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A Major Shock Makes Prices More Flexible and May Result in a Burst of Inflation or Deflation*

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The US and other advanced countries suffered bursts of severe inflation in 2021and the first half of 2022, followed by declines of inflation later in 2022, in some countries. In times of high volatility of price determinants—cost and productivity—inflation can jump upward and fall downward at high speed, contrary to the uniformly sticky behavior associated with traditional Phillips curves. This paper establishes that sectors with standard New Keynesian price stickiness are vulnerable to rapid transitions from stickiness to flexibility, as sellers elect to reset their prices and abandon anchoring. The paper shows that the cross-industry volatility of price determinants grew substantially in the inflation episode accompanying the pandemic. Volatility remained elevated even in late 2022. The logic of the New Keynesian model of the Phillips curve links inflation to volatility, because a larger fraction of sellers are pushed out of their regions of inaction when volatility is elevated. The New Keynesian Phillips curve becomes much steeper in volatile times.

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1 Introduction

In advanced modern economies, the central bank's remit is typically stabilization of inflation at a rate around two percent per year. Nonetheless, many central banks allowed inflation to approach or even exceed 10 percent per year starting in 2021, reaching a maximum in mid-2022. Inflation grew much faster than implied by the models employed by central banks and by most practical macroeconomists. Subsequently, inflation in the U.S. fell rapidly in the second half of 2022, returning to about 3 or 4 percent per year. Inflation was considerably more volatile than expected by the Fed, forecasters, securities traders, and the public.

In the mainstream New Keynesian model, the price of a particular product remains fixed until a certain amount of pressure has accumulated to cause a discrete change in the price. Absent that pressure, the price remains constant as long as the pressure is within a range of inaction. The contribution of a given seller to inflation in a given period depends on whether or not the seller's range of inaction moves so that it no longer contains the price. The overall rate of inflation depends of the fraction of sellers who take action and the average magnitude of the price changes for the price-changing sellers. In general, one can think of this setup as providing an error-correction feedback loop for the price level.

A seller in a more volatile environment will adopt policies that involve more frequent adjustments of the seller's price, compared to one in a less volatile environment. Consequently, prices will respond more quickly to driving forces and the relation between inflation and driving forces will be steeper.

2 Cost Shocks Can Cause Large Increases in Price Flexibility

2.1 Model

Firms produce output q from a single input x with constant returns and unit productivity, so their production functions are $q = x$. The input x is available in a competitive market at price c, a random variable. Firms sell at price p in differentiated markets facing constant-elastic demand $q = 1/p^{-2}$. When free of constraints, firms charge the myopic profit-maximizing price

$$p^* = 2c. \tag{1}$$

The firm is myopic in the strong sense that it discounts all future values to zero.

Sellers incur a cost κ to make a price change of positive magnitude. The profit net of

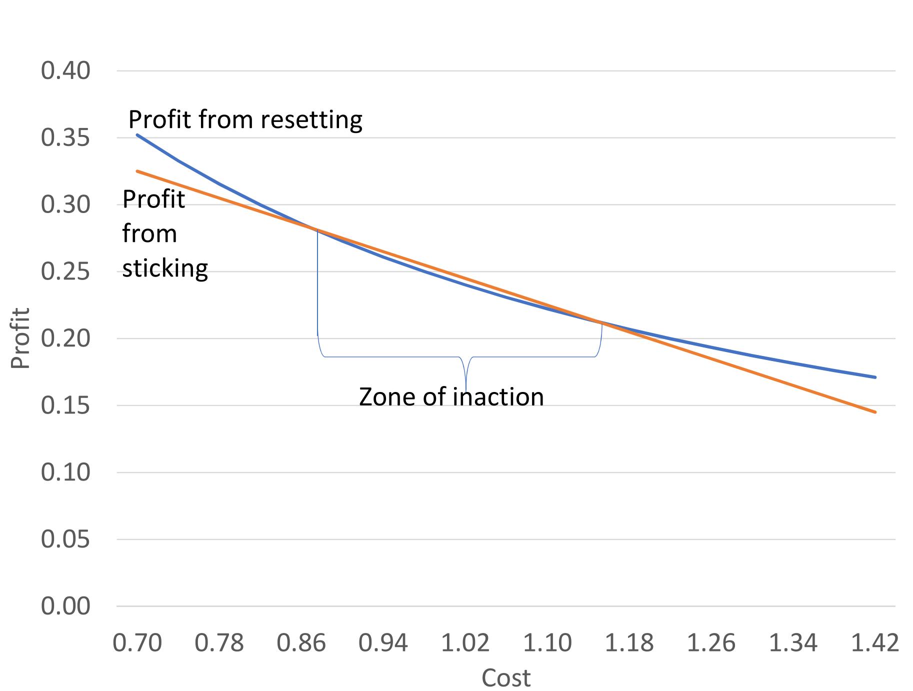

Figure 1: Profit Levels as a Function of Cost, and the Resulting Zone of Inaction

that cost is

$$\frac{2c - c}{2c^2} - \kappa = \frac{1}{4c} - \kappa \tag{2}$$

The profit from retaining last period's price $\bar{p}$ when this period's cost, c, may have changed since last period, is the product of margin and volume:

$$\frac{\bar{p} - c}{\bar{p}^2} \tag{3}$$

The condition for indifference between the two outcomes is a level of cost, $\hat{c}$, satisfying

$$\frac{1}{4\hat{c}} - \kappa = \frac{\bar{p} - \hat{c}}{\bar{p}^2} \tag{4}$$

This equation is quadratic in $\hat{c}$. If the elasticity of demand differs from 2 and exceeds 1, the result in this section still holds, but the reasoning is less transparent. One of the equation's roots is the level of cost at the lower end of the zone of indifference and the other root marks the upper end of the zone. Figure 1 shows the two functions, with the zone of inaction they define, between the two crossing points. For this illustration, the calculation uses a value of the cost of changing the price of $\kappa = 0.005$.

Movements of cost within the zone of inaction leave the price unchanged. Outside the zone, the price moves with cost according to $p = 2c$. Figure 2 shows the relation between

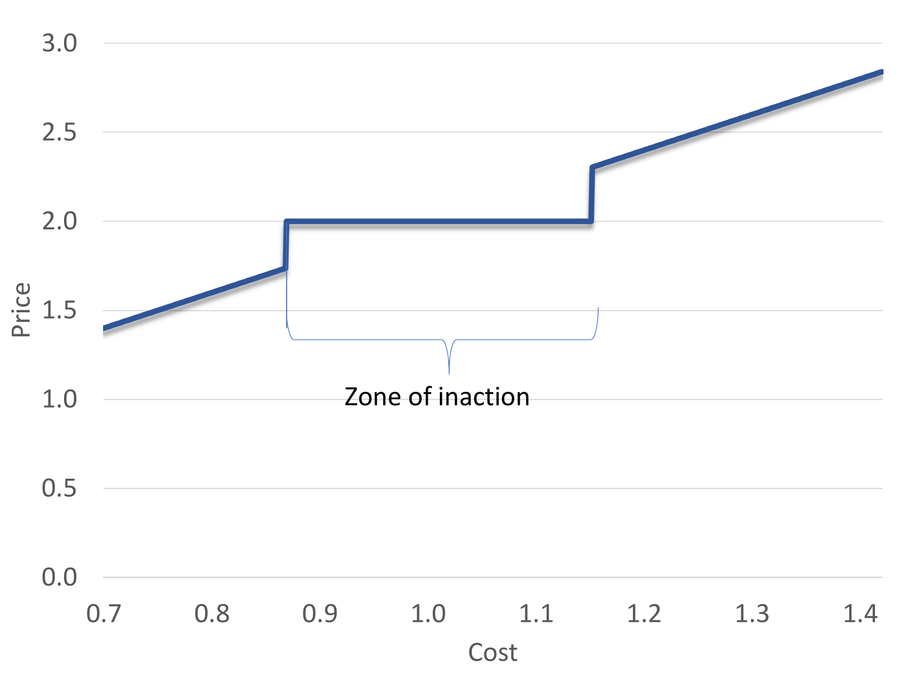

Figure 2: Price as a Function of Cost

cost and price. At the beginning of a period, a new draw of cost occurs. If the new cost is inside the zone of inaction, price remains the same, whereas if below or above the zone, the price changes to twice the new cost.

If, most of the time, the previous price turns out to be near the middle of the zone, the price level will tend to be sticky—the new cost must rise or fall by enough to move the zone far enough that a change in the price is mandated. If most of the previous prices are near the lower end of the zone, price cuts will be likely and price increases unlikely, and the reverse for a pileup at the upper end of the zone.

As Figure 2 shows, a fixed cost of adjustment does not uniformly make price adjustment stickier. What matters is the location of the earlier level of cost compared to the inaction zone of the current level of cost.

A large literature on the effects of a fixed cost of adjustment of prices, investment, and other decision variables, describes the implications of the setup of Figure 1. Chapter 7 of Romer (2019) is a detailed and lucid presentation of the economics of sticky prices. It observes, in this connection,

> One can say relatively little about the P_t that maximizes [expected profit] in the general case. Two assumptions allow us to make progress, however. The first, and most important, is that inflation is low and that the economy is always close to its flexible price equilibrium. The other is that households' discount factor, β,

is close to 1.

Auclert, Rigato, Rognlie and Straub (2022) have recently extended the literature under these assumptions.

The aim of this paper is to explore the behavior of the price in the opposites of these assumptions, that is, when (1) volatility is high, and (2) discounts are high, so the firm ignores the future consequences of its pricing. Thus the paper pursues the exact opposites of the two key features of the New Keynesian case as developed by Romer. The relation between the volatility of the cost shock and the flexibility of the price level is the subject of the rest of this paper.

Suppose that the cost shock is an iid draw from a uniform distribution on the interval

$$[1-\delta, 1+\delta]. \tag{5}$$

The parameter δ controls a mean-preserving spread of the cost shock around the mean, which is 1. A seller chooses to *reset* the price if

$$\frac{1}{4c_t} - \kappa > \frac{p_{t-1} - c_t}{p_{t-1}^2} \tag{6}$$

or *stick* otherwise. The price is $p_t = 2c_t$ for *reset* and $p_t = p_{t-1}$ for *stick*.

The following experiment reaches an important conclusion about the relation between the shock size δ and the frequency of the *reset* action. For each of 300 values of δ from zero to 0.3, I calculate one million observations of the time series, and tabulate the fraction of the actions that are *reset* over the million observations. The initial value of the price is $p_0 = 2$, corresponding to δ at its mean of 1.

Figure 3 graphs the results of these calculations. In an economy with small shocks, up to $\delta = 0.0855$, it never pays to reset. Above that critical value, it begins to pay to reset. There is no discontinuity—the limit from the right of the critical value is zero, like the limit from the left—but the curve becomes infinitely steep from the right (the derivative from the right is discontinuous). To the right of the critical value, it rises steeply up to a reset fraction of 0.25 and then follows a smooth concave path.

If the reset fraction is one, prices are fully flexible, and responsive to current conditions. At a shock value of 0.3, flexible pricing would occur for about 70 percent of transactions. Below a shock value of 0.0855, pricing is fully sticky, independent of current conditions.

There is a critical configuration of the model such that at lower values of the of the cost volatility δ, the price is a constant over time—resetting never occurs, except possibly to bring the price into the zone of indifference at the beginning of time.

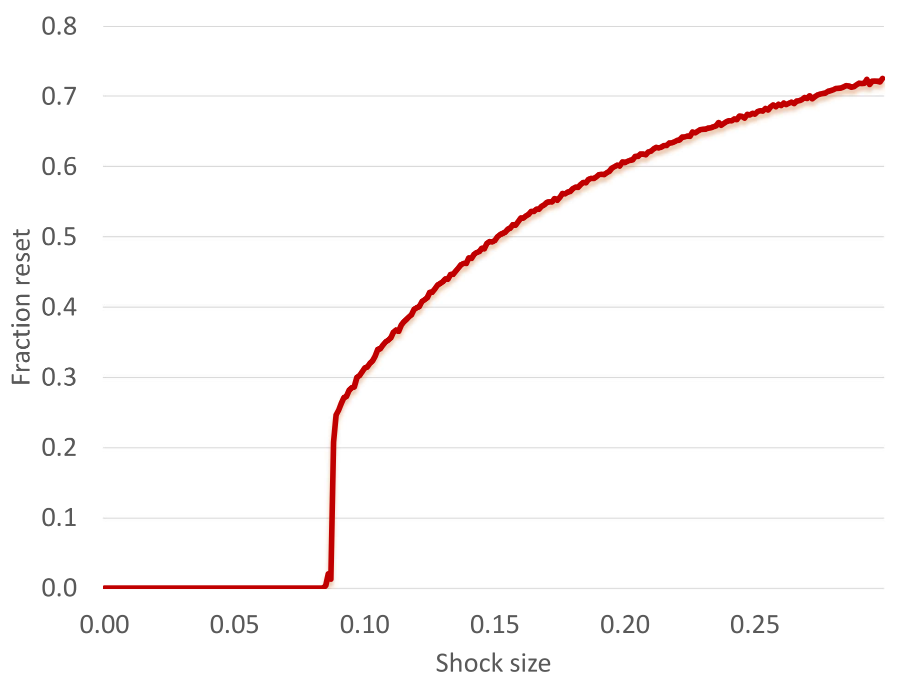

Figure 3: Relation between Shock Size and Fraction of Periods with Resets

The surprising implication of this investigation is that an increase in the volatility of cost that leaves the average level of cost unchanged can trigger a near collapse of price stickiness. The next section of the paper presents an empirical analysis demonstrating a large increase in cost volatility around the time of a burst of inflation during and after the pandemic, followed by a reversal.

As noted earlier, the rule for setting the reset price, $p^* = 2$, is myopic. It ignores the principle that a price set at t may influence prices in the future. Leaving out the fascinating details of the Calvo-style model is intentional. It gives rise to a simple but rigorous treatment of the endogenous timing of the resetting of the potentially sticky price when the volatility of pricing determinants is high. Of course, the extensive literature based on low volatility of shocks and forward-looking price-setting remains relevant for calmer times.

2.2 Robustness of the model

Wide variations in the parameters of the model preserve the basic property that the price is constant over time if the volatility of the cost shock is below the critical level, and that the incidence of unimpeded pricing explodes if the volatility is just above the critical level.

In general, the model delivers its basic message across broad variations in the initial price p_0, in the cost of resetting κ, in the elasticity of demand with respect to price, and in the serial correlation of the cost shock.

The basic idea of this paper is that a substantial rise in the volatility of costs and other determinants of prices can completely free the prices of a significant fraction of goods and services from the grip of New Keynesian stickiness, when the volatility of cost rises.

3 Measuring the Determinants of Price Volatility

The study of cross-industry standard deviations documents a large increase during the pandemic in the volatility of two variables directly involved in price formation, input cost and total factor productivity.

With variations in total factor productivity (TFP), denoted A, the pricing equation becomes

$$p = \mu \frac{c}{A}. \tag{7}$$

This equation implies that volatility in cost, productivity, and market power breeds volatility in product prices. I focus on cost and productivity because measurement of the volatility of market power is still a quite unsettled area of research.

The Bureau of Economic Analysis (BEA) publishes indexes of intermediate-input prices for 71 industries at quarterly frequency, starting in 2005. The published tables include many aggregations across industries, which I omit, so there is no overlap among the series I consider. The most recent observation is for the third quarter of 2022. I construct quarterly input-price growth ratios for each industry. A compact but informative statistic of volatility each quarter is the standard deviation of the growth ratio across the 71 industries. To deal with higher-frequency noise, I smooth the data by calculating 4-quarter moving averages.

Figure 4 shows the time series of the volatility of intermediate cost. Starting in the second quarter of 2020, volatility tripled. The one-year growth of cost volatility was 0.039, from 2020 Q1 to 2021 Q1. It remained high until the present, at more than double the level of the calm period from 2017 until the beginning of 2020. Volatility also rose moderately around 2006 and 2016. The biggest bulge, greater than the one associated with the pandemic, occurred during the financial-crisis recession, peaking in 2009.

The Bureau of Labor Statistics, in cooperation with the BEA, publishes annual data on TFP, starting in 1987, for essentially the same industries as in Figure 4. As of March 2023, the most recent year available is 2020; data for 2021 should be available in May 2023.

Figure 5 shows the implied volatility of TFP. The last annual observation includes the first quarter of 2020, when TFP volatility was presumably at a low level comparable to 2019, along with the following three quarters of extreme pandemic-induced volatility. Thus the

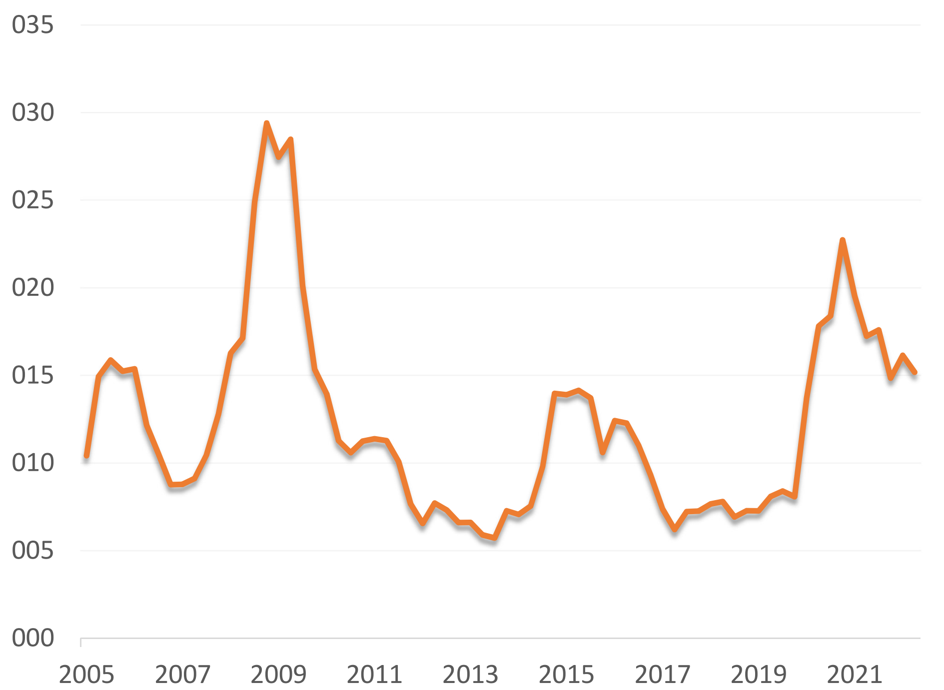

Figure 4: Cross-Industry Standard Deviation of Intermediate Cost, Quarterly

rate of increase over the three quarters of 2020 under the influence of the pandemic was higher than shown in the figure, possibly as high as for the financial crisis. Multiplying the observed increase of 0.029 by 4/3, as a rough estimate of what the 3-quarter increase would have been over an entire year, yields an estimated increase in volatility of 0.039.

The time paths of two determinants of price volatility, input cost and productivity, tell a common story. Volatility spiked during the upheaval of the pandemic. A spike of about the same amount occurred during and after the financial crisis that started in late 2008. A smaller burst of volatility occurred around 2015. And TFP experienced a spike of volatility in the tech recession of 2001.

It should be clear that volatility of the driving forces is not itself a driving force for inflation. In particular, in the financial crisis of 2008 and 2009, a large increase in volatility of both cost and productivity occurred, but inflation remained near normal levels. Rather, the volatility of the determinants of inflation influence the *slope* of the response of inflation to monetary policy. Section 5 explains this point in detail.

3.1 What about the volatility of output?

Figure 6 shows the quarterly time series of cross-industry variation in growth ratios for output. The relation between output and price is not as clean as the relations of input cost

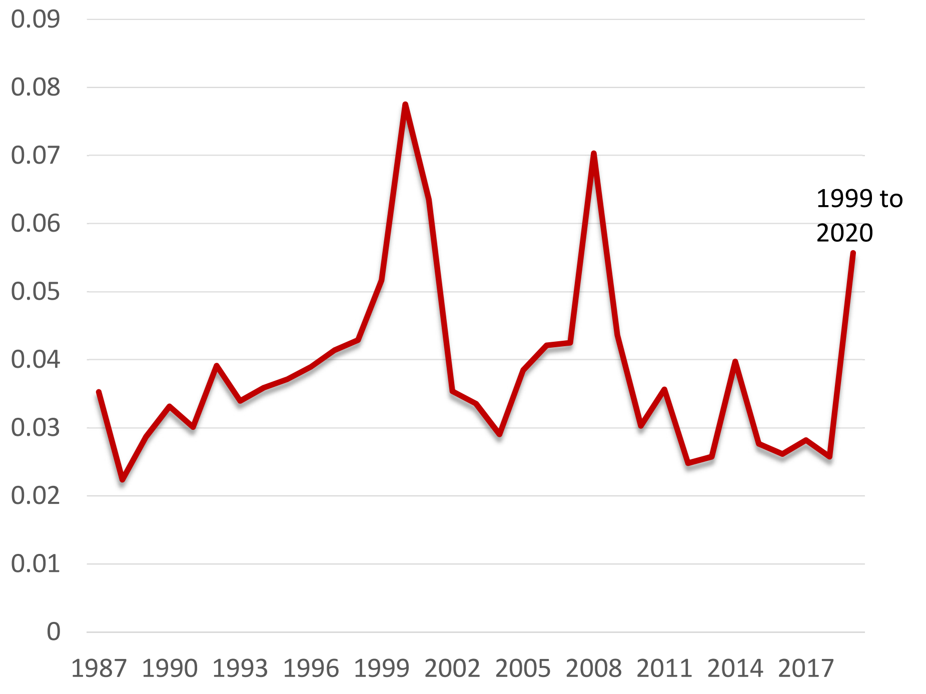

Figure 5: Cross-Industry Standard Deviation of Total Factor Productivity, by Year

and TFP, but the results suggest an important difference between the volatility burst in the pandemic compared to bursts from earlier sources. Two quarters stand out as having enormously higher volatility. The first is the change from the first quarter of 2020 (only barely affected by the pandemic) to the second quarter of 2020 (seriously affected). In that quarter, many industries had large declines in output and a few had large increases.

The second spike in output volatility occurred in the following quarter, measured as the change from the second quarter to the third quarter of 2020. Many of the industries with sharp declines in output in the previous quarter enjoyed recoveries. Overall volatility was slightly higher in this quarter than in the preceding quarter.

Work on this topic to date has uncovered two additional facts of importance. One is that past bulges in volatility of price determinants in recessions have not unlocked inflation or deflation, except recently, and long ago, in the great depression. The other is the tremendous increase in output volatility during the pandemic compared to other adverse shocks.

Figures Figure 7 and Figure 8 focus on output and price volatility early in the pandemic. The horizontal axis is the ratio of output in the second quarter of 2020 to output in the first quarter. The first shows the change ratios of the two variables as dots and the second repeats with balloons that display the sizes of the industries as measured by value added.

The two figures show that

1. quite a number of industries experienced little change in output or price;

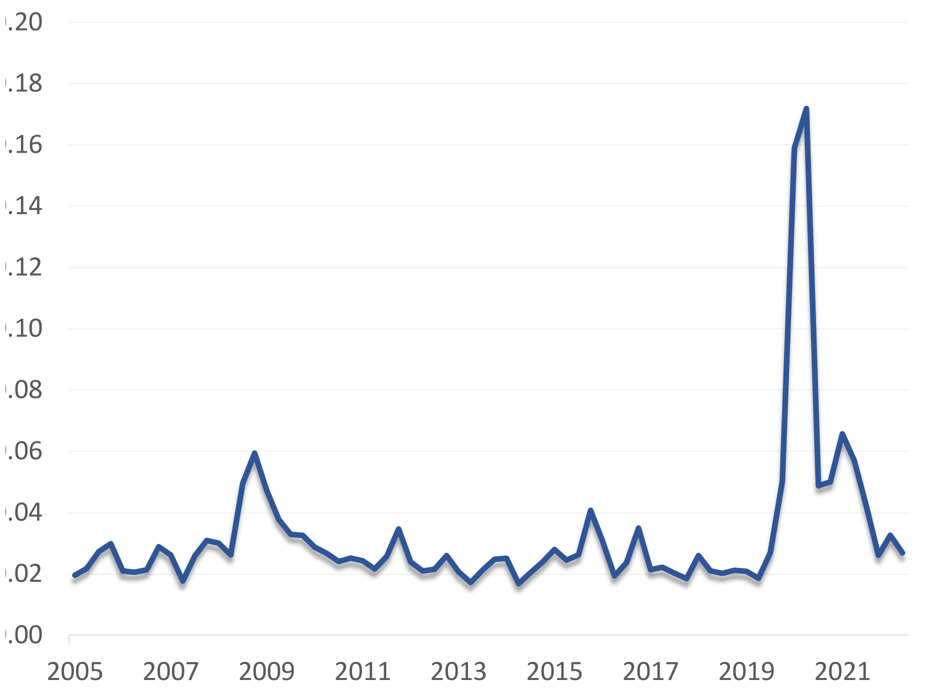

Figure 6: Cross-industry Standard Deviation of Output Volatility, by Quarter

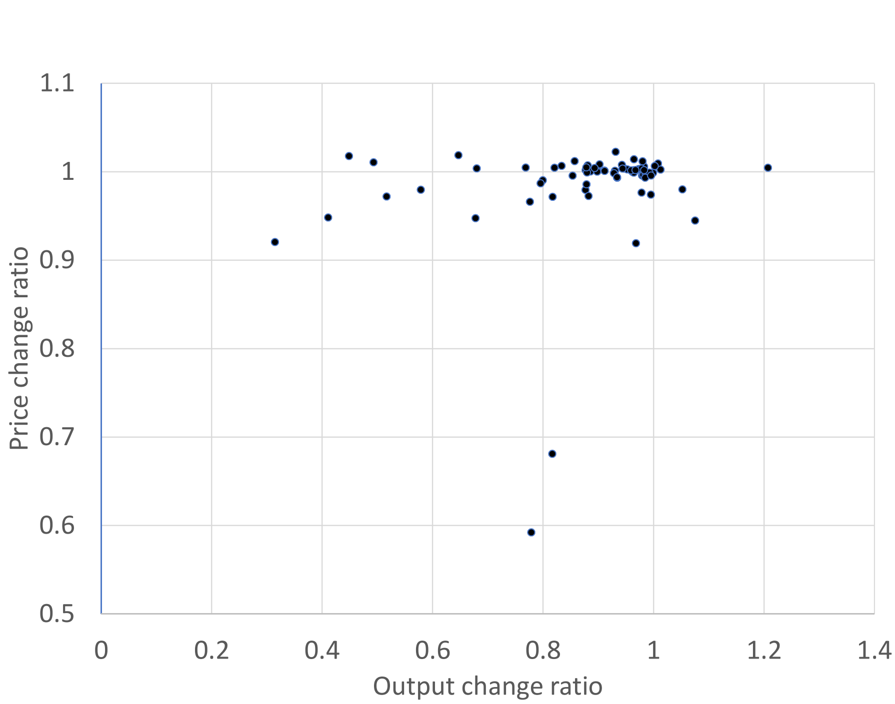

Figure 7: Joint Changes of Output and Price from the First Quarter of the Pandemic to the Second Quarter

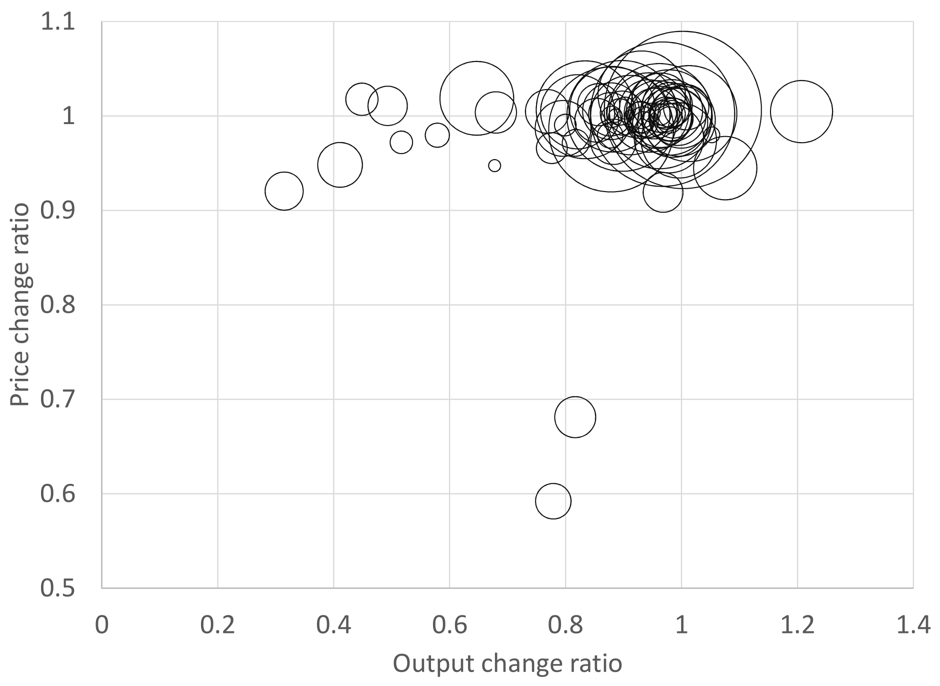

Figure 8: Joint Changes with Bubbles Indicating GDP of the Industry

2. no industries had substantial increases in prices;
3. two industries, *oil and gas extraction* and *petroleum and coal products* had substantial price declines;
4. one industry, *federal non-defense*, had a substantial increase in output;
5. many industries, led by *air transportation*, had substantial declines in output;
6. the scatter plot is quite flat—output varied much more than prices

4 The US Economy from 2018 to 2022

In this section I describe the movements of four key variables in the US, from 2018 to the present. Within this period, inflation switched from stable and low to a dramatic rise followed by a sharp decline.

Figure 9 shows inflation, the rate of change of the Consumer Price Index over 3-month intervals, multiplied by 400 to state it at annual percent rates. Prior to the pandemic, inflation fluctuated over a fairly tight range centered on the Fed's 2 percent annual target. Inflation plunged to negative 4 percent at the outset of the pandemic. It rose systematically

Figure 9: Inflation, π

to 10 percent in mid-2022, then fell rapidly to around three or four percent in the third quarter of 2022, where it remains, as of March 2023.

Many observers, using a 12-month moving average of monthly inflation, believe that inflation remains high as of this writing in March 2023. Figure 10 illustrates the effect of interposing the moving average calculation between the data and the results.

The blue line shows the rate of change of the price level over the past year. The average over 12 monthly observations smooths out short-run movements. The gray line, showing those movements, confirms the presence of confusing noise. But the use of the 12-month average may be going too far, smoothing out the signal as well as the noise. The orange line uses a 3-month average and smooths out the noise without obscuring what may be a true signal that inflation has fallen to around three percent per year. Eeckhout (January 2023) reaches a similar conclusion for the US and the Eurozone, in a formal econometric analysis. See also Blinder (January 5, 2023).

The conclusion that current inflation is not too far above the target applies to variant inflation measured based on the PCE deflator, favored by the Fed, and those calculated by removing food and energy. It is also supported by the financial-market pricing of inflation swaps for a year in the future.

Figure 11 shows monthly the real, safe, one-year term interest rate as compiled by the Cleveland Federal Reserve Bank, smoothed by taking 3-month averages and stated at annual

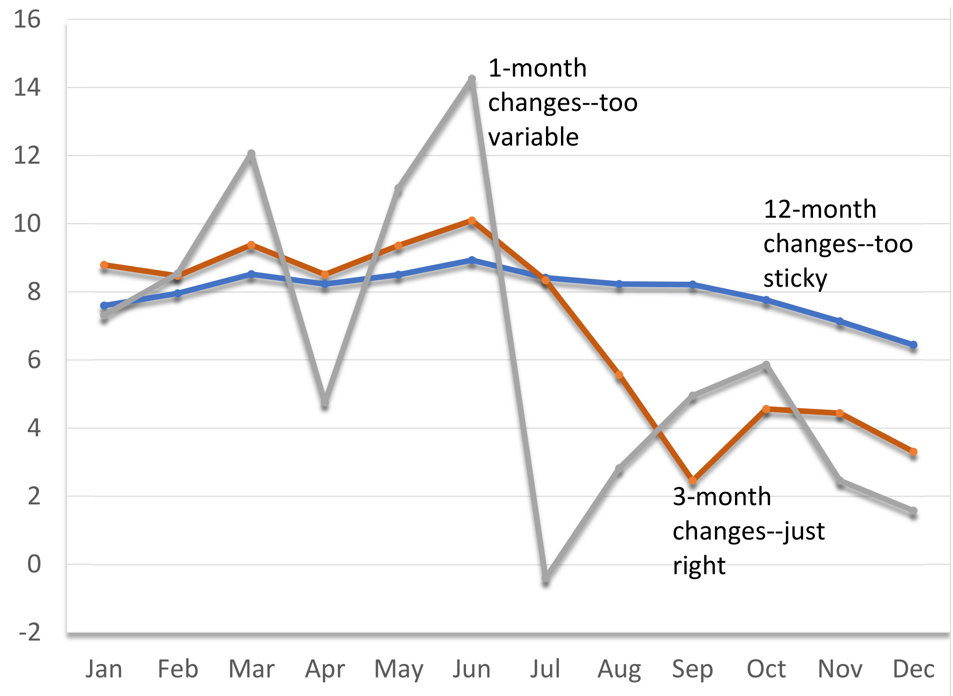

Figure 10: It Appears that Inflation Has Fallen Back to Around 3 or 4 Percent

percentage rates. The rate was about 1 percent prior to the pandemic, jumped briefly to 4 percent, declined steadily down to minus 5 percent, and finally returned to normal, as inflation dissipated. The bank derives the real interest rate from data on inflation swaps and other sources. See Haubrich, Pennacchi and Ritchken (2011) for further information.

Figure 12 shows the Fed's policy interest rate, stated at annual rate. The Fed immediately lowered its policy rate to zero at the onset of the pandemic. Its movements of the policy rate have been small compared to the movements of the real rate shown in Figure 11. And note that much of the increase in the policy rate has occurred while there was good evidence that inflation was falling.

The Fed describes the fed funds rate as its policy rate and identifies the rate paid on reserves as a tool for stabilizing the funds rate within a narrow target range. The distinction is immaterial for the present purposes because the funds rate tracks the reserve rate closely.

Figure 13 shows a comprehensive measure of fiscal policy, defined as total real government spending, from the NIPAs—purchases plus transfers divided by the CPI. It declined as inflation jumped up. Thus the simple idea that fiscal expansion stimulated runaway inflation is untenable.

Figure 11: Short-Term, Real, Safe Interest Rate, r

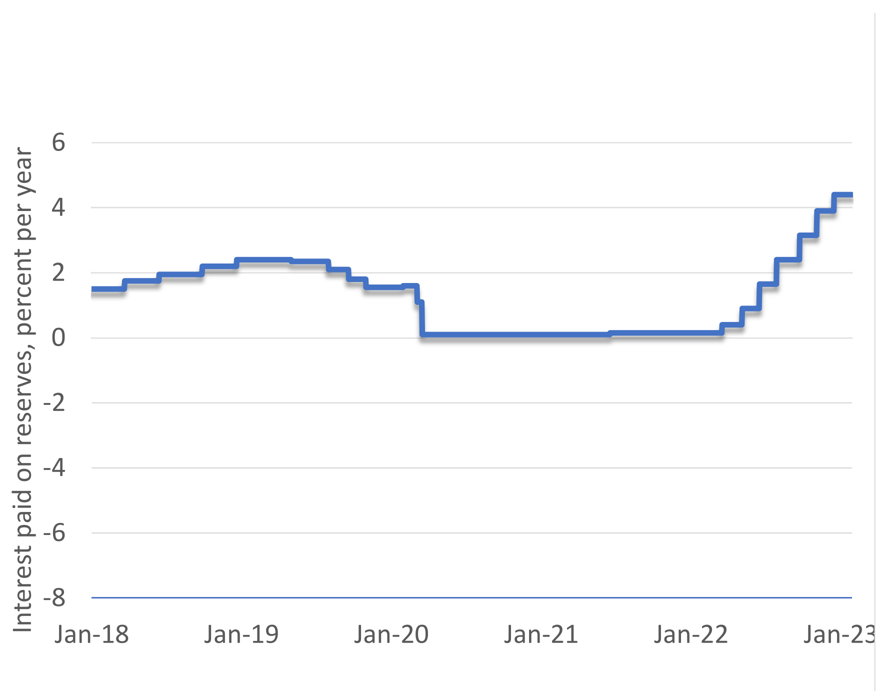

Figure 12: The Fed's Policy Interest Rate

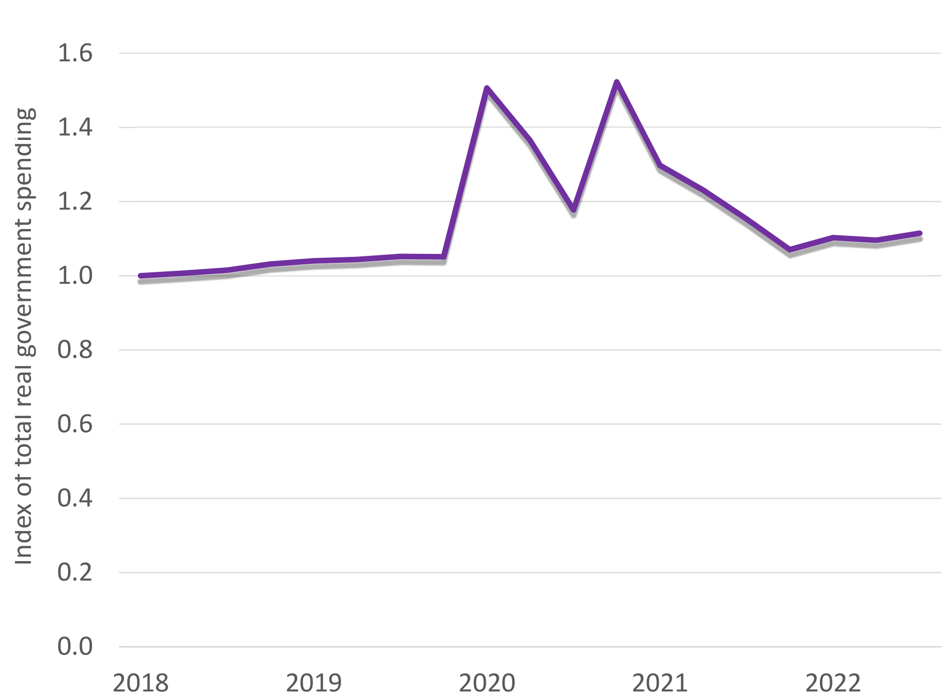

Figure 13: Index of Real Government Spending, g

5 Informal Analysis with Shifting Phillips Curve

I study the conditions underlying weakly anchored inflation in a diagram with inflation π on the vertical axis and the real interest rate r on the horizontal axis—see Figure 14. The economy's Fisher equation implies a line in that space with slope -1. The line is labeled M. The central bank determines the position of M by choosing its nominal policy rate, b. I take b to be a constant, to express the idea that the central bank's initial response to threatened inflation is inaction. Under reserve saturation, the real interest rate r tracks b closely, with r equal to b less the expected rate of inflation.

Next I turn to the question of where the economy operates along the M line. Figure 14 shows a curve, labeled X, of values of the real interest rate consistent with the economy's Phillips curve and IS curve.

In a real-business-cycle model with monetary neutrality, the real interest rate is unaffected by monetary considerations. The X curve is vertical, with r equal to a constant, say $\bar{r}$. In that economy, the equilibrium is $r = \bar{r}$ and expected π is equal to $b - \bar{r}$.

With nominal frictions, the rate of inflation and the real interest rate lie along an upward-sloping line, say

$$r = f(\pi). \tag{8}$$

The function $f(\pi)$ combines the roles of the IS curve and the Phillips curve in conventional

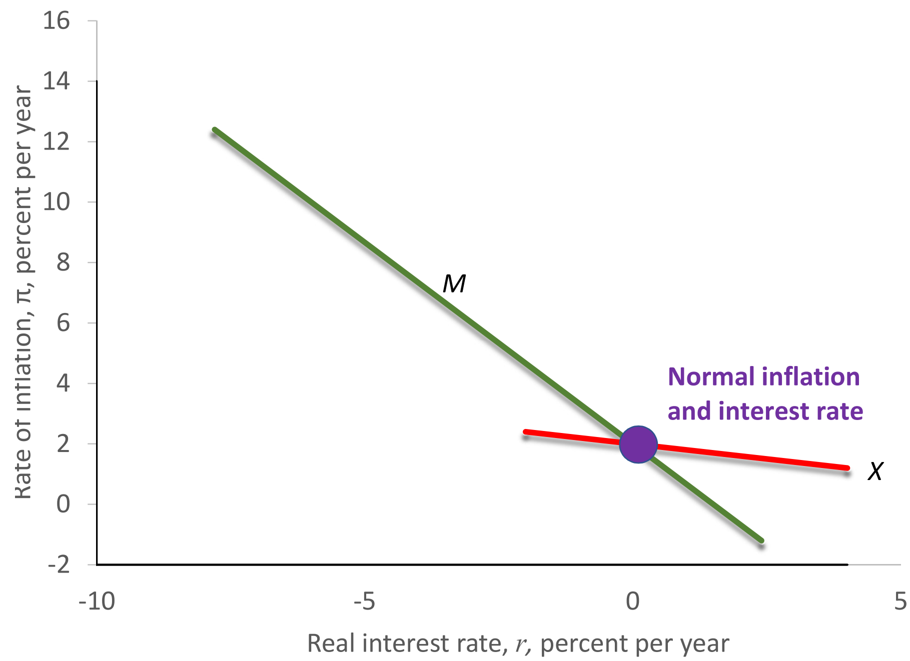

Figure 14: Equilibrium in normal times—$r = 0$ and $\pi = 2\%$

New Keynesian models. The increase in the interest rate depresses output and thus slackens markets. Then the Phillips curve indicates lower inflation.

Figure 14 shows the normal configuration of the model. Curves M and X intersect at a real interest rate of zero and a rate of inflation of 2 percent. These values were typical of actual experience before the pandemic.

The model is capable of generating a change comparable to what happened in the US economy between mid-2020 and mid-2022, as the real interest rate fell into deeply negative territory while inflation exploded.

Figure 15 shows the effect of a shock that causes runaway inflation. The M curve remains the same—there is no immediate response of monetary policy; the policy rate b is unchanged. The shifted X curve, shown as a dashed red curve, is steeper than normal. It intersects the M curve at values drawn from the data from mid-2022–the inflation rate is 10 percent per year and the real interest rate is minus 6 percent.

Runaway inflation occurs because of the delay in the central bank's response. Once the bank fights inflation by raising its policy rate b, the M curve shifts toward the origin and the economy moves down the dashed X curve and inflation and the real interest rate both fall.

Starting inlater 2022, the X curve has shifted back toward its normal position. Inflation has fallen and the real interest rate has risen as the economy returned toward normal.

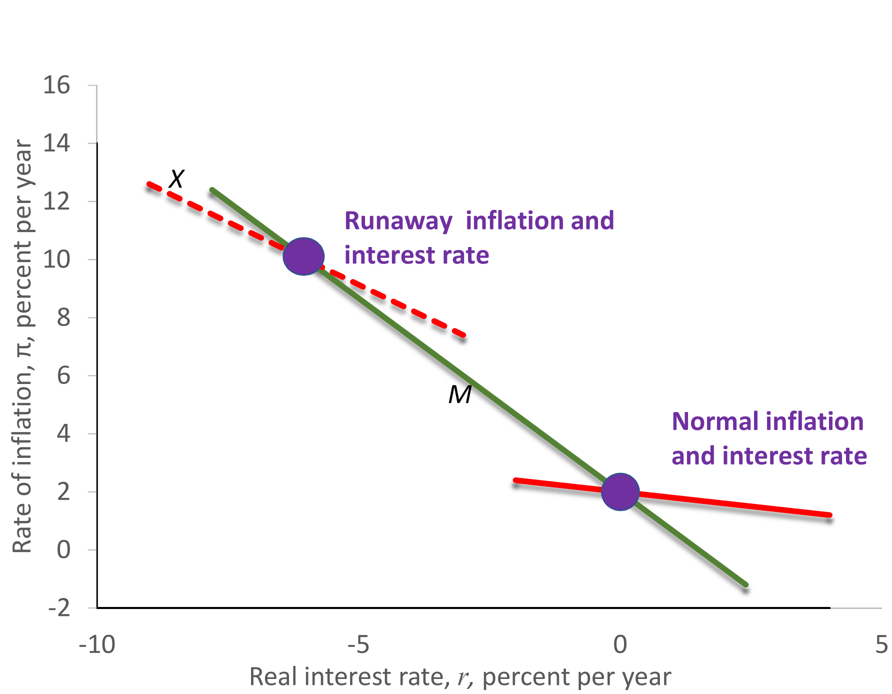

Figure 15: Runaway Inflation: $r = -6\%$ and $\pi = 10\%$

The US has raised its policy rate, as shown in Figure 12. Further, as noted earlier, there is reasonable evidence that US inflation is returning to target. Part of the decline in inflation has come from the tightening of policy and the rest from normalization of the Phillips curve.

DeLong and Summers (1986) diagnosed the issue considered in this paper. They observed that increasing flexibility of prices could raise the sensitivity of output and employment to disturbances.

5.1 Forces keeping the economy on its M curve

For any point on the M curve, the variables of the model satisfy the no-arbitrage condition mentioned earlier, which can be restated as the equality of the short-run nominal safe rate and the policy rate. Modern central banking ensures that the two rates are fairly close together by establishing a corridor where banks and other financial institutions can borrow from or lend to the central bank. Transactions in other safe instruments do not occur outside the corridor, because the central bank offers a better deal. Thus powerful forces of financial arbitrage keep the economy close to its M curve. See Castillo-Martinez and Reis (2019) for an extensive discussion of how modern central banks steer their economies.

6 Stabilizing the Inflation Rate

To achieve stable inflation, t is both necessary and effective to change the policy rate quickly to head off inflation or deflation. Recent experience has shown that a sluggish response to inflation based on a philosophy of wait-and-see has adverse practical consequences.

The "Taylor principle" of boosting the policy rate by 1.5 points for every point of excess inflation embodies this idea. But Taylor rules generally impose gradual adjustment of the policy rate that can result in runaway inflation. A Taylor rule with a term that loads on the lagged policy rate invites unstable rates of change of the price level. Inflation can decline rapidly, so these lessons apply in reverse as well.

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