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How Large is the Output Cost of Disinflation?*

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This paper examines estimates of, and drivers for, the sacrifice ratio, defined as the cumulative sum of foregone annualized output accruing from a disinflation of one percentage point. Three approaches are employed. The first reviews the literature on what sacrifice ratio might be expected. The second studies a generic disinflation experiment using 40 estimated macro models of the U.S. economy, calculating a distribution of sacrifice ratios. Those sacrifice ratios are high by historical standards and the paper discusses some stories for why this is so. The role of expectations formation and the credibility of policy is emphasized. The third approach gets under the hood of drivers of the output cost of disinflation by carrying out a selection of disinflation experiments using the FRB/US model, varying certain characteristics of the model's expectations formation mechanism. Pinning down a precise measure for the output cost of disinflation is challenging. But the literature and policy experiments do offer some guidance on how the sacrifice ratio can be reduced.

Keywords: monetary policy, disinflation, sacrifice ratio, expectations formation

JEL Codes: E4, E5, E3

* Senior Adviser, Division of Monetary Affairs, 20th and C Streets, NW, Washington, D.C. 20551, USA. Email: rtetlow@frb.gov I thank Giovanni Favara, Etienne Gagnon, Chris Gust, James Hebden and Ben Johannsen for helpful comments. Thanks as well to Jake Scott and Connor Brennan for excellent research assistance. All remaining errors are mine. The views expressed in this article are those of the author only and should not be attributed to the Federal Open Market Committee, the Federal Reserve Board or its staff.

1. Introduction

Inflation in the United States, as measured by the 12-month change in the core PCE price index, as of this writing, is 5.1 percent. And as upper panel in Figure 1 shows, inflation has been running above the Federal Reserve's longer-run inflation target of two percent for some time.[1] Moreover, the inflation problem is not particular to the United States; inflation has been above target in a host of countries worldwide, and thus the question of what trade-off policymakers might expect as they seek to reduce inflation is a timely one. One conventional measure of the purported trade-off between output and inflation is the sacrifice ratio; that is, the cumulative sum of foregone output accruing from a disinflation normalized to be one percentage point, expressed in terms of percentage points of one year of annualized output.[2] This is an old topic in monetary economics, but one that has received scant attention in the years following the Volcker disinflation and the subsequent Great Moderation.

This paper examines estimates of, and drivers for, the sacrifice ratio for the United States. There are several ways in which this can be done. In the United States, Federal Reserve participants' forecasts provide one view. In their most recent Summary of Economic Projections, FOMC participants suggested that the output to be forgone in the course of reducing inflation to 2 percent by 2025 would render a sacrifice ratio of about 2.2 percentage-point years of real growth.[3] As we will demonstrate below, this is a little on the low side, by most standards, but is within the plausible bounds.

This paper adopts three approaches to addressing this question. The first looks at what the literature has said the sacrifice ratio might be based on the historical experience. As useful as the data may be, however, history is replete with confounding shocks and conditions that make isolating the policy-driven part of any sacrifice difficult to uncover. Thus, in a second approach, a standard disinflation experiment is carried out using a range of modern macro models—40 of them, in fact—from which a distribution of sacrifice ratios is calculated. That step, while illuminating in some ways, also has its limitations, as we illustrate with the aid of some experiments using the Smets-Wouters model. Thus, the third approach attempts to get under the hood, as it were, of sacrifice ratio determination by

[1] The Federal Reserve's interpretation of the price stability half of its dual mandate is an inflation objective of 2 percent, in the longer run, measured in terms of 12-month headline PCE inflation. It commonplace, however, for the Fed to discuss inflation developments, and discuss policy options, in terms of 12-month core PCE inflation because core inflation is a better predictor of future headline inflation than is headline inflation itself. See Federal Open Market Committee (2022a) for details on the Fed's interpretation of its mandate.

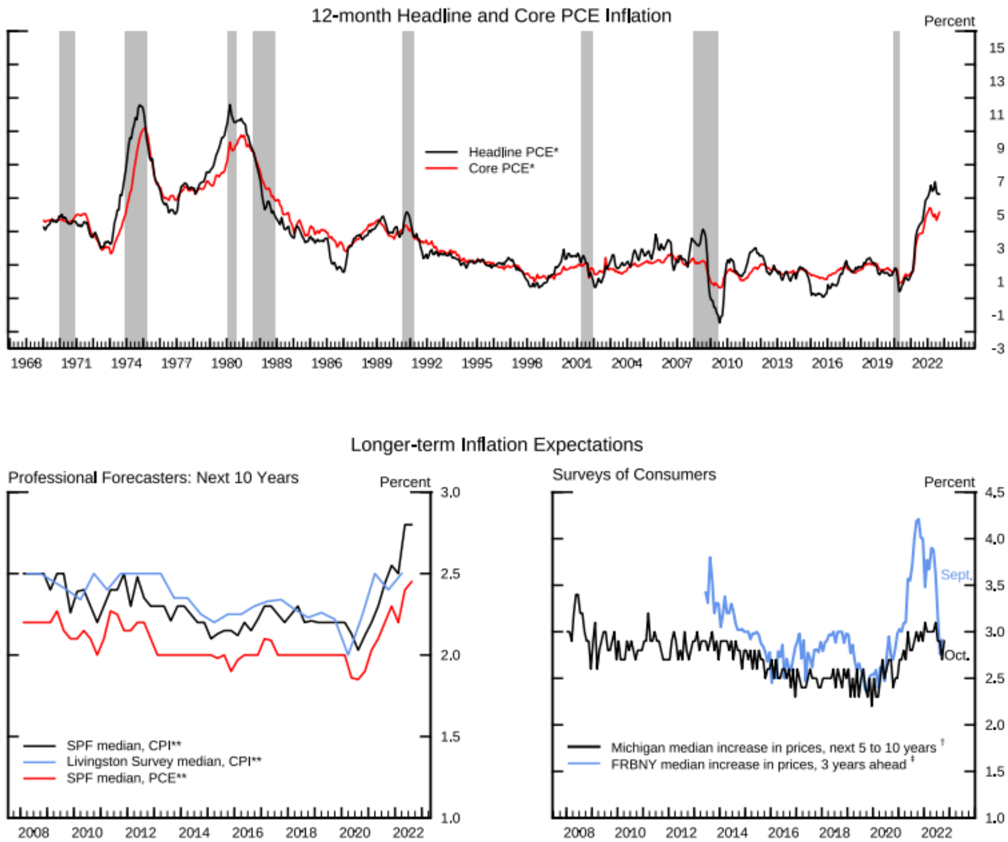
[2] This definition of the sacrifice ratio, which is entirely conventional, implies that a sacrifice ratio of, say, four is a loss of four percentage-point years of output in order to bring down inflation by one percentage point on a sustained basis. Some authors discount the cumulated output losses, and some use unemployment sacrifices which are sometimes then recalculated in output terms using an Okun's Law coefficient, as in footnote 1.

[3] The calculation in the main text is based on the medians of the September 2022 Summary of Economic Projections (SEP) and assumes that potential output grows at the 1.8 percent growth rate the Committee reports as its longer-run growth rate, that the projected shortfall of output growth from 1.8 percent in 2022 is a down payment on disinflation that has yet to occur, and that inflation falls from the 4.9 percent 12-month core PCE rate in August 2022 to 2 percent in 2025. A temporary change in the rate of growth of potential output brought on by the pandemic cannot be ruled out. See Federal Open Market Committee (2022a).

carrying out a selection of disinflation experiments using the FRB/US model, varying certain characteristics of that model's expectations formation mechanism.

Figure 1

Measures of Inflation and Longer-Term Inflation Expectations



*Source: U.S. Department of Commerce, Bureau of Economic Analysis.
** SPF is Survey of Professional Forecasters; Source: Federal Reserve Bank of Philadelphia.
† Source: University of Michigan Surveys of Consumers.
‡ Source: Federal Reserve Bank of New York Survey of Consumer Expectations reports expected 12-month inflation rate 3 years from the current survey date.
Note: The gray shaded bars indicate a period of business recession as defined by the National Bureau of Economic Research.

To preview the results, the historical record and the literature make clear that pinning down a precise measure for the output cost of disinflation is challenging, but as a statistical matter it appears to have risen significantly over the past 30 years or so and currently is probably quite high by post-war historical standards. However, there is reason to question how much the historical record can tell us, and there is some guidance from the literature in general and model-based exercises in particular, on how the cost can be reduced. Model experiments show, and the historical record supports, that the way a disinflation policy is implemented and how it is communicated can, in principle, affect how expectations adjust, which in turn can ameliorate the output cost of disinflation. Among the homilies that arise is an old favorite: it is helpful to act promptly and forcefully to counter high levels of inflation before higher inflation becomes embedded in long-term inflation expectations.[4]

2. What the literature has to say

The literature has traditionally focused on two key channels driving the sacrifice ratio, which can be usefully summarized under the headings of *intrinsic adjustment costs* and *expectational adjustment costs*. Intrinsic adjustment costs, which include sticky prices and wages and indexing, can differ from country to country, or period to period, but are thought to not vary with moderate changes in monetary policy. Expectational adjustment costs include the updating of beliefs regarding prices and wages and other aspects of the economy that determine price inflation, as well as the credibility of policy; expectational adjustment costs may vary with policy.[5]

Much of the normative debate on the determinants of the sacrifice ratio can be stated in terms of two questions. The first question concerns the proportion of the persistence of inflation that arises from intrinsic adjustment costs as opposed to expectational adjustment costs. The more one thinks of the persistence of inflation in history as having stemmed from expectations, the more the door is opened for policy to determine, at least in part, what the sacrifice ratio might be. The second question concerns how amenable expectational adjustment costs are to policymakers' decisions regarding how they carry out, and how they communicate, monetary policy. The more economic agents can be guided to adjust their expectations of future prices via policy communications and policy commitments, the less monetary policy has to do through the adoption of a restrictive policy stance and the lower the output cost of disinflation.

One traditional view is that disinflation is less expensive if it occurs slowly—*gradualism* in the application of tightening, to use the language that became conventional in the 1970s—so that wages and prices have time to adjust to tighter policy (see, e.g., Meltzer, 1980). An opposing view, often called the *cold turkey* approach, holds that a rapid disinflation can be less costly, because speed induces expectations to adjust discretely (Sargent, 1983; Bomfim *et al.*, 1997).[6] It was once common to argue—less so more recently—that disinflation is less costly if tight monetary policy is accompanied by incomes

[4] Writing in the Wall Street Journal on October 30, 2022, former Fed vice chair Alan Blinder articulated this point: "The inflation Mr. Powell is dealing with is a youngster...lasting high inflation isn't baked into people's beliefs. They remember low inflation, and they think it will return" (Blinder 2020).

[5] In the limiting case of full-information rational expectations with a completely credible monetary policy regime, expectational adjustment costs could be zero.

[6] It seems fair to say that the gradualist approach was the dominant view, from a normative perspective, in the late 1960s and '70s. The experience of the Volcker disinflation changed views and it is now the cold turkey approach that is preferred, on balance, if one is obliged to choose between those polar cases. It also seems fair to conclude that the proper course of action depends on certain conditions, of which the transparency and credibility of policy is perhaps the most important. Bordo *et al*. (2017) argue that gradualism is probably better in an environment of high policy credibility and cold turkey in a low credibility world where a costly policy move can signal fidelity to the disinflation goal.

policies or other efforts to coordinate wage and price adjustment.[7] Many researchers argue that the origins of price stickiness could mean that the initial inflation rate from which a disinflation is carried out would have sizable effects on costs (Ball, Mankiw, and Romer, 1988; Anderson and Wascher, 1999).[8] In many models, observed inflation tends to fluctuate around some concept of long-term inflation expectations (LTIE), with causality between the two often running in both directions. Reducing high observed inflation to the level of LTIE is, in many models, not very costly, but high inflation that mirrors high LTIE is thought to be more costly to bring down.[9,10] Other contributions to the literature suggest that the openness of the economy (Romer, 1991; Daniels, *et al.,* 2005; Boudler, 2009), or the nature of labor contracts should matter (Gordon, 1982).[11]

Table 1 shows sacrifice ratios for the United States for episodes of disinflation as gleaned from the academic literature of the past forty or so years. The right-hand column shows that measures of sacrifice ratios arise out of various methodologies. Some are calculated by simple arithmetic using raw data on output (or unemployment) and changes in inflation over the *ex post* identification of a period of falling inflation. Many of the calculations follow the methodology of Ball (1994) which defined a disinflation as a "substantial" decline in trend inflation, where the former is defined as two percentage points or more and the latter is calculated using a nine-quarter centered moving average of CPI inflation. Ball computes trend output as the level of output at the business cycle peak relative to what it was one year after the previous trough. Other sacrifice ratios are constructed from the estimated coefficients of

[7] James Tobin, addressed the question of how to bring down inflation in comments to a Washington Post reporter shortly after winning the Nobel prize in 1981. Tobin argued that "we are not going to have a successful disinflation without some kind of wage and price controls" and that "relying on tight money…will work eventually but is a very painful way to do it and very costly to the economy" (Quinn, 1981). The Volcker disinflation was indeed painful—the unemployment rate reached 10.8 percent—but Table 1 shows that Ball (1994) records a sacrifice ratio for that episode of 1.8, meaning that the cost per unit of inflation reduction was not all that large.

[8] Gagnon (2009) argues that the frequency of price changes should not be expected to increase substantially for modest increases in the aggregate inflation rate from low initial levels of inflation and provides some evidence from Mexico. Nakamura *et al.* (2018) use micro data to show that, contrary to what one might have expected, technological improvements in retail and wholesale trade have not increased the flexibility of prices in the U.S. over the last forty years.

[9] The distinction between actual inflation and LTIE is one reason why the level of inflation at the onset of a disinflationary episode is often posited as a determinant of the sacrifice ratio. Inflation that is unusually high may be above LTIE and thus easier to bring down, at least to the level of LTIE. On a more structural level, high levels of inflation may be associated with more rapid frequency of price adjustment which would result in a lower sacrifice ratio (Ball, Mankiw and Romer, 1988). As an empirical matter, the evidence on the importance of the initial level of inflation is mixed (Ball, 1994).

[10] Policy that is not regarded as credible could result in increases in inflation becoming embedded more rapidly in LTIE than otherwise in addition to raising the sacrifice ratio via dampening the expectations channel of transmission. See Goodfriend and King (2005) and Gibbs and Kulish (2017) expositions on the importance of the credibility of monetary policy for minimizing the output costs of disinflation.

[11] In international comparisons of sacrifice ratios, institutional features, such political stability, good governance, and central bank independence (CBI) are often cited as important (Fischer, 1996), although the evidence regarding CBI is mixed. The evidence on the significance of having an inflation-targeting regime in place is also mixed. More generally, Gibbs and Kulish (2017) shows that the distribution of sacrifice ratios calculated from the data using the Ball method also shows a lot of variability.

wage-price blocs of equations. Still others are computed from simulations of full models. The sacrifice ratios shown in Table 2 appear, roughly speaking, in order of the time period from which they were measured. Data can also matter as indicated by the difference in the calculations for the Volcker disinflation of Mankiw (1991), which was based on the GDP price deflator, and Ball (1994), who used a similar methodology but based on the CPI.[12]

Table 1
Estimates of Output Sacrifice Ratios from Historical Episodes
(selected academic references)

Source	Estimation Period	Sacrifice Ratio	Methodology
Okun (1978)	Various	6 - 18	Survey of 6 models
Gordon (1982)	1920 – 1921	0.2	Calculation
	1929 – 1933	1.7	Calculation
Ball (1994)	1969:4 – 1971:4	2.9*	Calculation (CPI)
Ball (1994)	1974:1 – 1976:4	2.4*	Calculation (CPI)
Gordon and King (1982)	1954 – 1980	4.3 – 5.8	Econometric model
Ball (1994)	1980:1 – 1983:4	1.8*	Calculation (CPI)
Sachs (1985)	1981 – 1984	3.0	Calculation
Mankiw (1991)	1982 – 1985	2.8	Calculation (PGDP)
Andersen and Wascher (1999)	1965 – 1985	2.7 – 4.3	Estimates of Phillips curves**
Sachs (1985)	1984 – 1987	3.7	Model simulation
Croushore (1992)	1959:1 – 1990:2	5.5	Simulation of Pstar model
MPS (1995)	1963 – 1993	3.6	Simulation***
Cecchetti and Rich (2001)*	1959:1 – 1997:4	1.4	Simulation of Cecchetti model
	1959:1 –1997:4	1.3	Simulation of Shapiro-Watson
	1959:1 – 1997:4	9.9	Simulation of Galí model
Andersen and Wascher (1999)	1985 – 1998	6.2 – 6.7	Estimates of Phillips curves**
Gibbs and Kulish (2017)	1990:1 – 1995:2	14.1	Calculation, Ball methodology
	2007:3 – 2010:1	3.1	Calculation, Ball methodology

Notes: Sacrifice ratios calculated or computed for specific historical events in the United States. Methodology can vary by source, but all adhere fairly closely to the definition from the main text: the sacrifice ratio is the cumulative sum of foregone output from a reduction of inflation scaled to one percentage point, expressed in terms of a single year's GDP. Ball (1994) is very often the template for calculations that followed thereafter. * Converted from an unemployment sacrifice ratio using Okun's Law coefficient of two. ** From the authors' tables 2 and 4, based on PGDP. *** Unpublished results from a simulation using the 1995 version of the MPS model.

[12] The official CPI for the U.S. is never revised even though the methodology for its construction has changed over time. However, Bolhuis, Cramer and Summers (2022) recently constructed an historical series for the CPI using current methods. Using their measure of CPI inflation, the Volcker disinflation was just 5 percentage points rather than 11 percentage points calculated using the official CPI. Measured in terms of headline PCE inflation, however, the Volcker disinflation calculated using the current vintage of data looks similar to vintages from early 1983.

Two conclusions can be drawn from this table. First, there is a lot of variation in sacrifice ratios. No single number jumps out as the correct one. Second, roughly speaking, there seems to be an upward trend in sacrifice ratios over time.[13]

In terms of the determinants, Ball (1994) finds that the sacrifice ratio is decreasing in the speed of disinflation; that is, speed in carrying out disinflations is beneficial, a finding that is consistent with Sargent (1983). Katayama *et al*. (2019) argue that the one finding that is robust across models in this literature is that fast is good. And indeed, as severe as the 1982 recession was for the U.S. economy, its cost per unit of inflation reduction was notably smaller than many commentators had expected.[14] Bomfim *et al.* (1997), among others, argue that two reasons why the Volcker disinflation was low cost were, first, because that disinflation was carried out shortly after the second OPEC oil price shock of 1979 and thus before the rise in inflation from that shock could become embedded in long-term inflation expectations, and second, because the disinflation was carried out rapidly. Authors often find that the sacrifice ratio is lower in countries with more flexible labor market contracts, as is the case in the United States. (Ball, 1994; Boudler and Nunziata, 2010).

The overall impression of a rising sacrifice ratio is confirmed in comparisons of the sacrifice ratios computed from different vintages of the FRB/US model. Figure 2 below, which is extracted from Tetlow and Ironside (2007), shows the *unemployment* sacrifice ratio indexed by model vintage on the x-axis, as computed from disinflation experiments. The figure shows that the FRB/US sacrifice ratio rose from a little over 2 from the model's inception in 1996, to a bit over 4 in 2003. The sacrifice ratio measured in terms of forgone output would be almost twice as high at each point. This result of a rising output cost of disinflation is not restricted to the FRB/US model; rolling estimation of simple Phillips-curve type models reveals the same basic property (see, e.g., Watson, 2014). In particular, a regression of the change in inflation on the output gap along with some controls for changes in food and energy prices and non-oil import prices, using a rolling window of data of any reasonable length, shows a distinct downward trend over time in the estimated coefficient on the output gap. In the special case of this simple "accelerationist" specification, the slope of the Phillips curve maps directly into the sacrifice ratio.

What to take from this evidence of the reduced sensitivity of inflation to fluctuations in output is not as clear as might appear to be the case. McLeay and Tenreyro (2019), among others, argue that the perceived decline in steepness of the Phillips curve could easily be a manifestation of weaker identification of that parameter arising from improved control of inflation by the Fed, and other central banks, during the Great Moderation era. That is, policymakers could be "victims of their own success" in

[13] This is true particularly for estimates that apply to specific, narrowly-defined episodes as opposed to model estimates for longer periods; that is, those other than Croushore (1992) and Cecchetti and Rich (2001).

[14] It is fair to say that Okun (1978) set the expectations of many regarding what output cost the Volcker disinflation should be: 6-18 percentage point years of economic growth, as shown in the first line of Table 1.

that good performance in controlling inflation has obliterated the information content of the data, thereby making continued good performance harder than would otherwise be the case.

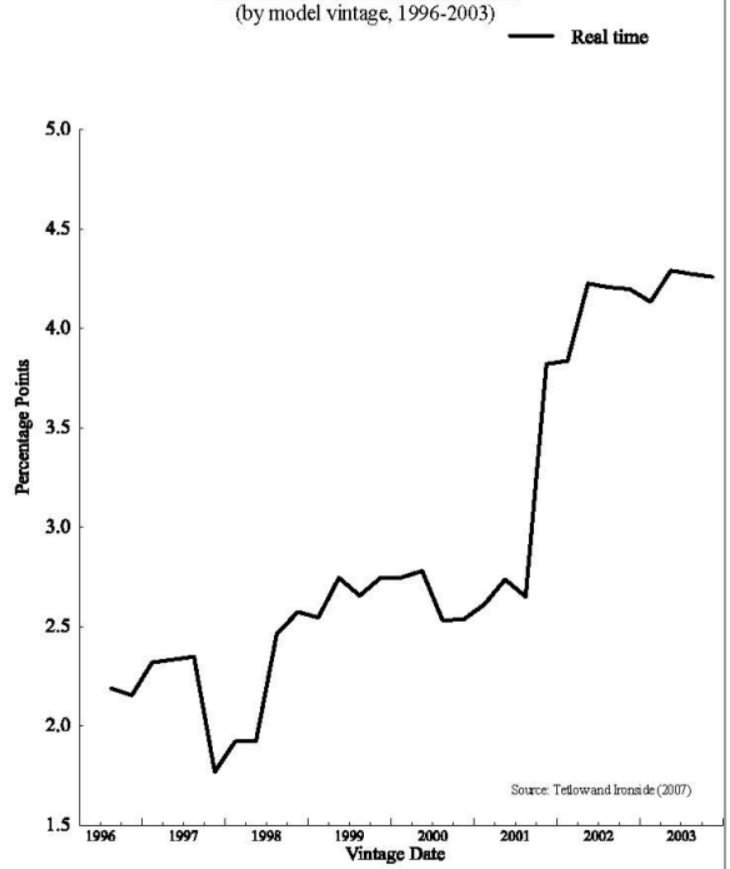


Figure 2
Sacrifice ratio of the FRB/US model
(by model vintage, 1996-2003)

3. What 40 macroeconomic models have to say

Volker Wieland and his colleagues at the Institute for Monetary and Financial Stability, Goethe University, Frankfurt, have created a macroeconomic model database of mostly U.S. and Euro area models. Authors of papers either volunteer, or are asked, to supply models for the purposes of comparing model properties in general and the robustness of alternative monetary policy rules in particular.[15] In this section, we explore what these models have to say about sacrifice ratios.

We began with the complete set of 88 U.S. macro models on the macromodelbase (MMB) website, but subsequently restricted attention to estimated models on the grounds that they are likely

[15] The Macromodelbase (MMB) project is a part of the Macroeconomic Model Comparison Initiative, a joint product of the Hoover Institution and the Institute for Monetary and Financial Stability at Goethe University. MMB is currently led by Volker Wieland with principal investigators, Michael Binder and John Taylor. Besides providing some of the models themselves, the people at MMB replicate certain features of model outputs and add code to facilitate cross-model comparisons. Find the project at https://www.macromodelbase.com.

to be more reliable for present purposes. Seven models were rejected as unsuitable for one reason or another, leaving 40 models. Sacrifice ratios were computed via simulation, implementing an unanticipated disinflation induced by a once-and-for-all reduction in the target rate of inflation.[16] Consistent with the definition used above, sacrifice ratios were calculated as the annualized cumulative output loss from the experiment divided by the decrease in headline PCE inflation as of quarter 60.[17] The results of these simulations are summarized in Table 2 and Figure 3 below. The 40 models and their sacrifice ratios are summarized in the Appendix.

Table 2
Sacrifice ratios from estimated U.S. macroeconomic models
(selected summary statistics)

mean	16.1
median	9.8
standard deviation	16.1
maximum	55.4
skewness	1.37
number of models	40

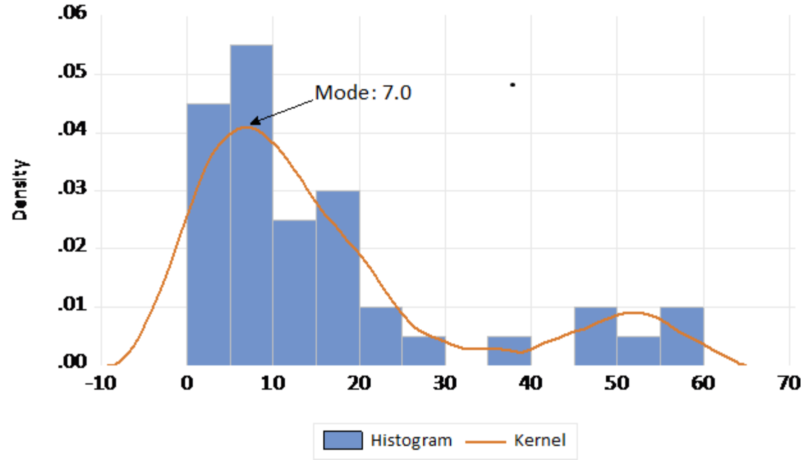
Notes: Sacrifice ratios are the annualized cumulated output loss divided by the absolute decline in the inflation rate, measured at the 60th period of a disinflation experiment using an inertial Taylor rule with a zero coefficient on output (or unemployment). Sources: Macromodelbase.com; author's calculations.

As in the survey summarized in Table 1, there is a lot of variation in the sacrifice ratios in Table 2 and Figure 3. That said, the sacrifice ratios are mostly clustered around the mode of 7, with a second smaller cluster at much higher values. More important, the sacrifice ratios computed from these models are notably higher than the bulk of the historical values shown in Table 1. Why might this be? Three reasons come to mind. First, the works covered in Table 1 prominently feature older models or historical calculations, covering mostly the period prior to the Great Moderation. In contrast, a substantial majority of the 40 models used in the construction of Figure 2 were estimated in the last twenty years mostly using data from the Great Moderation era. The early period was one of substantial volatility in inflation and in inflation expectations. Fluidity in inflation expectations is regarded as an asset in the quest for disinflation.

[16] In each case, the disinflation was carried out by reducing by one percentage point, once and for all at the outset of the experiment, the target rate of inflation in a Taylor-type monetary policy rule. The particular rule featured inertia in that it had a lagged policy rate with a coefficient of 0.75, a coefficient on four-quarter inflation of 2 and no coefficient on any real variable to ensure that attainment of the disinflation was not conflicted by any motive to smooth output. In order to ensure comparability, experiments were carried out from initial conditions of steady state. Essentially the same values of sacrifice ratios were obtained at moderately different points in simulation time.

[17] Calculations of cumulative output loss and the reduction in inflation were calculated relative to baseline. Because the models in MMB are linear (or linearized) the characteristics of the baseline are irrelevant, except for the effective lower bound on nominal interest rates, which we are ignoring.

Figure 3
Sacrifice Ratios for 40 Estimated U.S. Macromodels



As Figure 2 suggests, relying on more recent data tends to result in the estimation of flatter Phillips curves which in turn results in higher sacrifice ratios. The flatter Phillips curves of more recent vintage are presumably co-determined with the enhanced stability of late in longer-term inflation expectations. Second and relatedly, the experiments summarized in Table 2 and Figure 3 feature initial conditions where, by construction, inflation is, and has been for a long time, one percentage point above target levels. In contrast, the disinflations summarized in Table 1 are calculated from the historical data and, as such, the decline in actual inflation may exaggerate the decline in expected inflation. To the extent this is true, it follows that a rapid policy response to an incipient inflationary episode is advisable, consistent with conventional wisdom, in order to avoid high levels actual inflation becoming embedded in LTIE.[18] Third, the simulations summarized by the figure and table measure the implications of disinflationary efforts that should be viewed as unanticipated initially and thus not credible by economic decisionmakers in these models; this will result in a higher output cost of disinflation, all else equal.

To explore the implications of inflation expectations and their relationship to the specifics of how a disinflation is carried out, it is helpful to focus on a single model. For the present purposes, the model of Smets and Wouters (2007) serves as a useful benchmark. Smets-Wouters is arguably the canonical, medium-scale, estimated DSGE model of the U.S. economy; it is also one of the 40 models behind the results in Table 2 and Figure 3.

We begin with the same unanticipated disinflation experiment summarized above but focus on the dynamic responses of the Smets-Wouters model, shown by the red lines in Figure 4 below. The

[18] One common explanation from the older literature of the determinants of costly disinflation is unionized labor contracts. More generally, contracts of various sorts with overlapping terms are thought to impart intrinsic persistence into the wage-price mechanism of the economy. However, the percentage of private sector employees in the U.S. who are represented by unions has declined sharply over the years, from over 30 percent in the 1970s, to 7.0 percent in 2021. All else equal, one would have thought that this development would have *reduced* the sacrifice ratio, which is one reason why modeling wage equations using formal overlapping wage contracts has fallen out of favor.

upper panel demonstrates that, in order to initiate the disinflation, the policy rate needs to rise initially, albeit not by a great deal. However, because expected inflation falls, the modest rise in the nominal policy rate constitutes a substantial increase in the real interest rate, which produces a large decline in output. Inflation falls below policymakers' newly reduced inflation objective for a time and approaches the target from below. In this scenario, the sacrifice ratio is about 5.7, which is a bit lower than the mode for the 40 estimated U.S. models shown in Table 2. The blue lines show results for the same disinflation experiment except that the reduction in the inflation target is announced at the outset but is not formally carried out until four quarters hence. The deferred reduction in the target allows private decisionmakers to adjust their expectations before policy formally acts. As can be seen, the announcement effect associated with prior notice, if it is credible as is assumed to be the case here, obviates the need for an early increase in the nominal policy rate. The inset table in the figure quantifies how dramatically a credible announcement effect reduces the output cost of disinflation; it shows a modest 1.5 sacrifice ratio for this scenario. The stark difference in sacrifice ratios for an unanticipated and non-credible disinflation and a pre-announced, credible disinflation highlights the importance of policy communications for enhancing the transparency of policy intentions as well as other means for establishing the credibility of policy. Finally, the green lines in the figure show results for an optimal control (OC) simulation. Under OC, policymakers pick the path for the policy rate that minimizes a standard quadratic loss function defined over inflation, output and the change in the policy rate.[19] The inset table shows that for this experiment, one where policy is expertly chosen by credible policymakers with full knowledge of the model and with concern for output losses, the sacrifice ratio is a scant 0.9. The modest difference in sacrifice from an "optimal" policy and the *ad hoc* but anticipated and credible disinflation policy suggests that the added benefit stemming from the tactical precision employed by the OC policy is relatively modest compared to the outsize contribution that arises from disinflation being anticipated and credible.

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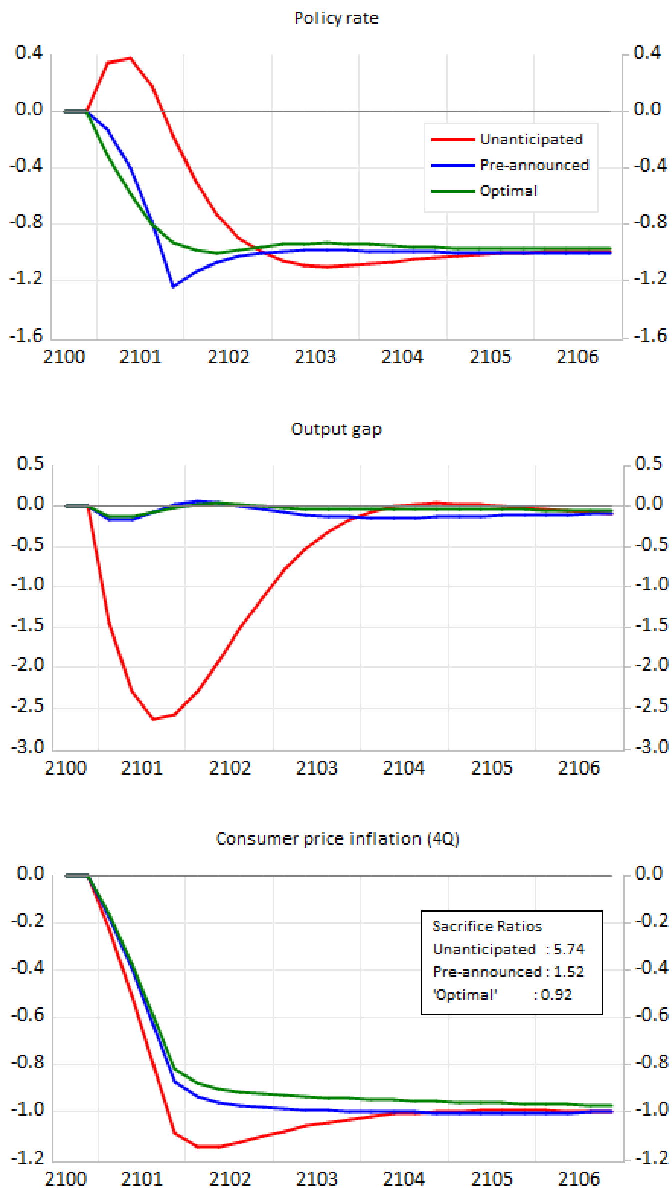
[19] Under the optimal control policy, the hypothetical policymaker chooses a path for the policy rate to minimize the discounted, equally-weighted, sum of squared deviations of output from potential output, four-quarter consumer price inflation from its target (newly reduced by one percentage point), and quarterly changes in the policy rate. The loss function minimization is defined over the period from the start of the simulation to 40 years hence. The optimal policy paths for the future that are computed at the outset are assumed to be followed through by subsequent policymakers in later periods, which means that the optimal control policy is a commitment strategy. Except for the fact that output gaps are used here in place of unemployment gaps, and the application is to the Smets-Wouters model, this specification of optimal control is the same as those that have appeared regularly in the Tealbook prepared by Federal Reserve Board staff for policymakers prior to FOMC meetings. See, e.g., the December 2016 Tealbook book B, p. 8 (Federal Reserve Board, 2016) which, as of this writing, was the latest Tealbook in the public domain. An appendix in that Tealbook contains more information on optimal control simulations.

Figure 4
Disinflation : Smets-Wouters (2007) Model
(Selected policies)



The experiments displayed in Figure 4 are built around a well-known, estimated New Keynesian model of the U.S. economy, one that features *model consistent expectations* (MCE). MCE means that the model's decisionmakers understand the environment in which they operate and take monetary policy decisions into account when they formulate their expectations. MCE is the standard modeling assumption in the construction of macroeconomic models, although there is a bit of movement away from assuming full-information rational expectations recently.[20] For policy purposes, however, it is often helpful to relax that assumption and consider expectations formation that is more eclectic. That is what we do in the next section.

4. What the FRB/US model has to say

This section takes a deeper dive into what the sacrifice ratio could be for a large-scale, estimated model of the U.S. economy, one that allows for greater flexibility in the characterization of expectations and beliefs—the FRB/US model. As noted above, expectations formation in general, and the related notion of the credibility of policy, are critical for the determination of the output cost of disinflation.

To clarify the results discussed in this section, it is useful to include a brief discourse on how expectations are modeled in FRB/US. In particular, subsection 4.1 discusses the FRB/US mechanism for the parsing of inflation expectations between the formation of *long-term inflation expectations* (LTIE)—that is, where decisionmakers in the model economy believe inflation is headed in the long run—and *dynamic expectations*, meaning those decisionmakers' expectations of inflation at business cycle frequency. Subsection 4.2 runs through some simple disinflation experiments. For those experiments, the mechanism by which decisionmakers form LTIE is held fixed, while dynamic expectations formation is allowed to vary with the class of decisionmaker. Subsection 4.3 then explores the implications of the alternative equations for adjustment of LTIE.

4.1 On expectations formation in FRB/US

To fix ideas, we begin with a slightly simplified representation of the main price equation in the FRB/US model:

$$\pi_t = \gamma_1 \pi_{t-1} + \gamma_2 \tilde{E}_t \pi_{t+1} + (1 - \gamma_1 - \gamma_2) \tilde{E}_t \pi_t^{\infty} + \gamma_3 y_t$$

where π, π^{∞} and y are core PCE inflation, long-term inflation expectations and the output gap. There are three noteworthy observations regarding this equation. First, note that expectations for inflation in the future are captured in *two* terms, one covering LTIE, $\tilde{E}_t \pi^{\infty}$, the other covering what we call dynamic expectations, $\tilde{E}_t \pi_{t+1}$. Second, observe that the coefficients on the three inflation terms sum to unity. This homogeneity restriction ensures that so long as the output gap is expected to eventually equal zero, then inflation will approach its long-term expectation over time. The third item to note is the tilde overstrike on the expectations operator, $\tilde{E}$, which signifies expectations need not be model consistent. In a standard New Keynesian model, such at the Smets-Wouters model, $\tilde{E}_t \pi_{t+1}$ is a model consistent expectation (MCE). In the FRB/US model, for the purposes of policy experiments, expected inflation can be taken as MCE, but the MCE assumption—that is, the assumption that decisionmakers have full knowledge of the structure of the economy, including monetary policy, and use that knowledge to formulate their expectations—can be replaced by the assumption that agents use a narrower set of macroeconomic variables and employ only the statistical comovement of those variables to formulate

[20] See, for example, Woodford (2019), Gabaix (2020) and Bianchi *et al.* (2022).

their expectations; that is, decisionmakers in the model may use small-scale vector-autoregression (VAR) models as the foundation for their expectations of dynamics. This formulation is known as *VAR-based expectations*.

In a broadly similar fashion there are choices for how long-term inflation expectations evolve over time. Here too we can either assume that LTIE are consistent with policymakers' intentions and policy communications, or we can instead assume that LTIE are more dependent on the historical data. The upshot is that we have two pairings of assumptions for each of two classes of expectations formation. These pairings are visualized in Table 3 below.

To illustrate how this works, we can consider the example of the pandemic shock of 2020, a disturbance that had many implications for the economy, including inflation. In modeling inflation expectations, we could assume *a priori* that decisionmakers in the model believe that the inflationary consequences of the pandemic shock were entirely temporary, meaning that LTIE remain fixed at pre-pandemic levels or, equivalently in our thinking, that LTIE are "well anchored," (row [1] of the table). That assumption for LTIE could be paired with either of our two assumptions for dynamic expectations. If we assume MCE, then we would be in column (B) of the table, which with well-anchored LTIE means decisionmakers have perfect foresight. Sticky prices and wages, along with indexation, would presumably rule out a completely costless disinflation in such a world, but disinflation from a known-to-be-temporarily-high inflation rate would generally be expected to be achievable at relatively low cost.[21]

Suppose instead we assume that the unusual origins of the shock impaired the formation of MCE and thus dynamic expectations are VAR-based.[22] This would put us in column (A) of the table, which along with well-anchored LTIE, means that decisionmakers have limited information about inflation dynamics but have confidence that the effects of the pandemic will be temporary. But what if long-term inflation expectations are not well anchored? We can assume that LTIE moves slowly but continuously in response to the data through the use of an updating rule for LTIE. This would put us in row [2] of the table. And, as before, that choice can be paired with either VAR-based or MCE for dynamic expectations.

We can also think of policy credibility in the context of the model and Table 3. An announced, credible change in the target rate of inflation could be modeled as a one-time discrete change such that LTIE shifts discontinuously to its new level, row [1]. If decisionmakers also form expectations using the full structure of the model, then dynamic expectations are model consistent, column (B): credible policy giving rise to perfect foresight. This is the case where one might expect that disinflation would be the least costly, although a proof of that conjecture is not possible. However, even if decisionmakers find an

[21] Indeed, there are models in the New Keynesian class that would allow a zero or even a negative output cost of bringing down inflation under perfect foresight if the disinflation is carried out in a particular way and is credible.

[22] See Brayton and Tinsley (1996), Brayton *et al.* (1997) and Brayton, Laubach and Reifschneider (2014) for material on FRB/US in general and on expectations formation in the model in particular. Setting aside the expectations formation mechanism, the main price equation in the FRB/US model is based on Cogley and Spordone (2008).

announcement fully credible, one need not assume that they also have access to full information about the economy's dynamics. In this case, they may use an agnostic method for updating to dynamic expectations based on the history of the data—that is, VAR-based expectations.

Table 3
The modeling of expectations in FRB/US

	Long-term expectations formation π^{∞}	**Dynamic expectations formation**	
		VAR-based (A)	Model consistent (B)
[1]	Fixed ("well anchored") or moving discontinuously (credible)	Limited information but "well anchored" or credible	Model consistent and credible (perfect foresight)
[2]	Moving continuously (learning)	Limited information and adjusting or learning	MCE but not credible (learning $E\pi^{\infty}$)

4.2 The implications of dynamic expectations formation

We now turn to an investigation of the implications of different methods of dynamic expectations formation for the output cost of disinflation in the FRB/US model. To introduce the topic, Figure 5 shows the macroeconomic dynamics for the same disinflation experiment that was run on the 40 models covered in section 3 as well as on the Smets-Wouters model: a permanent one-time reduction in the target rate of inflation.[23] For these experiments, we hold fixed the specification of LTIE adjustment and vary the means by which decisionmakers are assumed to formulate dynamic expectations. In particular, LTIE are assumed to be equal, initially, to the original target rate of inflation and then to evolve sluggishly in response to movements in actual inflation. The precise equation for LTIE adjustment is shown as equation (3) in Table 4 below and is labelled "base case," although the name is arbitrary. The base case specification for LTIE features a small coefficient on four-quarter core PCE inflation and a similar-sized coefficient on the announced target rate of inflation. The presence of a coefficient on the target rate of inflation and, more important, the large coefficient on lagged LTIE imparts the sluggishness that implies well-anchored long-term inflation expectations.

[23] See footnote 15 for details. The disinflation is carried out from steady-state equilibrium in order to remove the effect of initial conditions from the simulation results.

Table 4

Long-term expectations adjustment equations

(FRB/US model)

Equation #	*Equation name*	*Specification*
(1)	credible	$\pi_t^{\infty} = \pi_{t-1}^{*}$
(2)	public model	$\pi_t^{\infty} = 0.90 \cdot \pi_{t-1}^{\infty} + 0.05 \cdot \pi_{t-1} + 0.05 \cdot \pi_{t-1}^{*}$
(3)	base case	$\pi_t^{\infty} = 0.96 \cdot \pi_{t-1}^{\infty} + 0.02 \cdot \pi_{t-1}^{4} + 0.02 \cdot \pi_{t-1}^{*}$
(4)	accelerationist	$\pi_t^{\infty} = 0.90 \cdot \pi_{t-1}^{\infty} + 0.10 \cdot \pi_{t-1}^{4}$

Notes: $\pi^{\infty}$is long-term inflation expectations (LTIE); that is, agents' expectations of inflation as *t* approaches infinity, conditional on information available in period *t=0*. π is core PCE inflation, quarterly at annual rates; π^4 is four-quarter core PCE inflation; and π^* is policymakers' target rate of inflation.

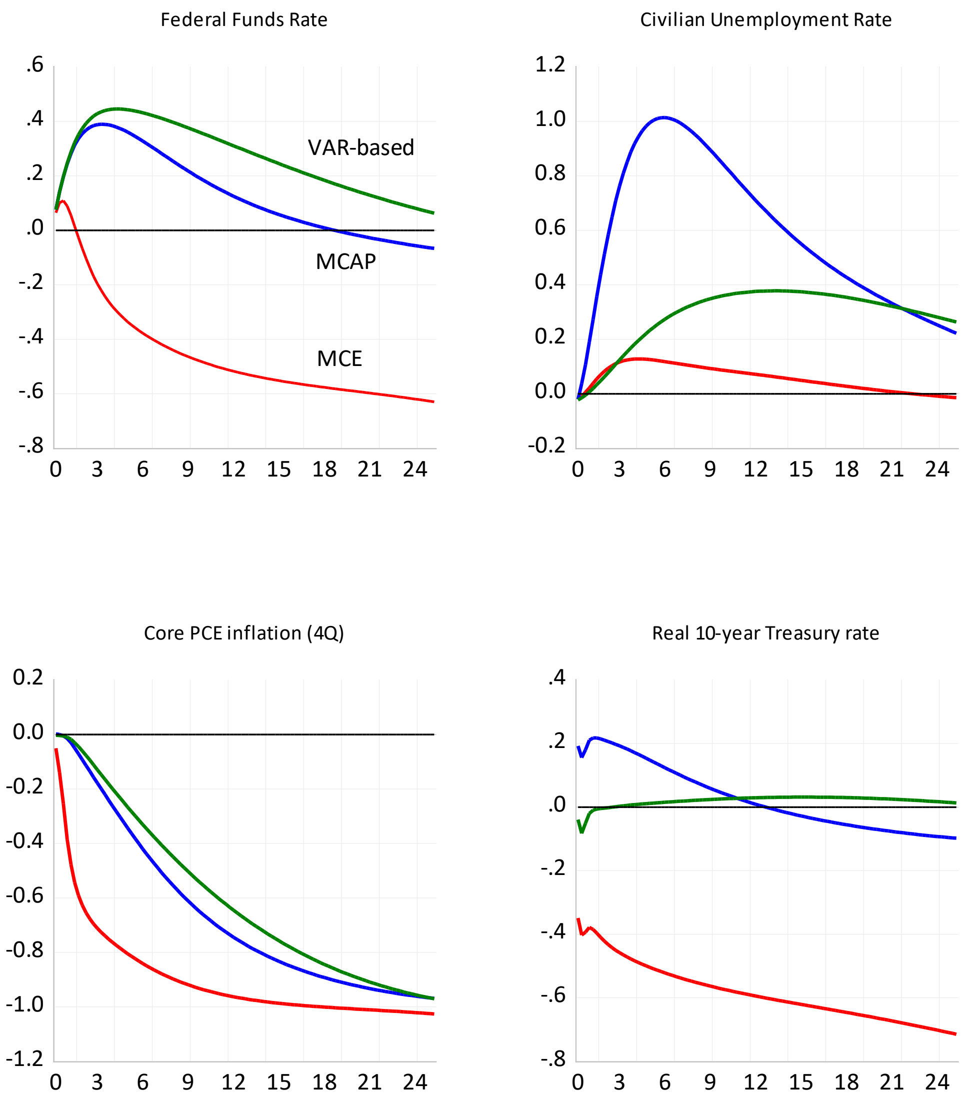
Three sets of dynamic expectations formation are considered. In one case, those decisionmakers in the model who are critical to the determination of the sacrifice ratio—namely, financial market participants and wage-and-price-setting decisionmakers—are assumed to have MCE. We refer to this as the MCE case.[24] In a second case, we assume that MCE are restricted to financial market participants, implying that wage-and-price setting decisionmakers employ VAR-based expectations. We refer to this case as *m*odel-*c*onsistent *a*sset *p*ricing, or MCAP. Finally, for the third case we assume that all decisionmakers in the model use VAR-based expectations. In each case, for those decisionmakers who do not employ model consistent expectations, the base case equation for the LTIE updating is used, while LTIE are assumed to move discreetly to the new target rate of inflation in those sectors where MCE are employed.

The dynamics of disinflation for the MCE case are shown by the red lines in Figure 5. As can be seen, when those decisionmakers in the model that are critical for engineering a disinflation have MCE, the policy rate does not have to rise very much and not for very long. This is because an announcement of an incipient reduction in the inflation target is, by assumption, a credible and well-understood claim. Expectations of workers and firms decline at the outset of the scenario and inflation plunges—the lower-left panel—which allows the policy rate to decline promptly as well. Indeed, the 10-year real interest rate, shown in the lower-right panel, declines in an effort to catch up, in a sense, to the falling inflation; even so, sticky wages and prices mean that the unemployment rate rises, albeit only modestly. Sticky prices and wages, even in the presence of model consistent expectations, mean that disinflation is

[24] Our use of MCE for this case takes a bit of license because, for technical reasons, decisionmakers in several sectors of the model including the consumption and investment sectors, employ VAR-based expectations. However, these sectors are not what critical for the points we make in this section.

generally costly. The output cost of disinflation from this experiment is summarized in by line [3] in Table 5 below where it is shown to be 2.2.

Figure 5
Disinflation : FRB/US Model
(Selected models of expectations formation; deviations from baseline)



The MCAP case, shown by the blue lines in the figure, demonstrates that when the assumption of model consistent expectations in wage and price setting is dropped and those expectations are instead based on the historical relationships captured in a small-scale VAR-model, the policy rate must rise significantly higher, and for longer, than in the MCE case. MCAP allows asset prices to move discretely with the change in policy, but because the expectations of wage and price setters are sticky, monetary policy must "pay in advance" to achieve disinflation, creating negative output gaps in order to push wage and price expectations in a direction consistent with policy intentions. There is no *announcement effect* that can generate a near-costless disinflation when wage and price expectations are VAR-based. The increase in the unemployment rate is substantially larger than in the MCE case, while the decline in inflation is initially smaller. The sacrifice ratio for this scenario, as shown on line [3] of Table 5, is 17.1.

Table 5

FRB/US model sacrifice ratio calculations

(selected expectations formation mechanisms and LTIE updating conventions)

Dynamic Exp.→	MCE		MCAP		VAR-based	
LTIE updating ↓	*20Q*	*60Q*	*20Q*	*60Q*	*20Q*	*60Q*
[1] credible	0.6	1.0	1.1	1.4	0.8	1.9
[2] public model	0.4	1.1	5.8	8.2	2.2	5.9
[3] base case	1.0	2.2	13.0	17.1	4.2	10.2
[4] accelerationist	0.5	1.3	29.3	26.9	19.3	24.9

Notes: Sacrifice ratios are the annualized cumulated output loss divided by the absolute decline in the inflation rate, computed from a disinflation experiment using an inertial Taylor rule with no coefficient on output. Selected expectations formation mechanisms and long-run inflation expectations (LTIE) updating mechanisms; measured at selected simulation intervals as shown. Economic decisionmakers form expectations using small-scale VAR models (VAR-based expectations) except MCAP: model-consistent expectations in the setting of asset prices (bond rates, equity prices, nominal exchange rate); and MCE which adds to MCAP model-consistent expectations in the determination of wages and prices. Source: author's calculations.

Finally, when all agents have VAR-based expectations, financial market participants do not take monetary policy announcements into consideration and thus (real) bond rates do not move significantly. With VAR-based expectations, the power of monetary policy can depend on idiosyncrasies of the historical record that enters into the VAR model driving expectations, which can result in a wide range of possible outcomes. Nothing in recent history looks like the disinflation policy being conducted in the experiment, so disinflation is costly. The right-hand panel of Table 5 shows, again on line [3], that the sacrifice ratio for this scenario is 10.2.

Note that the sacrifice ratio under VAR-based expectations is lower than under MCAP expectations, a result that is surprising on its face. There is often a presumption that if expectations are not model-consistent then they are sluggish, but VAR-based expectations merely track the historical data, and the U.S. data has, on average, has featured a great deal of persistence, implying that once the data start moving in a certain direction, expectations emerge for that process to continue. In this example, as wage and price expectations begin to adjust, there is considerable momentum such that the increase in the unemployment rate needed to complete the disinflation is actually smaller, for a time, than in the MCAP case. However, this result is not likely to be general. Once one drops the notion of model consistent expectations, there is no generally accepted view of the appropriate alternative. The VAR-based expectations used here is a sensible formulation, but there are other plausible alternatives including ones that have expectations that adjust sluggishly on a persistent basis.

4.3 The implications of long-run expectations adjustment

As noted, the experiments displayed in Figure 5 were conditioned on the assumption that LTIE adjustment follows the base case equation in those sectors other than the ones where MCE are assumed. In the MCE experiment, LTIE for financial market participants and wage-and-price-setting decisionmakers are assumed to be equal to the target rate of inflation; that is the essence of what it means to assume that policy is fully credible in this context.

Whatever the merits of the base case LTIE adjustment equation, it seems prudent to examine the implications of alternative specifications. Indeed, the two panels at the bottom of Figure 1, back on page 2, show that proxies for inflation expectations show a range of possibilities for the level and persistence of inflation expectations, broadly defined, depending on whose expectations are sought and for what horizon those expectations are collected. Accordingly, Table 4 above shows three such alternatives, alongside the base case equation, already discussed. Equation (2) is the specification that is supplied with the public version of the FRB/US model.[25] It features considerably less persistence.[26] Equation (4) is an "accelerationist" equation for LTIE, which means that it is based entirely on the history of inflation, placing no weight on the target.[27] Finally, equation (1) is a depiction of credible policy: applicable decisionmakers are assumed to believe, without question, the announced target of policymakers, with a one-quarter lag.

The implications for the sacrifice ratio of these alternative means of LTIE formulation and adjustment are summarized in Table 5. The updating equations are shown in the table in the increasing order of their presumptive output cost of disinflation. That is, a credible policy is presumed to make disinflation less costly than an equation that is inertial and depends on a demonstrable history of declining inflation in order for LTIE to fall. Focusing on the results for experiments at quarter 60, we see sacrifice ratios do not differ very much across LTIE adjustment specifications in the case of MCE expectations, the gray shaded column to the left. This should not be surprising as LTIE do not matter for asset pricing and wage and price determination in those instances; they do affect expenditure decisions, but those sectors are not central to the wage and price determination and thus not central to the output cost of disinflation.

It is the MCAP and VAR-based expectations cases where the evolution of LTIE gets interesting. There we see, as expected, that the more weight that is placed on the objective of monetary policy in

[25] Public versions of the FRB/US model along with data and documentation are available in Eviews and Python. For details, go to: https://www.federalreserve.gov/econres/us-models-about.htm

[26] That is, its lagged endogenous variable carries a coefficient of 0.90 instead of the base case equation value of 0.96. The half-life of an AR(1) process with a coefficient of 0.90 is 6.6 quarters while for a coefficient of 0.96 it is 17.0 quarters. Also, unlike equations (3) and (4), equation (2) responds to annualized quarterly core CPE inflation instead of the four-quarter rate.

[27] This model for LTIE updating has been used on several occasions in the past, including in a 2014 memo to the FOMC. See, e.g., Laubach *et al.* (2014). Kozicki and Tinsley (2001) document that equation (4) does a good job of tracking the behavior of long-run inflation expectations in the late 1970s and early 1980s.

LTIE adjustment, the lower is the cost of disinflation. When policy is credible, as with equation (1), the sacrifice ratio is very low regardless of whether expectations dynamics are MCAP or VAR-based. Moving down Table 5, however, we see that the “stickier” are LTIE, the model expectations dynamics matter. Results for VAR-based expectations will always depend in complicated ways on precisely how LTIE interact with expectations dynamics, and possibly on how a disinflation is carried out, but in the cases explored here disinflation is more costly under MCAP than under VAR-based expectations.

5. Concluding remarks

This paper has examined the output cost of disinflation—that is, the sacrifice ratio—for the United States. We found that history, the extant literature, and a collection of models suggest that disinflation is costly, but that pinning down what cost one should expect to pay to bring down inflation is challenging. Taken at face value, the data suggest that the cost has probably risen over time. Whether the seemingly increased statistical sacrifice ratio is a quasi-structural feature of the evolving U.S. economic landscape or a phantasm of the stability of inflation over the past forty years of data is a debatable proposition.

The persistence of inflation in history is the outcome of a confluence of events and a mixture of influences of intrinsic adjustment costs borne by economic decisionmakers, which cannot be readily influenced by monetary policy, and expectations adjustment costs, which in principle are under the influence of policy. Disinflations are less costly the more that expectations formation is amenable to policy actions and communications, and according to conventional models, the more adroitly policy and communications are conducted. Evidence on how expectations are formed and how they can be influenced in a monetary context is patchy. We can readily observe how forward guidance, for example, has influenced asset prices; its effects on wage- and price-setting is more elusive.

More tantalizing is the prospects for policy communications and credible commitments for moving outcomes out of the MCAP column of Table 5 toward the MCE column where the output costs of disinflation are much lower. In this regard, it worth noting that the dynamics of expectations adjustment captured in Figure 5 and Table 5 take a long time to complete, a manifestation of the persistence of inflation in the data and the linearity of expectations equations in the FRB/US model. As noted above, the Volcker disinflation, while costly in an absolute sense, was not very costly when measured in terms of the sacrifice ratio. That disinflation took notably less time to carry out than in the model experiments shown here, an observation that may speak to the virtues of speed discussed above in Section 2.

The simulations discussed in sections 3 and 4 began with inflation that was above the target rate of inflation and long-term inflation expectations that were also at that undesirably high level. The current situation is one where high inflation is a recent phenomenon and for that reason the rise in long-term inflation expectations is probably less egregious, consistent with recent indicators such as the inflation expectations data shown in Figure 1. Thus, disinflation could end up being less costly than a simple sacrifice ratio calculation based on an initial 12-month core inflation rate of 5.1 percent would suggest. Finally, the historical record and the literature support the notion that prompt policy steps to contain inflation expectations and communications to assure economic decisionmakers that inflation will be contained could pay large dividends.

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7. Appendix: The models used in Section 3.

Table A1
Models used for disinflation experiments and their sources
(https://www.macromodelbase.com)

MMB mnemonic	Sacrifice ratio	Original source
US_KS15	0.568	Kriwoluzky and Stotenberg EJ (2014)
US_RE09	0.668	Reis NBER wp 14732 (2011)
US_FGKR15	0.986	Fernandez-Villaverde, Guerron-Quintana, *et al.*, AER (2015)
US_IR11	1.752	Ireland, JMCB (2011)
US_PM08fl	2.447	Carabenciov, *et al.*, IMF wp 08/278 (2008)
US_CFOP14	2.899	Carlstrom, Fuerst, Ortiz and Paustian, JEDC (2014)
US_PV15	3.206	Poutineau and Vermandel, JEDC (2015)
US_CMR10	3.417	Christiano, Motto and Rostagno, ECB wp 1192 (2010)
US_RA07	3.489	Rabanal, JEDC (2007)
US_AJ16	5.052	Ajello, AER (2016)
US_CCTW10	5.348	Cogan, Cwik, Taylor and Wieland, JEDC (2010)
US_SW07	5.714	Smets and Wouters, AER (2007)
US_YR13	6.598	Rychalovska, JEDC (2016)
US_CMR10fa	6.722	Christiano, Motto and Rostagno, ECB wp 1192 (2010)
US_OW98	7.147	Coenen, Orphanides and Wieland, BEJMacro (2004)
US_JPT11	7.359	Justiniano, Primiceri and Tambalotti, RED (2011)
US_IN10	7.383	Iacoviello and Neri, AEJMac (2010)
US_CPS10	9.231	De Graeve, JEDC (2008)
US_KK14	9.307	Kliem and Kriwoluzky, RED (2014)
US_CMR14noFA	9.422	Christiano, Motto and Rostagno, AER (2014)
US_FM95	10.236	Fuhrer and Moore, QJE (1995)
US_RS99	12.956	Rudebusch and Svensson, NBER vol. (1999)
US_IAC05	13.693	Iacoviello, AER (2005)
US_CD08	13.914	Christensen and Dib, RED (2008)
US_OR03	14.995	Orphanides, JME (2003)
US_VMDno	15.505	Verona, Martins and Drumond, IJCB (2013)
US_PM08	16.273	Carabenciov *et al.*, IMF wp 08/278 (2008)
US_BKM12	17.101	Bils, Klenow and Malin, AER (2012)
US_VMDop	17.523	Verona, Martins and Drumond, IJCB (2013)
US_FU19	17.817	Fratto and Uhlig, RED, (2020)
US_DNGS15	19.209	Del Negro, GIannoni and Schorfheide AEJMac, (2015)
US_DG08	23.003	De Graeve, JEDC (2008)
US_CMR14	23.852	Christiano, Motto and Rostagno, AER, (2014)
US_FMS134	29.918	Feve, Matheron and Sahuc, AEJMac, (2013)
US_VI16bgg	39.824	Villa, MD (2016)
US_MR07	47.804	Mankiw and Reis, JEEA (2007)
US_VI16gk	48.717	Villa, MD, (2016)
US_LTW17	52.207	Leeper, Traum and Walker, AER (2017)
US_MI07	55.443	Milani, JME (2007)
US_MI07AL	55.443	Michaillat, AEJMac (2014)