation to jump – it implies considerably more price level persistence.

6.2. The Volcker disinflation

Even as U.S. inflation rose to double digit rates in the 1970s, most prominent economists were supportive of a gradualist approach in which inflation would be reduced to its desired level within a time frame of roughly 3–5 years. This stance was buttressed by model-based analysis which typically concluded that a rapid disinflation would be very costly due to the

¹² The figure shows results in percent deviations from steady state levels (or percentage point deviations for interest rates).

¹³ In an earlier version of this paper, we attempted to account for the effects of the massive decline in government spending following the November 1918 armistice by including a sequence of contractionary government spending shocks. We found that the inclusion of these shocks markedly dampened the effects of the post-war monetary expansion on output. However, given that the government spending declines were concentrated in 1919, they had a small effect on the behavior of output and prices thereafter. Hence, given our focus on the period following the monetary contraction of early 1920, we have confined our attention to monetary shocks.





existence of long-term contracts, especially in the labor market.¹⁴ But as discussed in Sections 2 and 3, the actual conduct of the Volcker disinflation seemed in sharp contrast to these prescriptions in favor of gradualism.

In this section, we argue that there is a much stronger rationale for adopting an aggressive approach to stabilizing inflation *under certain conditions* than appears to have been recognized in the previous literature. In particular, a key benefit of an aggressive policy is that it can play a useful signalling role in indicating a policy shift (towards lower inflation) in an environment in which the private sector has imperfect information about the central bank's inflation target. Our framework builds on earlier work by Erceg and Levin (2003) that attributes inflation persistence and persistent output losses to imper-

¹⁴ For example, Taylor (1983) used a model with overlapping wage contracts to show that it was desirable to reduce money growth gradually in the early stages of a disinflation in order to minimize adverse effects on the real economy. However, Taylor also cautioned that the desirability of this gradualist approach was predicated on the disinflation having a high degree of credibility.



Fig. 4. The estimated policy reaction function during the Volcker disinflation.

fect information about the central bank's inflation target. However, the perceived evolution of the inflation target was not influenced by the parameters of the monetary policy rule in that model, implying that policy could only influence inflation expectations through the costly channel of creating a deep recession.

A key innovation of the framework discussed below is to allow the aggressiveness of the response to the inflation gap in the policymaker's rule to influence how rapidly agents learn about a shift in the underlying target. Because policymakers have greater latitude to influence inflation expectations through choice of an aggressive rule, such a policy is relatively more appealing to consider. Although the downside of an aggressive rule is that it generates a relatively large initial output contraction, both the inflation gap and output gap close much more rapidly than under a less aggressive, or gradualist, policy.

Our first step in modelling the Volcker disinflation episode consists of estimating a stylized version of the central bank's reaction function, which we specify as a slightly modified version of the Taylor rule:

$$i_{t} = \gamma_{i}i_{t-1} + (1 - \gamma_{i})(\bar{r} + \pi_{t}) + \gamma_{\pi}(\pi_{t} - \pi_{t}^{*}) + \gamma_{\nu}(\Delta y_{t} - \bar{g}) + e_{t}$$
(26)

Here i_t is the short-term nominal interest rate, π_t is the four-quarter change in the GDP price deflator, π_t^* is the central bank's inflation target, Δy_t is the four-quarter change in real GDP, and e_t denotes the shock to the policy reaction function, where all variables are expressed at annual rates in percentage points.¹⁵ The policy reaction function is estimated over the sample period 1980:3 through 1986:4, thereby excluding the policy reversal that occurred early in Volcker's tenure (as discussed in section 2.3).¹⁶ Least squares estimation over this sample period yields $\gamma_i = 0.63$, $\gamma_{\pi} = 0.69$, and $\gamma_y = 0.29$. As seen in Fig. 4, this simple form of the reaction function accounts reasonably well for the evolution of the funds rate over the sample period.

Agents cannot directly observe the long-run inflation target π_t^* , or the monetary shock e_t ; but given that agents observe interest rates, inflation, and output growth (as well as all of the structural parameters of the model), they can infer a composite shock ϕ_t which is a hybrid of the inflation target shock and the monetary policy shock:

$$\phi_t = -\gamma_\pi \pi_t^* + e_t \tag{27}$$

¹⁵ For simplicity, the constant terms have been suppressed in Eq. (26). The output gap has been omitted from the Taylor rule because, as found by Erceg and Levin (2003), it does not improve specification fit over this period.

¹⁶ In this regression, the short-term nominal interest rate is measured by the federal funds rate, the steady-state real interest rate \bar{r} is set to 3% (consistent with our specification of the discount factor β), steady-state output growth \bar{g} is set to 2.5%, and the inflation target π^* is specified as 4% over this sample period.

The unobserved components in turn are perceived to follow a first-order vector autoregression:

$$\begin{bmatrix} \pi_t^* \\ e_t \end{bmatrix} = \begin{bmatrix} \rho_p & 0 \\ 0 & \rho_q \end{bmatrix} \begin{bmatrix} \pi_{t-1}^* \\ e_{t-1} \end{bmatrix} + \begin{bmatrix} \upsilon_1 & 0 \\ 0 & \upsilon_2 \end{bmatrix} \begin{bmatrix} \varepsilon_{pt} \\ \varepsilon_{qt} \end{bmatrix}$$
(28)

The inflation target π_t^* is highly persistent, and has an autoregressive root ρ_p arbitrarily close to unity. For simplicity, we assume that the random policy shock e_t is white noise (so $\rho_q = 0$). The innovations associated with each shock, ε_{pt} and ε_{qt} , are mutually uncorrelated with unit variance.

Given this linear structure, we assume that agents use the Kalman filter to make optimal projections about the unobserved inflation target π_t^* . The inflation target perceived by agents evolves according to a first order autoregression. Agents update their assessment of the inflation target by the product of the forecast error innovation and a constant coefficient. This coefficient, which is proportional to the Kalman gain, can be expressed as a function of the signal-to-noise ratio $(\gamma_{\pi} \frac{\nu_1}{\nu_2})$. Clearly, the signal-to-noise ratio depends on the relative magnitude of innovations to each of the components of the observed shock ϕ_t ; but crucially, it also depends directly on the weight γ_{π} on the inflation target in the central bank's reaction function. Intuitively, if policy is aggressive in reacting to the inflation gap, agents will attribute more of any unexplained rise in interest rates to a reduction in the central bank's long-run inflation target, rather than to random policy shocks. Thus, the policy rule parameters have a direct effect on how the perceived inflation target responds to shocks, including a downward revision to the inflation target.

Our approach to modeling the filtering problem contrasts to that in previous analysis by Erceg and Levin (2003) in which $\phi_t = -\gamma_\pi (\pi_t^* - e_t)$. Although the difference in specifications may seem immaterial at first blush, the latter implies that the signal-to-noise ratio ratio is independent of the coefficient on the inflation gap γ_π in the monetary rule, and hence precludes any role for signalling through an aggressive policy rule. We estimate the signal-to-noise ratio (i.e., $\frac{v_1}{v_2}$, using the estimated value of γ_π) by choosing the value that minimizes the

We estimate the signal-to-noise ratio (i.e., $\frac{\nu_1}{\nu_2}$, using the estimated value of γ_{π}) 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.¹⁷ In particular, we minimize the loss function:

$$Loss = \sum_{j=0}^{20} \left[\mathbb{E}_{t+j} \pi_{t+3+j}^4 (survey \ data) - \mathbb{E}_{t+j} \pi_{t+3+j}^4 (mod \ el) \right]^2$$
(29)

The estimation period is 1980:4 through 1984:4. The model expectation in (29) is the expected rate of four-quarter ahead inflation that agents project at each date, given an assumed one-time shift in the inflation target of 6 percentage points that occurs in 1980:4. Our estimation routine yields a point estimate of $(\frac{\nu_2}{\nu_1})$ that implies a Kalman gain coefficient on the forecast error innovation of about 0.10.

We next evaluate the ability of our model to fit the Volcker period. Fig. 5 shows the effects of a 6 percentage point immediate reduction in the Federal Reserve's inflation target in our benchmark model. The learning problem about the inflation target plays a critical role in allowing our model to account for the main features of the Volker disinflation episode discussed above, including sluggish inflation adjustment, a persistently negative output gap, and an initial rise in the nominal interest rate. The inflation rate declines in roughly exponential fashion in our model simulation, with about half of the eventual 6 percentage point fall occurring after four quarters, and most of it after ten quarters. Our model's predicted path for inflation is very similar to that observed during the actual episode. Moreover, long-run expected inflation in our model (see the lower right panel) declines much more slowly than current inflation, which is also consistent with the historical experience. This pattern in our simulation reflects that long-run inflation is largely determined by expectations about the future course of the inflation target, which evolve very slowly, while short-run inflation can drop more quickly in response to the depressed state of real activity.

Our model does quite well in accounting for both the magnitude of the output decline and its timing. As shown in the upper-left panel, real GDP exhibits a substantial and persistent decline, with a cumulative loss (relative to trend) of about 10 percentage points over the period 1981 through 1984. This loss is consistent with a sacrifice ratio of about 1.7, remarkably close to the sacrifice ratio implied by the OECD output gap data shown in Fig. 2 and to Ball's (1994a) estimate of 1.8 for this episode.

Interestingly, the model does well in accounting for the timing of the output trough: as in the OECD data, the trough occurs about 6 quarters after the initial shock. Our model's ability to capture the timing of the Volcker recession provides support for specifying adjustment costs as dependent on the change in investment, rather than following a traditional Q-theory approach in which adjustment costs depend on the change in capital stock.¹⁸ By contrast, Erceg and Levin (2003) utilized a Q-theory specification, and found that investment dropped precipitously following the initial rise in interest rates, so that the peak decline in both output and the expenditure components occurred roughly one quarter after the shock.

The ability of our model to account for the Volcker period is enhanced by allowing for the dynamic indexation of nominal wage contracts. In the absence of dynamic wage indexation, real interest rates exhibit a smaller and less persistent increase,

¹⁷ We use the median of four-quarter ahead inflation forecasts taken from the Survey of Professional Forecasters; this series is plotted in Fig. 2).

¹⁸ Christiano et al. (2005a) argued that such a specification provides a much better account of investment dynamics in response to a monetary policy shock.





and output contracts much less than under our benchmark specification. It might be supposed that the additional inclusion of dynamic price indexation would produce an even larger output decline, and hence improve on our benchmark model's ability to account for the output contraction under Volcker. We found, however, that incorporating this form of structural persistence in the inflation rate produced only a marginally larger output decline in our model simulation, while implying a much slower drop in inflation than occurred in the historical episode.

While we think that the ability of a relatively simple model to account for the broad features of the Volcker recession is impressive, we suspect that the inclusion of credit market imperfections and sectoral differentiation in production could enhance the model's ability to account for the depth of the Volcker recession. In particular, a model that could account for the massive increase in default spreads that occurred in the early 1980s, such as the financial accelerator framework of Bernanke et al. (1999) and related work by Christiano et al. (2010), might well provide an even closer quantitative match to the actual experience.





We next turn to applying our model to evaluate some of the criticism levelled at the rapid pace of the Volcker disinflation and the highly aggressive policy stance required to support it. Our analysis indicates that this critique would have been justified if the Federal Reserve's policies were regarded as highly credible. In particular, Fig. 6 reconsiders our benchmark scenario under the assumption that agents have complete information about the shift in the inflation target π_t^* . We interpret this setting as approximating the case of a highly credible and transparent policy environment. As might be expected, inflation converges to the new target in a little more than a year while the output decline is correspondingly much shorterlived. Nevertheless, a policymaker placing a sufficiently high weight on the output gap relative to inflation might view this output decline as unnecessarily costly. Accordingly, the figure also depicts a rule that responds much less aggressively to the inflation gap; that is, $\gamma_{\pi} = 0.25$ rather than 0.69 as in our benchmark rule. In this case, the output decline is a bit smaller while inflation declines almost as rapidly. Conversely, a more aggressive rule with a coefficient of $\gamma_{\pi} = 2$ would only succeed in bringing inflation down a bit more quickly than under the benchmark rule but at the cost of a significantly larger output decline.





Thus, in an environment with complete information about the central bank's underlying inflation target, the level of inflation comes down rapidly even if the monetary reaction function is fairly nonaggressive in responding to inflation. This is because the expectation of slower growth in future prices and wages – associated with the mere announcement of a lower inflation target – immediately exerts a strong restraining effect on current inflation. Nevertheless, because there is some structural persistence in inflation due to dynamic wage indexation, attempting to disinflate too quickly – meaning faster than in roughly 5 or 6 quarters in our model – can still produce a sizeable contraction in activity. Given these tradeoffs, a more gradualist course would seem preferable unless the policymaker placed virtually no weight on output gap stabilization.

However, this argument in favor of a gradualist policy is predicated on high credibility and transparency of the underlying inflation target, assumptions which seem implausible in the environment faced by Volcker. As discussed above, our model with imperfect information has been formulated to highlight some of the potential benefits that may accrue through a signalling channel of adopting an aggressive policy stance. A given-sized change in the inflation target induces a sharper rise in interest rates if γ_{π} is large: thus, in an environment where agents must infer policy actions rather than observe

In this vein, Fig.7 compares the implications of our benchmark policy rule under incomplete information (repeating the analysis of Fig.5) to two alternative rules that vary the weight on the inflation gap in the same way as just considered above: thus, we consider a less aggressive response with $\gamma_{\pi} = 0.25$, and a more aggressive response with $\gamma_{\pi} = 2$. We model the signalling value associated with an aggressive policy response by assuming that the innovations v_1 and v_2 of the observable ϕ_t are constant in our experiments, which has the effect of reducing the Kalman gain coefficient as γ_{π} falls. Thus, the Kalman gain coefficient falls from 0.10 in our benchmark to 0.04 in the alternative with a coefficient of $\gamma_{\pi} = 0.25$; conversely, the Kalman gain rises to 0.27 with the aggressive coefficient of $\gamma_{\pi} = 2$.

Considering the same 6 percentage point shock to the inflation target, it is evident in the lower right panel that longterm expected inflation declines much more gradually for the lower value of γ_{π} . In particular, long-run expected inflation is still close to 5% even at the end of the decade; in contrast, under the benchmark rule, these expectations approach very close to the 4% target within about five years. Unsurprisingly, output exhibits a smaller short-run contraction under the alternative policy rules compared with the benchmark rule, reflecting less pronounced increases in both short-term and long-term real interest rates. But importantly, because private agents learn more slowly about the new inflation target under this alternative, output shows a less rapid recovery in these cases than under the benchmark rule, and real interest rates remain persistently above baseline. Conversely, while a policy that responded even more aggressively to inflation than under the benchmark would produce a larger initial downturn, it causes inflation to fall even more quickly, and hence generates a faster recovery.

Overall, while the less aggressive rules succeed in reducing the severity of the initial output downturn relative to our benchmark scenario, these rules also lead to a somewhat more protracted recession, and markedly prolong the period over which inflation remains above target. Thus, even if gradualism might seem highly attractive under policy credibility for a wide range of policymaker preferences (provided preferences aren't tilted toward reducing inflation at all costs), a much more aggressive response might be warranted in cases of low policy credibility.

7. Conclusions

Our work has highlighted how the implications of alternative strategies of gradualism vs. aggressive disinflation hinge on the perceived credibility and transparency of the central bank. Under imperfect credibility, aggressive policy may play a very useful signalling role and help move inflation expectations more quickly towards target; conversely, a gradualist approach may contribute to a more prolonged, even if somewhat shallower, recession. Applied to historical experience, it appears that a gradualist course would have been more appropriate after WWI, given the high credibility of the prevailing Gold standard, and could have helped avoid the sharp recession. But it seemed warranted to pursue an aggressive policy in the early 1980s; in particular, Volcker's abrupt tightening probably contributed to a relatively fast decline in inflation expectations, and ultimately shortened the duration of the recession.

Admittedly, the nature of the signal extraction problem in our framework is quite stylized. The private sector understands both the form and parameters of the monetary policy rule, and the perceived inflation target converges monotonically to the new target desired by central bank. Clearly, actual episodes of sharp disinflation or deflation typically involve considerable uncertainty about the objectives of the central bank, the approach it will adopt to bring about these objectives, and about whether it has the means to achieve them. In future work, it would be of interest to investigate the consequences of uncertainty about the central bank's policy rule, possibly in a framework with Bayesian learning about key parameters. It would also be desirable to consider the implications of possible reversion to a higher inflation target in the spirit of Ball (1995) and Goodfriend and King (2005). It is plausible that the benefits of aggressive policy would be even higher in such an environment.

Acknowledgements

We thank Gauti Eggertson, Benjamin Friedman, Dale Henderson, Jinill Kim, Lee Ohanian, Thomas Sargent, Anna Schwartz, Lars Svensson, John Taylor, Francois Velde, Marc Wiedenmeier, and Tack Yun for helpful comments and suggestions, as well as seminar participants at Columbia University, the Federal Reserve Board, the Federal Reserve Bank of San Francisco, Harvard University, the International Research Forum on Monetary Policy conference, and at an NBER Monetary Economics meeting. Bordo received financial support from the Federal Reserve Board on this project. The views expressed in this paper are solely the responsibility of the authors and should not be interpreted as reflecting the views of the Board of Governors of the Federal Reserve System or of any other person associated with the Federal Reserve System.

References

Balke, Nathan, S., Gordon, R.J., 1986. Data appendix b in. In: Gordon, R.J. (Ed.), The American Business Cycle: Continuity and Change. University of Chicago Press, Chicago.

Anderson, G.S., Moore, G., 1985. A linear algebraic procedure for solving linear perfect foresight models. Econ. Lett. 17, 247-252.

Balke, S. Nathan, Gordon, R.J., 1989. The estimation of prewar gross national product: methodology and new evidence. J. Polit. Econ. 97 (1), 38–92. Ball, Lawrence, 1994a. What determines the sacrifice ratio?. In: Mankiw, N.G. (Ed.), Monetary Policy. University of Chicago Press, Chicago.

Ball, Lawrence, 1994b. Credible disinflation with staggered price-setting. Am. Econ. Rev. 84, 282-289.

Ball, Lawrence, 1995. Disinflation and imperfect credibility. J. Monet. Econ. 35, 5-24.

Beney, Ada, 1936. Wages, Hours, and Employment in the United States, 1914-1936, New York, National Industrial Conference Board, Inc.

Bernanke, Ben, Gertler, Mark, Gilchrist, Simon, 1999. The Financial Accelerator in a Quantitative Business Cycle Framework. In: Taylor, J., Woodford, M. (Eds.), Handbook of Macroeconomics. Elsevier, Amsterdam.

Bils, Mark, Chang, Y., Kim, S.-B., 2016. How sticky wages in existing jobs can affect hiring, yonsei university working paper no. 2016rwp-91.

Blanchard, Olivier, 1984. The Lucas Critique and the Volcker Disinflation, NBER Working paper 1326.

Blanchard, Olivier, Kahn, C., 1980. The solution of linear difference models under rational expectations. Econometrica 48, 1305-1311.

Bullock, Charles J., 1921. Review of the year 1920. Rev. Econ. Stat. 3 (1), 7-10.

Calvo, Guillermo, 1983. Staggered prices in a utility maximizing framework. J. Monet. Econ. 12, 383-398.

Chari, V.V., Kehoe, Patrick, McGrattan, Ellen, 2000. Sticky price models of the business cycle: can the contract multiplier solve the persistence problem. Econometrica 68, 1151–1179.

Christiano, Lawrence, Eichenbaum, Martin, Evans, Charles, 2005a. Nominal rigidities and the dynamic effects of a shock to monetary policy. J. Polit. Econ. 113 (1), 1–45.

Christiano, Lawrence, Eichenbaum, Martin, Evans, C., 2005b. Nominal rigidities and the dynamic effects of shocks to monetary policy. Nation. Bureau Econ. Res. 8403. Working Paper no.

Christiano, Lawrence, Motto, Roberto, Rostagna, Massimo, 2010. Financial factors in economic fluctuations. ECB Working Paper 1192.

Erceg, Christopher, Guerrieri, Luca, Gust, Christopher, 2005. Can long-run restrictions identify technology shocks. J. Eur. Econ. Assoc. 3 (6), 1237–1278.

Commercial and financial chronicle, 1919-1922, various issues.

Erceg, Christopher, Levin, A., 2003. Imperfect credibility and inflation persistence. J. Monet. Econ. 50, 915–944.

Feldstein, Martin, 1993. American economic policy in the 1980s: a personal view. American Economic Policy in the 1980s, 1993. Feldstein, M., University of Chicago Press.

Firestone, John, 1960. Federal receipts and expenditures during business cycles, 1879-1958, Princeton: Princeton University Press.

Fisher, Irving, 1920. Stabilizing the Dollar. The Macmillan Company, New York.

Fisher, Irving, 1934. Stable money. Adelphi Company Publishers, New York.

Friedman, Milton, Schwartz, A., 1963. A Monetary History of the United States. Princeton University Press, Princeton, pp. 1867–1960.

Goncalves, Carlos Eduardo, S., Carvalho, A., 2009. Inflation targeting matters: evidence from OECD economies' sacrifice ratios. J. Money Credit Bank. 41 (1), 233–243.

Goodfriend, Marvin, 1993. Interest rate policy and the inflation scare problem: 1979-1992. Feder. Res. Bank Richmond Econ. Q. 79 (1), 2-23.

Goodfriend, Marvin, King, R., 2005. The incredible Volcker disinflation. J. Monet. Econ. 52 (5), 981–1015.

Gordon, Robert, 1982. Why stopping inflation may be costly: evidence from fourteen historical episodes. In: Hall, Robert E. (Ed.), Inflation: Causes and Effects. University of Chicago Press, Chicago, pp. 11–40.

Hamilton, James, 1992. Was the deflation during the great depression anticipated? evidence from the commodities futures markets. Am. Econ. Rev. 82 (1), 157-178.

Keynes, J.M., 1925. The economic consequences of Mr. Churchill. L. and V. Woolf, London.

Levin, Andrew, Onatski, Alexei, Williams, John, Williams, Noah, 2005. Monetary Policy under Uncertainty in Micro-Founded Models. In: Gertler, Mark, Rogoff, Kenneth (Eds.), NBER Macroeconomics Annual, vol. 20, pp. 229–311.

Meltzer, Allan, 2003. A History of the Federal Reserve, Volume 1, 1913-1951. University of Chicago Press, Chicago.

Nakamura, Emi, Steinsson, J., 2013. Price rigidity: microeconomic evidence and macroeconomic implications, annual review of economics. 133-163.

Review of Economics and Statistics 1919–1921 Monthly Survey of General Business Conditions, vol. 1–3, various issues.

Rockoff, Hugh, 2005. Monetary statistics before the national banking era, in. Historical Statistics of the United States, Millenial Editional, Colonial Times to the Present. Cambridge University Press, Cambridge.

Romer, Christina, 1988. World war i and the postwar depression: a reinterpretation based on alternative estimates of GNP. J. Monet. Econ. 22, 91–115.

Romer, Christina, 1989. The prewar business cycle reconsidered: new estimates of gross national product, 1869-1908. J. Polit. Econ. 97 (1), 1-37.

Smets, F., Wouters, R., 2003. An estimated dynamic stochastic general equilibrium model of the euro are. J. Eur. Econ. Assoc. 1, 1124–1175.

Taylor, John, 1983. Union wage settlements during a disinflation. Am. Econ. Rev. 73 (5), 981-994.

Yun, Tack, 1996. Nominal price rigidity, money supply endogeneity, and business cycles. J. Monet. Econ. 37, 345-370.