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What Caused the U.S. Pandemic-Era Inflation?

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ABSTRACT

We answer the question posed by the title by specifying and estimating a simple dynamic model of prices, wages, and short-run and long-run inflation expectations. The estimated model allows us to analyze the direct and indirect effects of product-market and labor-market shocks on prices and nominal wages and to quantify the sources of U.S. pandemic-era inflation and wage growth. We find that, contrary to early concerns that inflation would be spurred by overheated labor markets, most of the inflation surge that began in 2021 was the result of shocks to prices given wages, including sharp increases in commodity prices and sectoral shortages. However, although tight labor markets have thus far not been the primary driver of inflation, the effects of overheated labor markets on nominal wage growth and inflation are more persistent than the effects of product-market shocks. Controlling inflation will thus ultimately require achieving a better balance between labor demand and labor supply.

Introduction

Central bankers and most outside economists failed to predict the sharp rise in inflation that began in 2021, and policymakers, both in the United States and in other advanced economies, were accordingly slow to react. Action was further delayed by the view that the inflation burst would be temporary.

Misjudgments of the economic effects of covid-era fiscal programs are one potential explanation of the failure to forecast the subsequent inflation. Federal Open Market Committee (FOMC) forecasts of inflation changed little between the September 2020 and June 2021 iterations of the *Survey of Economic Projections*, and the Committee continued to expect that inflation would return close to the Fed's 2 percent target by 2023, despite congressional passage of a bill in December 2020 that included $900 billion for covid relief and the $1.9 trillion American Rescue Plan signed by President Biden in March 2021. These two programs came on top of the $2.2 trillion CARES Act, passed in March 2020 and signed by President Trump, which had already strengthened firms' and households' balance sheets and increased future ability to spend. Overall, as a share of GDP, the headline costs of these three covid-era fiscal packages were about 4-1/2 times the size of the American Recovery and Reinvestment Act (ARRA), enacted in response to the 2008 financial crisis and the ensuing recession.[1]

According to conventional economic theory, expansionary fiscal policies can stoke inflation if they cause labor markets to become overheated and output to exceed the economy's potential. Indeed, some early analyses of the American Rescue Plan using standard fiscal multipliers concluded that the additional federal spending would indeed overheat the economy, possibly leading to higher inflation (Blanchard, 2021; Edelberg and Sheiner, 2021). These studies acknowledged uncertainty about magnitudes, as the fiscal impacts on employment, output, and inflation would depend on many factors, including the effects of the pandemic on potential output, the size of the initial output gap, households' propensities to consume out of the one-time checks authorized by the bill, and the relation between labor market tightness and inflation.

Inflation optimists (Reifschneider and Wilcox 2022) argued that, even if the new fiscal spending were to drive down unemployment by more than expected, a large burst of inflation was still unlikely, as many studies had concluded that the Phillips curve is quite flat (that is, inflation is relatively insensitive

[1] The headline cost of the CARES Act and the December supplemental appropriations package together totaled about 15 percent of gross domestic product (GDP) in 2020, and the American Rescue Plan was roughly 8 percent of 2021 GDP. By comparison, the ARRA of 2009 was slightly more than 5 percent of that year's GDP.

to labor market tightness), and—in light of more than three decades of low inflation in the United States—inflation expectations were likely to remain well anchored.

In contrast, some economists (including one of the authors) argued that wage inflation, and consequently price inflation, could rise much more than predicted by conventional calculations predicated on a flat Phillips curve (Summers, 2021; Blanchard, 2021). Their concerns were that the increase in aggregate demand likely to result from the unprecedentedly large fiscal transfers, together with the cumulative effects of the easing of monetary policy begun in March 2020, could cause more overheating of an already-tight labor market than the optimists expected. An extremely low unemployment rate might in turn cause the Phillips curve to steepen. Moreover, higher and, consequently, more psychologically salient levels of inflation might lead inflation expectations to de-anchor, raising the potential for a wage-price spiral.

The critics' forecasts of higher inflation would prove to be correct—indeed, even too optimistic—but, in substantial part, the sources of the inflation would prove to be different from those they warned about. Labor market overheating did indeed occur in 2021 and 2022, as reflected by several indicators, including unsustainably high rates of job creation, an increasing ratio of job openings to unemployed workers, and low levels of quits. But, as this paper will show, the behavior of wages in 2021 and 2022 was broadly consistent with the relations the Fed had relied on, and medium-term inflation expectations rose modestly by some measures but did not de-anchor. In short, labor market overheating would indeed ultimately prove to be a source of persistent inflation, as the critics expected, but the traditional wage Phillips curve mechanism was not the main event, at least not until recently.

In retrospect, the failure to forecast the inflation burst reflected in large part the fact that, in focusing on the labor market, both the Fed and its critics underestimated the inflationary potential of developments in goods markets, that is, from increases in prices given wages. The shocks to prices came from several sources. First, like other forecasters (including participants in commodity futures markets), most economists did not anticipate either the magnitude or the duration of the rise in commodity prices that began in 2021. Beyond the more-familiar (but large and sustained) shocks to food and energy prices, the pandemic itself led to unusual distortions in key product markets, such as those for new and used vehicles. Demand shifts (e.g., from services to goods) during the pandemic combined with supply chain problems to create shortages and sectoral price increases not offset by decreases in other sectors (Guerreri et al., 2022; di Giovanni et al., 2023). These sectoral mismatches between demand and supply proved more intractable and longer-lasting than many had expected. Together, these shocks to prices given wages would prove to be the critical triggers of the rise in inflation.

This is the story we develop in this paper.

We start with a simple analytical model, focusing on the behavior of wages, prices, and short and long-run inflation expectations, taking labor market slack and shocks to prices as given. We show the very different dynamic effects on wage and price inflation of overheating in the labor market and price shocks in goods markets. Appreciating these differences is essential for understanding the changing relative importance of the two sources of inflation, and by implication, the evolution of inflation over time.

We then estimate an empirical version of the model, allowing for a generous lag structure to accommodate flexible dynamics and estimating it on the pre-covid period. We examine the stability of the wage, price, and short and long-run inflation expectations relations betweem the pre-covid and covid periods, taking into account the roles of labor market tightness, energy and food price shocks, and sectoral shortages. We use the estimated model to decompose the sources of the pandemic-era inflation into the effects of the various shocks. Our decomposition captures general equilibrium effects, lags, and linkages among alternative sources of inflation operating through inflation expectations and other channels. We conclude that labor market tightness made at most a modest contribution to inflation early on, resolving the puzzle of how inflation could rise so much despite a flat wage Phillips curve. Instead, most of the early action in inflation came from the goods market, in the form of sharp increases in some relative prices, including commodity prices and prices in supply-constrained sectors. To the extent that commodity prices stabilize and supply chains return to normal—processes that both seem well advanced as of this writing (May 2023)—the goods market component of inflation is likely to decrease in importance, and the labor market component to become more dominant. Looking forward, with labor market slack still below sustainable levels and inflation expectations modestly higher, we conclude that the Fed is unlikely to be able to avoid slowing the economy to return inflation to target. The extent of that slowing will depend however on the evolution of certain structural features of the labor market, notably the efficiency of the process of matching workers with jobs.

I. A Brief Literature Review

Much recent work has provided empirical analyses of the pandemic-era inflation. Ball et al (2022) propose a decomposition of inflation into weighted median inflation (instead of the conventional core measure of inflation) and a residual, equal to headline inflation less median inflation. Their use of median inflation rather the more conventional measure of core inflation is intended to remove large price spikes, due not only to the prices of energy and food, which core inflation does, but also due to sectoral shortages, which have made this inflation episode different from earlier ones. They find that much of the increase in median inflation is explained by the tightness of the labor market. This conclusion is broadly consistent with our findings that labor market developments were the primary source of a slowly strengthening, underlying inflation trend, while the larger, shorter-term movements in headline inflation were explained largely by shocks to prices given wages.

Cecchetti et al (2023) study the recent inflation and the prospects for disinflation in a historical context. As we do, they provide a stripped-down model of the inflation process. However, in contrast to the largely unconstrained dynamics that we allow in the empirical model presented below, they impose a tight New Keynesian structure; and their focus is on projecting the likely path and consequences of disinflation, rather than estimating the sources and dynamics of the inflation. They argue that nonlinearities in the Phillips curve are important for explaining inflation (see also Benigno and Eggertsson 2023, Gagnon and Sarsenbayev 2022). In contrast, we find that a linear relation between labor market tightness and wages, estimated on pre-covid data, fits the covid-era data reasonably well and is adequate to explain the recent behavior of wages.

Guardone and Gertler (2023) provide an alternative story for the origins of the inflation. Using a calibrated DSGE model to structure their analysis, they argue that the Fed's commitment to high employment in the face of inflationary oil price shocks explains the sharp rise in the pace of price increases. (Cecchetti et al. likewise blame the Fed's failure to tighten pre-emptively as a source of the inflation.) Guardone and Gertler's attention to oil price shocks parallels our own focus on factors directly affecting prices given wages. Their main contributions concern the role of the Fed's reaction function and policy framework in the over-expansion of aggregate demand during the recovery from the pandemic—an important topic but not the focus of our own paper.

Koch and Noureldin (2023) of the International Monetary Fund conduct a post-mortem of their institution's failure to forecast the inflation. Like other papers in the literature, they find an important role for increased aggregate demand and, especially, pandemic-induced supply constraints in setting off the inflation. However, they pay limited attention to dynamics, and in particular place less weight than we would on commodity price shocks and their effects on other prices and inflation expectations over time.

II. A Simple Model of Wage-Price Determination

To help interpret recent inflation developments without imposing too much a priori structure, we use a bare-bones but flexible model of aggregate wage-price determination. Our approach to inflation is aggregative, or "top down"; with a partial exception discussed in the next section, we do not consider the microeconomic determinants of sectoral price changes, e.g., factors affecting the behavior of rents or the differential impact of the pandemic on different industries. Our model reduces to four equations, which jointly determine nominal wages, prices, and short-run and long-run inflation expectations. As already noted, when we take the bare-bones model to the data in the next section we incorporate a more flexible lag structure, to allow for richer dynamics, and include measures of key shocks to product and labor markets to account more explicitly for the forces affecting inflation.

The wage equation

We start with an aggregate wage equation. We make the standard assumptions that nominal wages depend on the expected price level and the degree of labor market slack. In a departure from the standard specification, we pursue the question of whether workers accept losses in purchasing power resulting from unanticipated price shocks, or whether instead, in their wage bargaining, they try to "catch up" with prior inflation.

Specifically, we assume that the nominal wage *w* in each quarter depends on the expected price for that quarter p^e, an aspiration real wage ω^A (see below), and an indicator of the tightness of the labor market x:

(Eq 1) $w = p^e + \omega^A + \beta x$

Wages, prices, and expected prices are in log-levels, so differences should be interpreted as growth rates. We use ω to designate the real aspiration wage as a reminder that that variable is in real terms, in distinction to the nominal wage *w*. We discuss empirical measures of labor market tightness x in the next section, only noting here the sign convention that we interpret higher values of x as corresponding to a tighter labor market. We suppress the time subscript for current-quarter variables.

We include the aspiration real wage ω^A in the model as a device for modeling a possible catch-up effect, in which workers seek to make up for past losses of purchasing power, implying a degree of real-wage rigidity. The aspiration wage may be thought of as the real wage that workers believe is achievable—a focal point in wage bargaining, perhaps—given recent developments in wages, prices, and other factors. Alternatively, the aspiration real wage might be thought of as representing the long-run equilibrium real wage, toward which the actual real wage gradually adjusts. Adopting the notation $q(-n)$ to stand for the variable q lagged n quarters, we assume that the aspiration real wage in each quarter is a weighted average of the previous quarter's aspiration wage and realized real wage, plus a shock term z_{ω}, standing for all the other factors that affect wage determination:

(Eq 2) $\omega^A = \alpha\omega^A(-1) + (1-\alpha)\big(w(-1) - p(-1)\big) + z_{\omega}$

When estimating the model, we also allow wage growth to depend on an exogenous trend in productivity growth. For simplicity of exposition, we ignore that term here.

Putting the two equations above together to eliminate ω^A yields:

(Eq 3) $w - w(-1) = \big(p^e - p(-1)\big) + \alpha\big(p(-1) - p^e(-1)\big) + \beta\big(x - \alpha x(-1)\big) + z_w$

Examination of these equations suggests two cases of interest, depending on the value of the "catch-up" parameter α. If $\alpha = 0$ then, from (Eq 2), the aspiration real wage in each quarter is just the real wage in the previous quarter (adjusted for trend productivity growth, in the empirical version of the model later) plus an error term. Further, from (Eq 3), in the special case of $\alpha = 0$, the change in the nominal wage equals the expected rate of inflation in the previous quarter, $p^e - p(-1)$, plus a term that depends on the degree of labor-market tightness x—in short, a standard expectations-augmented wage Phillips curve.

If $a \neq 0$, on the other hand, then (Eq 3) implies that among the factors determining nominal wage growth is the difference in the previous period's price level and the price level that had been expected for that period, $p(-1) - p^e(-1)$. We call this term the catch-up term. The existence of a catch-up term implies that, in their bargaining with employers, workers seek to be compensated for last period's unexpected inflation. In other words, to the extent that workers' expectations or focal points (or those of their institutional representatives) influence the wage bargaining process, the economy exhibits a degree of real-wage rigidity. Note also from (Eq 3) that, if $a \neq 0$, the term relating to labor-market tightness can be rewritten as $(1-a)x + a(x - x(-1))$, implying that wages depend on both the level and change of labor-market tightness.

The price equation

Given wages, we assume that the price level p depends on the level of nominal wages plus a shock term z_p that captures the relative costs of nonlabor inputs, variations in markups, and other factors affecting price-setting:

$$p = w + z_p$$

Or, in first differences:

(Eq 4) $$p - p(-1) = (w - w(-1)) + (z_p - z_p(-1))$$

In the empirical model, we will flesh out the shock term by including variables such as commodity price shocks and supply-chain problems that increase prices given wages. Since prices should depend on unit labor costs rather than wages per se, in the estimation we also include the productivity trend in the price equation. We will not treat producer markups as an independent variable but note that markups will endogenously increase in our model when strong sectoral demand confronts exogenous constraints on supply (see below).

Inflation expectations equations

The model is closed by equations that describe the behavior of the public's short-run and long-run inflation expectations. Short-run inflation expectations are a weighted average of long-run inflation expectations, π^*, and last period's inflation:

(Eq 5) $$p^e - p(-1) = \delta\pi^* + (1 - \delta)(p(-1) - p(-2))$$

Long-run inflation expectations in turn evolve as a weighted average of last period's long-run inflation expectations and actual inflation:

(Eq 6) $$\pi^* = \gamma\pi^*(-1) + (1 - \gamma)(p(-1) - p(-2))$$

The parameters δ and γ capture the degree of anchoring of short and long-run inflation expectations. If both δ and γ are close to 1, expectations are well anchored. Both δ and γ play important though different roles in determining the dynamic effects of shocks on inflation. The parameter δ affects short run dynamics, and the degree to which price inflation affects wage inflation: the lower δ, the more persistent the dynamic effects of a price shock. The parameter γ affects long run dynamics, and in particular the effect of transitory shocks on long run inflation.

Inspection of the equations above shows that, in the long-run steady state, both inflation expectations and the inflation rate consistent with full employment are indeterminate. For any value of long-run expected inflation π^*, assuming that $x = 0$, the model solution implies that short-run inflation expectations, wage inflation, and price inflation all equal the arbitrarily chosen value of π^*. Put another way, the value of π^* at any point in time is determined by the history of inflation. An episode of higher inflation leads to higher steady-state inflation; the longer the episode, or the lower γ, the stronger the effect on steady-state inflation. One can think of the "de-anchoring" that pessimists worried about at the start of the inflation episode as decreases in either δ or γ. Other things equal, such de-anchoring would lead to stronger and more persistent inflation following an inflationary shock.

When the aspiration wage is substituted out, as above, the model determines the evolution of four endogenous variables: π^*, p^e, w , and p. Despite its simplicity, the basic model displays interesting dynamic properties.

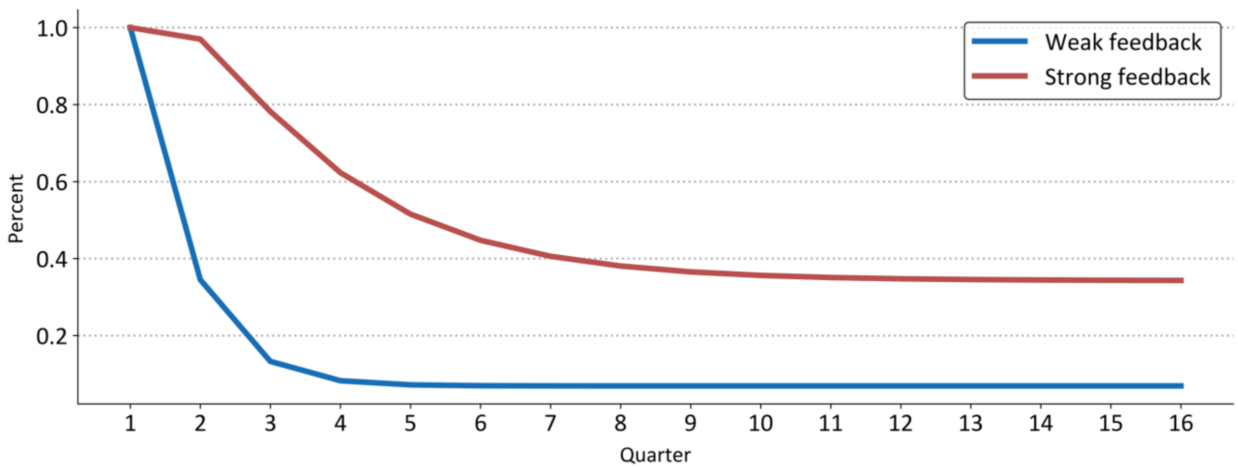
To illustrate, Figure 1 below shows, for alternative parameter assumptions, the model-implied dynamic responses of inflation to a one-time shock to the price equation. Specifically, we simulate the full model under the assumption that the price shock z_p rises permanently by one unit in period 1. (Note that a permanent shock to the price level is a one-period shock to price inflation). We consider two cases: In the first, we assume a limited catch-up effect and stable inflation expectations ($\alpha = 0.2, \delta = 0.9, \gamma = 0.95$).[2] In this case, as Figure 1 shows, the shock to the price level leads to a sharp increase in inflation that is almost completely reversed after a few periods (see the curve marked "weak feedback"). The low persistence of inflation in this case reflects the weak catch-up effect (workers are unable to recoup the effects of unexpected inflation on their real wages) and well-anchored inflation expectations. Because of the (small) effect of the inflation shock on long-run expectations, however, inflation ends up permanently slightly higher, by 0.06 percent in this example. With a limited catch-up effect and well-anchored expectations, the conventional wisdom that monetary policymakers can "look through" temporary supply shocks is justified.

The response of inflation to a one-time price shock is quite different when the catch-up effect is stronger and inflation expectations are less well anchored (say, $\alpha = 0.6, \delta = 0.7, \gamma = 0.9$). In this

[2] We do not need to assign a value to β as doing so would not affect these simulations.

second case the inflation response to a one-time price shock dies down only slowly (see the curve marked "strong feedback" in Figure 1). A stronger catch-up effect implies that a "price-wage spiral" is operating, with inflation triggering higher nominal wage demands, which in turn imply higher prices and greater inflation persistence. In this case, the long-run effect on inflation of a temporary inflation shock, 0.34 percent, is no longer negligible. Again, the simulation is consistent with conventional wisdom at central banks, which holds that poorly-anchored inflation expectations lead to more extended episodes of inflation and to higher inflation in the long run, thereby requiring a strong policy response.

FIGURE 1. RESPONSES OF INFLATION TO A PRICE SHOCK FOR ALTERNATIVE PARAMETER CHOICES

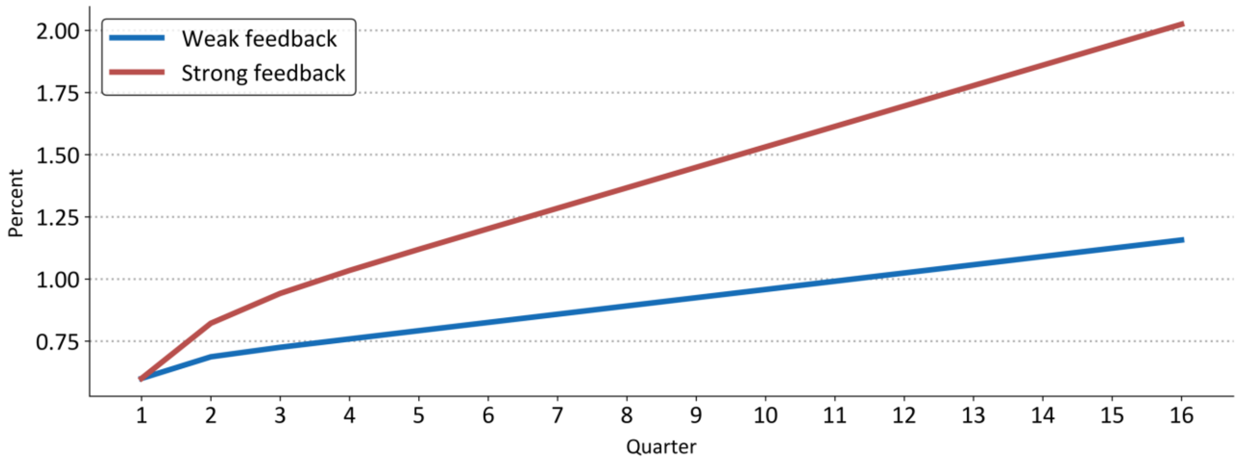


Note: The figure shows inflation in alternative simulations of the model, starting from steady state and assuming a permanent shock to the price level in period 1. Parameter choices that imply less wage catch-up and well-anchored inflation expectations lead to less persistent inflation (weak feedback). Parameters implying greater catch-up and less well-anchored expectations lead to more persistent inflation (strong feedback).

Inflation can also originate in the labor market in our model. For the same two parameter configurations as in Figure 1, Figure 2 shows the simulated behavior of inflation following a one-time, permanent one-unit increase in labor market tightness x. After an initial increase, inflation continues to increase over time as the labor market remains tight. The rate at which inflation increases depends on the degree of anchoring of expectations, and to a lesser degree, the strength of the catch-up effect. With well-anchored expectations and little catch-up effect (case 1), a tight labor market results in a relatively slow increase in price inflation (see the curve labeled "weak feedback" in Figure 2.) However, real-wage rigidity and loosely-anchored inflation expectations (case 2) magnify the effects of labor market tightness on wages and, in turn, on prices (the curve marked "strong feedback" in Figure 2).

Thus, the longer the overheating episode, the stronger the catch-up effect, and the weaker the anchoring of expectations, the larger is the effect of labor market tightness on inflation, and, implicitly, the stronger the eventual monetary contraction needed to return inflation to target, all else equal.

FIGURE 2. RESPONSES OF INFLATION TO A PERMANENT INCREASE IN LABOR MARKET TIGHTNESS FOR ALTERNATIVE PARAMETER CHOICES



Note: The figure shows inflation in alternative simulations of the model, starting from steady state and assuming a permanent one-unit shock to labor market tightness in period 1. Parameter choices that imply less catch-up and well-anchored inflation expectations lead to a weaker effect of labor market tightness on inflation, while parameters consistent with stronger catch-up effects and less well-anchored inflation expectations lead to a stonger effect.

Figures 1 and 2 yield important conclusions. If, in our model, an economy experiences large price shocks, they will lead to strong but mostly temporary increases in (headline) inflation. The persistence of those increases depends on the anchoring of expectations and the degree of real-wage rigidity. If the economy experiences overheating in the labor market, it will see a slow but steady increase in inflation, with the rate of increase reflecting not only the sensitivity of wages to labor market tightness, but, as in the case of a price shock, on the degree to which inflation expectations are anchored and the extent of real wage rigidity. If the two types of shocks hit the economy simultaneously, the shock to prices will dominate inflation initially. However, as those effects fade, higher underlying inflation emanating from the labor market will become increasingly important.

III. Empirical Implementation of the Model

In this section we discuss the empirical implementation of the model, including our choices of exogenous driving variables, and we summarize the estimation results for each of the four equations. More complete estimation results and results for alternative specifications are presented in the Appendix. The model is estimated using quarterly data. For data availability reasons, and because there is evidence of a break in inflation dynamics around 1990 (e.g., Blanchard, 2016), we begin our estimation in 1990Q1, using a data set that, to accommodate four quarterly lags, begins in 1989Q1.

For our baseline results, in order to see whether pre-covid relations can explain what happened since covid struck, we end the sample in 2019Q4, thus excluding the covid period (2020Q1-2022Q4), with one exception: In order to include meaningful variation in the state of supply chains, we estimate the baseline price equation over the full sample, including the covid period. Generally, the results obtained for the wage and inflation expectations equations (as well as for the price equation, excluding the supply chain term) are very similar whether we use the pre-covid period or the whole sample. This suggests that, given the shocks, the conditional process generating prices, wages, and expectations during the pre-covid period remained largely stable during the covid era.

Our estimation strategy is a hybrid approach that approximates a structural vector autoregression (SVAR) with added exogenous variables. In the spirit of SVAR analysis, we imposed restrictions on the contemporaneous relationships among the variables based on our simple model but left the coefficients on lagged variables largely unrestricted.[3] Specifically, in each estimated equation we included four lags of each of the endogenous and exogenous variables included in that equation. (We included only one lag of the productivity trend, which is already constructed as an eight-quarter moving average, in the price and wage equations.) Identification of the wage equation is achieved by assuming that wages respond to other variables with a lag of one quarter. Wage inflation then affects inflation, and by implication, inflation expectations contemporaneously.

We turn now to estimation of the model equations. With the estimated parameters in hand, we will be able to evaluate the drivers and dynamics of any of the endogenous variables, including wage

[3] In the reported results, we imposed a homogeneity restriction on the estimates that implies that, in the long run, a given change in inflation implies an equal change in short-run and long-run inflation expectations. Alternatively, the restriction can be interpreted as requiring that the long-run Phillips curve be vertical. Under either interpretation, the restriction seems economically justified. The restriction is not rejected at the 5 percent level for the wage and price equations but is rejected at the 2 percent level for the two expectations equations. However, even in the latter case, the estimates under the restriction are close to the unrestricted estimates. Consequently, the restriction has no material effect on the main results of the paper.

and price inflation. For reference, Table 1 below lists the mnemonics and data sources of the endogenous and exogenous variables in the empirical model.

Table 1. Variables and mnemonics used in estimation of the model

Endogenous variables

- *gp* Price inflation, as measured by quarterly annualized rates of change in the Consumer Price Index (CPI), Bureau of Labor Statistics (BLS)
- *gw* Rate of growth of nominal wages, quarterly and annualized, as measure by the rate of change in the Employment Cost Index (ECI), BLS
- *cf1* Short-term inflation expectations, measured by one-year inflation expectations as constructed by the Federal Reserve Bank of Cleveland
- *cf10* Long-term inflation expectations, measured by the Cleveland Fed's ten-year inflation expectations series
- *catch-up* Losses to workers' purchasing power due to inflation, measured by the four-quarter average of CPI inflation minus the one-year inflation expectation four quarters earlier. Catch-up is a linear combination of past *gp* and *cf1*.

Exogenous variables

- *grpe* Rate of growth of the relative price of energy, quarterly and annualized, measured as the rate of change of the ratio of CPI energy prices to the ECI
- *grpf* Rate of growth of the relative price of food, quarterly and annualized, measured as the rate of change of the ratio of CPI food prices to the ECI
- *v/u* Ratio of job vacancies to unemployment, from the BLS job openings and labor turnover survey (JOLTS) and the BLS Employment Report. Earlier data from Barnichon (2010)
- *shortage* An index of supply chain problems based on Google searches; described below
- *gpty* Trend productivity growth, measured by the change in the eight-quarter moving average of nonfarm business value added divided by nonfarm employee hours, from the BLS

The wage equation

Following our simple model, we posit that nominal wage growth depends on labor market tightness, short-run inflation expectations, the catch-up effect (the tendency of wages to rise to compensate for past unexpected inflation), and trend productivity growth.

We choose the Employment Cost Index (ECI), wages and salaries component, as our measure of the nominal wage. The ECI is generally thought to be a better measure of wages than the main alternative, average hourly earnings as collected by a BLS survey of employers, because it corrects for changes in average earnings due to changes in the composition of employment. The ECI is available only quarterly, but that is not a problem here since we are using only quarterly data in estimation. Official ECI data begin in 2001Q1. To allow our estimation to start in 1990, we extended the series backward using an older ECI series based on a different BLS survey.[4]

We need a measure of the tightness of the labor market, denoted x in the previous section. Traditionally, the state of the labor market has been measured by the unemployment rate u, or sometimes by the difference between the unemployment rate and the "natural" or sustainable unemployment rate, u^*. The perceived importance of unemployment as a labor-market indicator is reflected in the fact that it is one of only four macroeconomic variables forecast by the FOMC in its *Summary of Economic Projections*.

A conceptual weakness of the unemployment rate as an indicator is that it is based solely on information about the status of households and does not directly incorporate information on the hiring plans of employers. But the labor market involves costly search by employers for workers as well as by workers for jobs. In principle at least, a given unemployment rate could be consistent with either a strong labor market, with upward pressure on wages, or a weak labor market and low wage pressure, depending on whether job openings are plentiful or scarce.

An alternative indicator of labor market slack that uses information from both workers and employers is the ratio of the vacancy rate (job listings reported by employers divided by the labor force) to the civilian unemployment rate, v/u. Normally u and v/u usually move closely (inversely) together—their correlation in our pre-covid sample is -0.88—and they perform similarly in wage Phillips curves estimated over the pre-covid period (Ball et al., 2022; Cecchetti et al., 2023). However, as has been widely noted, including in Federal Reserve communications, during the covid era these two

[4] The older survey was discontinued in 2005. That series is an index for total compensation for all civilian workers, that is including benefits, seasonally adjusted. The BLS mnemonic is ECS10001I. We thank David Reifschneider for calling this series to our attention. We used a dummy variable to correct for a level shift between the pre-2001 ECI data and the currently official post-2001 series.

indicators diverged dramatically. Following a spike during the pandemic lockdowns, the unemployment rate declined gradually. By the end of 2021 it appeared to stabilize at a level modestly below 4 percent, implying—under the FOMC's maintained assumption of a 4 percent natural unemployment rate—that labor market conditions, though moderately tight, were not becoming significantly tighter. Moreover, the unemployment rate in late 2021 was comparable to or slightly higher than that just prior to the pandemic, a period without evident inflation pressures. The signal from the unemployment rate was consequently that labor market overheating was not an imminent threat to price stability.

The picture portrayed by the vacancy-to-unemployment ratio during the covid era was quite different. That ratio rose from less than 1.0 in April 2021 (that is, less than one open job per unemployed worker) to a historically high level of about 1.9 (nearly two job openings per unemployed worker) a year later. This increase implied an exceptionally rapid pace of labor-market tightening, to a level considerably greater than during the immediate pre-covid period and, indeed, any period since these data have been collected. As of this writing, v/u has declined only moderately from its peak, consistent with a labor market that remains overheated.

Which indicator of labor market tightness is better? As their high correlation and comparable performance in Phillips curves suggests, in normal times the two indicators give very similar assessments of labor market conditions. However, the relationship between vacancies and unemployment changed materially during the covid period, with more vacancies (more search effort by employers) needed to achieve a given rate of hiring, holding constant the number of unemployed (Blanchard, Domash, and Summers 2022). Equivalently, the Beveridge curve, the downward relation between vacancies and unemployment, appears to have shifted upward since 2020.[5] If labor market tightness, as reflected in workers' bargaining power, depends on the number of jobs available relative to the number of people looking for work, then the ratio of vacancies to unemployment remains a good measure of tightness even when employers must search more intensively to find potential hires. In contrast, given the number of unemployed, workers' bargaining power and labor market tightness is much greater when there are many vacancies to be filled than when vacancies are scarce. We conclude that v/u is a more reliable indicator of labor market conditions in times, as during the pandemic and its aftermath, in which

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[5] Many factors no doubt contributed to this shift. Firm closures implied that laid-off employees had to find new jobs rather than return to their old ones. Changes in family arrangements, illness, and other effects of the pandemic lockdowns may have reduced the (unobserved) intensity of search effort of some unemployed workers. Employers may have failed to appreciate the extent to which, because of concerns about returning to jobs involving personal contact or perhaps because of reassessments of work-life balance, workers had increased their reservation wages.

the efficiency of the employer-worker matching process has changed materially. For this reason, and following the direction taken in much recent research and in Federal Reserve policy communications, we use v/u as our empirical measure of labor market pressure.[6]

To capture short-term inflation expectations, we use one-year inflation expectations as constructed by the Federal Reserve Bank of Cleveland. This expectations series is partly retrospective and model-based, which is a drawback, but it has the advantage of combining several types of real-time information, including data from financial markets and from surveys. We have also estimated our model using forecasts of the Survey of Professional Forecasters (SPF) as proxies for inflation expectations (see the Appendix for the results).[7] When we use this alternative measure, the differences for both the wage equation and the other equations are minor, and the conclusions we draw in the text do not change. We comment on some results for alternative data choices and sample periods below.

We construct our measure of the wage catch-up term as the difference between realized CPI inflation over the current and past three quarters and the one-year expectation of inflation as of four quarters earlier. The catch-up variable thus equals unexpected inflation, which we hypothesize may affect subsequent wage bargains if workers are focused on maintaining the real buying power of their wages. As has been noted, our measure of labor productivity is an eight-quarter moving average of nonfarm productivity growth.

As also discussed above, we want to be guided by our formal model while maintaining flexible lag structures. Accordingly, we keep the identifying assumption that wages respond only to lagged values of the independent variables, and we regress wage growth *gw* on a constant, four (quarterly) lags of itself, four lags of short-run inflation expectations *cf1*, four lags of the unexpected inflation term *catch-up*, four lags of our proxy for labor market tightness v/u, and one lag of trend productivity growth *gpty*.

Table 2 below reports, for each right-side variable in the wage equation, the included lags, the sum of the estimated coefficients for each variable and two p-values. The first p-value, denoted *p-value (sum)*, is the probability of rejection of the null hypothesis that the sum of current (if applicable) and lag coefficients for a given variable is zero. The second p-value, *p-value (joint)*, tests the joint hypothesis that each of the current and lag coefficients is separately zero. To ensure that the long-run wage Phillips

[6] For more on the Beveridge curve, and an early argument for the use of the vacancy-to-unemployment ratio as a measure of labor market tightness, see Blanchard and Diamond (1989).

[7] The SPF forecasts are made in real time, an advantage. However, they raise some issues of timing, e.g., ten-year forecasts in each quarter are for the subsequent decade, rather than for the ten years beginning in the forecast quarter. This feature leads to discontinuities between fourth-quarter and first-quarter ten-year forecasts.

curve is vertical, we impose a homogeneity assumption (see footnote 3 for more discussion), which here implies that the sum of coefficients on lagged nominal wage growth and lagged short expectations is equal to one.

Table 2. Wage growth regression: Dependent variable = *gw*

Independent variable	gw	v/u	catch-up	cf1	gpty
Lags	-1 to -4	-1 to -4	-1 to -4	-1 to -4	-1
Sum of coefficients	0.460	0.693	-0.024	0.540	0.031
p-stat (sum)	0.008	0.030	0.765	0.002	0.608
p-stat (joint)	0.071	0.023	0.994	0.022	0.608
R-squared			0.583		
No. observations			120		

Notes: Sample is 1990Q1 to 2019Q4. *p-value (sum)* is the p-value for the null hypothesis that the sum of coefficients is zero, *p-value (joint)* is the p-value for the joint hypothesis that each of the lag coefficients separately equals zero.

Table 2 suggests that, when v/u is used as the measure of slack, the wage Phillips curve remains alive and well, in that the estimated effect of labor market conditions on wage growth is significant, both statistically and economically. Based on the sum of estimated coefficients for the four quarterly lags of the vacancy-to-unemployment ratio, and the sum of the coefficients on lagged nominal wage growth, an increase in v/u from, say, 1.0 to 1.5, holding constant other factors, has a long-term effect on nominal wage growth of 0.5 x 0.693/(1-.460), or 0.64 percentage points.[8] (When we use the SPF 1-year forecast, the effect of v/u is marginally larger, 0.74, and highly statistically significant.)

The sum of the coefficients on short-run inflation expectations is high relative to the sum of coefficients on lagged nominal wage growth (under the homogeneity assumption, the sums of the coefficients on the two variables add to one). This estimate suggests that short-run inflation expectations feed fairly quickly into wages, although, as we shall see below, short.-run inflation expectations react slowly to actual price inflation.

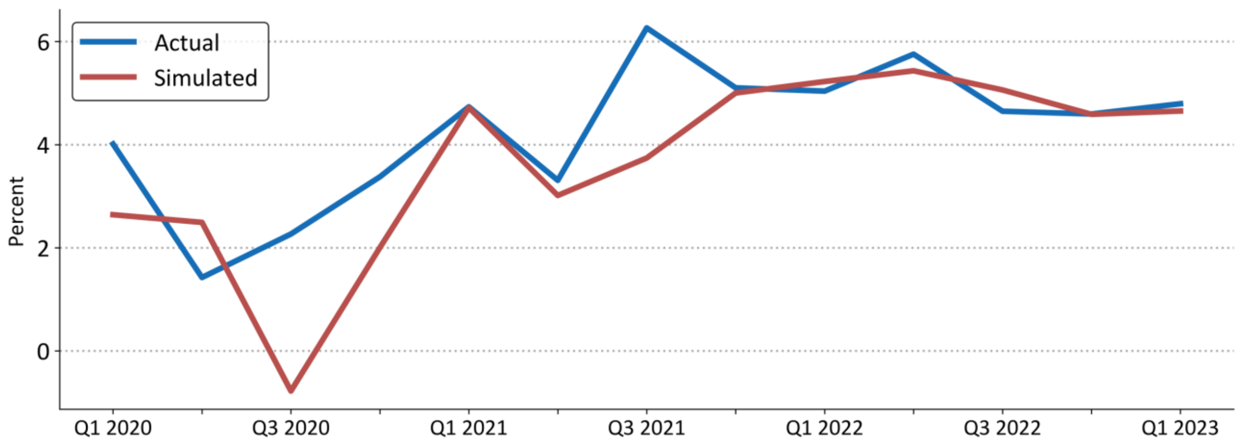
There is no evidence of a catch-up effect in Table 2. When we use SPF 1-year forecast to measure short-run inflation expectations instead, the catch-up effect is estimated to be small and positive, and marginally significant, with sum of coefficients equal to 0.1. When we estimate the

[8] Note the importance of "holding constant other factors". As we saw in the simple model, and as is the case in the empirical model as well, in general equilibrium, letting other factors adjust leads to steadily increasing inflation.

equation over the full sample, for either measure of short-term expectations, the estimated catch-up effect remains small, and is statistically insignificant. The moving-average trend in productivity growth has no statistically significant effect on wage growth, suggesting that some of the effect of productivity growth may be captured by the constant term of the equation.

As a check on our specification, we can see how the wage equation estimated on the pre-covid sample fits wage data during the covid period (2020Q1-2023Q1). As Figure 3 shows, the estimated wage equation predicts wage behavior after 2019 reasonably well, including the upward trend in wage growth over the period. The fitted wage equation's largest miss is for 2020Q3, when the equation predicts a larger decline in wage growth than actually occurred. Given the tremendous deterioration in labor market conditions in the early stages of the pandemic, it is not surprising that the equation predicts a commensurate decline in wages in that quarter. Downward nominal rigidity in wages and pervasive measurement issues likely explain most of the miss.

FIGURE 3. WAGE GROWTH, 2020Q1-2023Q1, COMPARED TO PREDICTIONS OF WAGE EQUATION



Note: The figure shows actual and predicted nominal wage growth, 2020Q1-2023Q1, based on the wage equation estimated on the pre-covid sample.

The price equation

We turn now to the determinants of price inflation. In our model, price growth depends on nominal wage growth and on other factors that affect prices given wages, such as growth in other input costs. Our estimated equation includes four lags of inflation and the current value and four lags of wage growth. We use the more familiar and timelier Consumer Price Index (CPI) as our measure of the price level. The Appendix shows that measuring prices using the personal consumption expenditures (PCE) deflator leads to very similar results. We continue to use the ECI as our measure of nominal wages.

A substantial part of the pandemic-era inflation surprise reflected rapid, largely unanticipated increases in food and energy prices. We consequently included in our specification contemporaneous values and four lags each of the growth rates in food (*grpf*) and energy prices (*grpe*), as defined by the CPI, with both measured relative to the contemporaneous growth rate in nominal wages. Shocks to these variables should thus be interpreted as shocks to relative rather than absolute prices. Since lags of nominal wage growth are included in the estimated equation, however, the fit of the equation would be the same independent of whether the growth of input prices enters in relative or absolute terms.

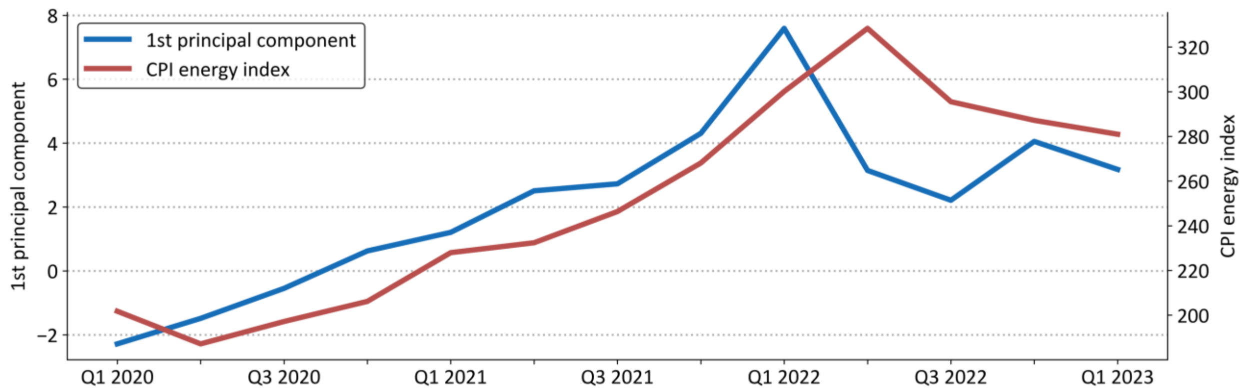
Simply treating relative food and energy prices as exogenous in the price equation, per conventional practice, is a bit unsatisfying, as it leaves unanswered the question of why these prices moved up so sharply and, apparently, in a roughly synchronized way. To gain some insight into this question, we performed the following experiment.

We hypothesized that common movements in the prices of a range of disparate commodities were more likely to reflect the influence of global demand changes (the result of global macroeconomic policies, reopening from the pandemic, and large geopolitical events like the Ukraine war) rather than changes in supply, as conditions affecting the supplies of diverse commodities, such as local weather conditions or the opening of new mines, are likely to be largely idiosyncratic. To find the common trend in commodity prices, we used a principal components approach.

Specifically, we collected monthly prices for 1990 to the present of the 19 commodities included in the familiar Commodity Research Bureau (CRB) commodity price index.[9] We standardized each commodity price series to have mean zero and a standard deviation of one. We calculated the first principal component of these price series, finding that it explained 66.0 percent of the overall variance. The two figures below show the estimated principal component (converted to a quarterly frequency), together with the CPI energy (Figure 4) and food price (Figure 5) components since 2020Q1.

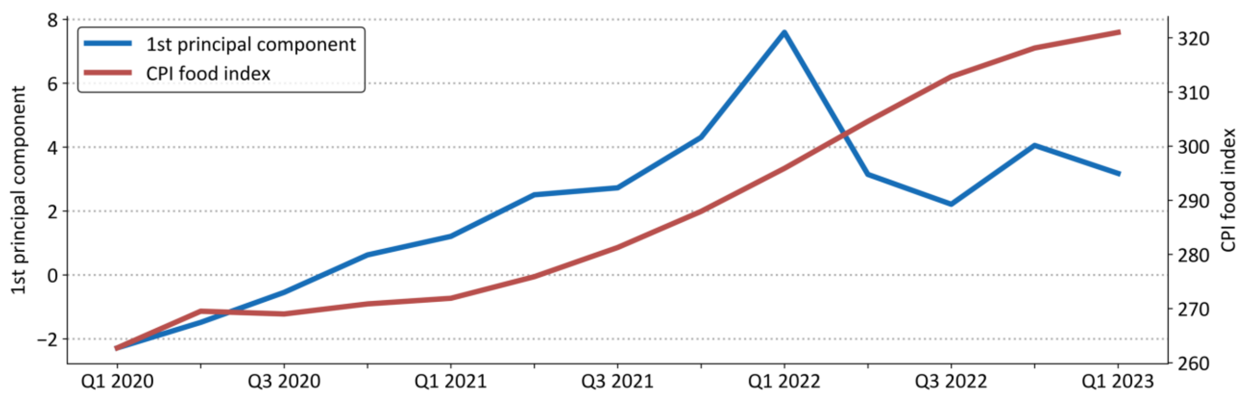
[9] The CRB index currently comprises prices of 19 commodities, including energy, metals, and agricultural commodities. We gathered prices of commodities currently included in the index, ignoring changes since 1990 in the composition of the index. Commodity prices were weighted equally in our principal components exercise. R^2s of regressions of each commodity price on the principal component, using monthly data from 2020M1, were high for energy, food, and metals, with a few exceptions, notably gold ($R^2 = 0.08$), cocoa ($R^2 = 0.0$), and orange juice ($R^2 = 0.41$).

FIGURE 4. CRB PRICES PRINCIPAL COMPONENT AND ENERGY PRICES, 2020Q1-2023Q1



Note: The figure shows the first principal component (common trend) of the prices of 19 commodities currently included in the CRB commodity price index, together with the CPI price of energy, in levels (1982-84 = 100).

FIGURE 5. CRB PRICES PRINCIPAL COMPONENT AND FOOD PRICES, 2020Q1-2023Q1



Note: The figure shows the first principal component (common trend) of the prices of 19 commodities currently included in the CRB commodity price index, together with the CPI price of food, in levels (1982-84 = 100).

Figures 4 and 5 present a mixed picture. Energy prices generally moved in line with the common component, rising for a period, spiking in early 2022, and then declining. Food prices followed the common component upward as well but continued to rise after the common component peaked and began to decline. Our interpretation is that in the earlier part of the pandemic, energy and food prices were indeed driven primarily by demand factors, including global fiscal and monetary policies and the reopening of many economies from covid lockdowns. The Russian invasion of Ukraine that began on

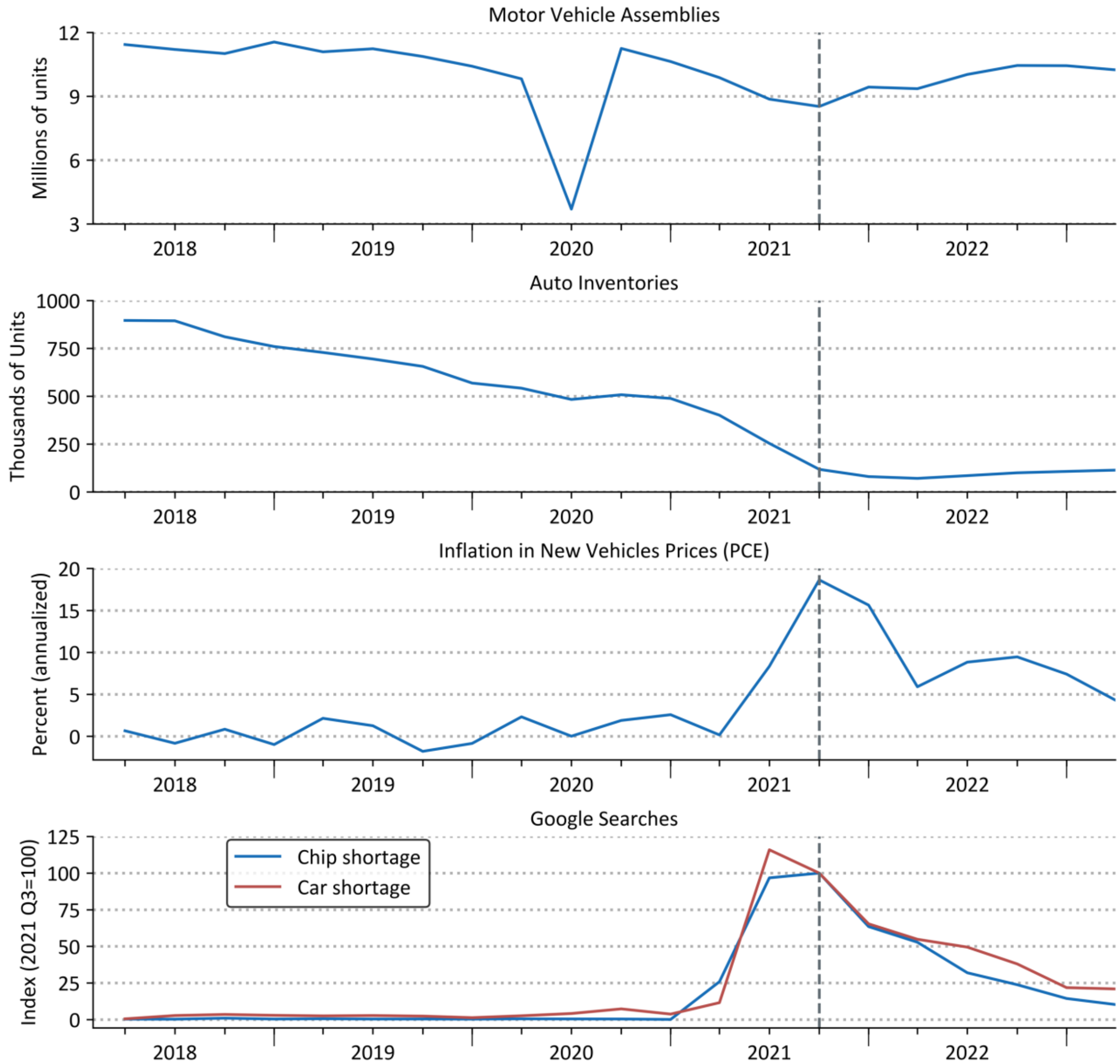
February 24, 2022, caused a further spike in commodity prices, which waned as the perceived threat to global commodity supplies moderated. That story is consistent with the behavior of energy prices. However, the continued increase in food prices following the sharp decline in the prices of raw commodities, a phenomenon not confined to the United States, bears further investigation. Since retail food prices reflect many inputs beyond raw commodities, including labor, changes in non-commodity input prices and wages could be one reason for this divergence. Non-competitive behavior is another possibility., as the food price index includes distribution margins, and the retail food industry has become more concentrated in recent decades (Zeballos, Dong, and Islamaj, 2023).

Besides commodity prices, pervasive shortages of certain goods have often been cited as a source of inflation during the pandemic period (Comin, Jones, and Johnson 2023). These shortages and disruptions have reflected developments in both demand and supply. On the demand side, lockdowns and fears of infection led to a shift in consumer spending from in-person services to goods, especially durable goods. The share of nominal consumer spending devoted to durable goods rose from about 10 percent in the years before the pandemic to about 13 percent once the pandemic began, an increase of nearly a third. On the supply side, global supply chains were disrupted by pandemic-induced shutdowns of the production of key components and critical transportation links. The combination of sharply increased demand for goods, which would have put strains on even a normally functioning supply system, and the gaps at critical points of supply chains and transportation networks, created shortages and sharp price increases.

One might argue that increases in relative demand in some sectors, and associated higher prices, should have been largely offset by decreases in relative demand in other sectors, and associated lower prices. Shortages however introduce a fundamental asymmetry. If we think for example of firms facing a flat marginal cost up to some physical constraint where supply becomes vertical, then relative demand increases, if large enough, will move prices along the vertical supply curve, but the corresponding relative demand decreases will move prices along the horizontal portion of the supply curve. The increase in prices in some sectors will not be offset by a decrease in prices in the others. This effect will be stronger, the larger the variation in relative demand or in relative supply constraints. Both factors seemed to have played a role in the past three years.

The automobile sector, an important contributor to the early surge in inflation, illustrates the role of demand and of supply constraints (see Figure 6 below).

Figure 6. PRODUCTION AND SHORTAGES IN THE U.S. AUTOMOBILE INDUSTRY, 2018Q1-2022Q4



Note: Motor vehicle assemblies data pertain to the United States, inventories represent inventories held in the U.S. of vehicles assembled in North America. Google searches are measured by an index, 2021Q3=100. Sources include the Federal Reserve Board of Governors, Bureau of Economic Analysis, Google Trends.

U.S. vehicle production plunged during the initial lockdowns then recovered when factories reopened. Assemblies ran at about an 11.7 million annual rate in July 2020, comparable to or slightly higher than pre-pandemic production rates (top panel of Figure 6). However, persistent shortages of critical chips and other key components subsequently restrained vehicle production, which fell below an annual rate of 9 million units—a decline of about a quarter—by the fall of 2021. The other panels of the figure show that the reduced production did not reflect a lack of potential customers. Inventories of new cars for sale fell to record low levels as dealers could not keep up with demand (second panel of Figure 6) and, consequently, new automobile prices spiked (third panel). The bottom panel of Figure 6 shows an index of Google searches for “chip shortage” and “car shortage,” both of which rose sharply in 2021. The vertical dashed line in the figure at 2021Q3 illustrates the close relationship between these developments. That quarter saw the trough in automobile production, the decline in inventories to record low levels, the spike in auto prices, and (a quarter earlier) the peak in Google searches, consistent with a shortage-induced price jump.

As the figure suggests, the Google search variables appear to be good proxies for the sectoral demand shifts and supply chain disruptions, at least in one very important industry. (Shortages of new cars spilled over to the prices of used cars, which at times were also important drivers of inflation.) This led us to use an index of the number of Google searches for the term “shortage” in our price equation as a proxy for the combined effects of the shift in demand towards durable goods and the disruptions of supply chains. We experimented with several other measures of supply chain problems used in the literature, including the Federal Reserve Bank of New York’s supply chain index, the Baltic Dry Index, supplier delivery times as reported by the Institute for Supply Management, the ratio of durable goods to services spending, and others, but found that the Google search variables provided, by far, the most explanatory power.

The collision of high demand and limited supply in some sectors can account for at least some of the increase in markups observed during the pandemic period. While other factors no doubt influenced markups, including for example the fiscal transfers that directly affected demand in product markets, at least in this simple specification we do not find that including these factors is needed to explain the behavior of pandemic-era inflation (see Figure 7 below).

A summary of estimation results for the price equation is given in Table 3 below. As before, the Appendix provides more complete results, as well as estimation results using the PCE deflator rather than the CPI as the measure of prices.

Table 3. Price inflation regression (dependent variable = *gp*)

Independent variable	gp	gw	grpe	grpf	shortage	gpty
Lags	-1 to -4	0 to -4	0 to -4	0 to -4	0 to -4	-1
Sum of coefficients	0.335	0. 665	0.066	0.126	0.018	-0.143
p-stat (sum)	0.037	0.000	0.000	0.050	0.281	0.026
p-stat (joint)	0.066	0.000	0.000	0.050	0.000	0.026
R-squared				0.947		
No. observations				133		

Note: Sample is 1990Q1 to 2023Q1. *p-value (sum)* is the p-value for the null hypothesis that the sum of coefficients is zero, *p-value (joint)* is the p-value for the joint hypothesis that each of the lag coefficients separately equals zero.

The table reports the results of a regression of price inflation on a constant, four lags of itself, the current value and four lags of nominal wage growth, and the current values and four lags each of inflation in the relative prices of energy and food. Also included as independent variables were the current value and four lags of Google searches for *shortage*, and one lag of trend productivity growth, which should affect unit labor costs and thus prices. Recall that, in order to include the *shortage* variable, which is roughly constant and small pre-covid, the inflation equation, unlike the other equations, is estimated for a sample that includes the covid period. (Estimation of the price equation in the pre-covid sample, excluding *shortage*, produced similar estimates for the other variables in the equation.[10]) The equation reflects the imposed homogeneity assumption that the sum of the coefficients on past price and on wage inflation sum to one.

In Table 3, the large sum of coefficients on nominal wage growth relative to the sum of coefficients on lagged inflation implies a fairly rapid passthrough of wages to prices. The relative prices of energy and food also affect inflation, as expected, though the sum of the coefficients on the relative price of food is only marginally statistically significant. The estimated long-run effect of an energy price shock on the price level, other things equal, is 0.066/(1-0.335) = 10 percent, so about a third larger than energy's share in the CPI basket (7.4 percent). The estimated long-run effect of a food price shock is equal to 0.126/(1-0.335) = 19 percent, so about 30 percent larger than the share of food in the basket

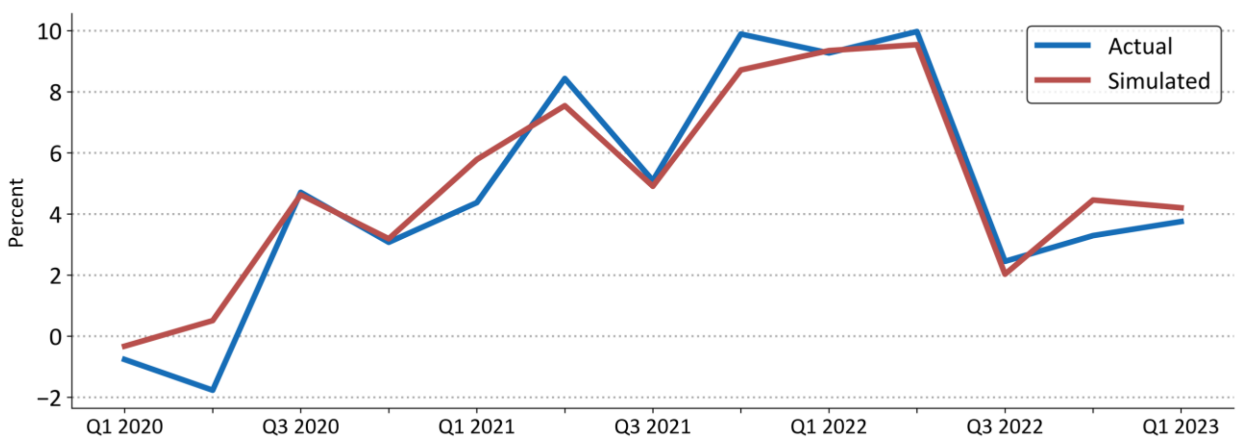
[10] In the full sample estimation, to avoid an artificial jump between the pre-covid and covid-era parts of the sample, *shortage* was set to 5 index points in the pre-covid sample, roughly the mean value of this variable for the period prior to 2021 when data were available. From 2020Q1 on, the quarterly average of the index for *shortage* peaked twice, at 48 in 2021Q2 and 33 in 2022Q4.

(14.4 percent). Since wages are controlled for, these findings suggest the presence of some second-round price-price effects of energy and food price shocks on the prices of other goods over time.

The sum of the coefficients on the shortage variable is not statistically significant, though the joint hypothesis that the lag coefficients are each zero is strongly rejected. We interpret these findings as suggesting that shortages have a strong, but temporary effect on price inflation. Trend productivity growth enters with the expected negative sign (higher productivity reduces unit labor costs, given wages), with an estimated coefficient that is statistically significant at the 5 percent level.

As we did for wage growth above, we can use this estimated equation to predict the path of inflation over the covid period As Figure 7 shows, the predicted inflation series is quite close to the actual covid-era data.

FIGURE 7. INFLATION, 2020Q1-2023Q1, COMPARED TO PREDICTION OF PRICE EQUATION



Note: The figure shows predicted and actual inflation, 2020Q1-2023Q1, based on the price equation estimated over the full sample.

Inflation expectations equations

The final equations to be estimated are those determining short-run and long-run inflation expectations. Inflation expectations can be measured in many ways, including through financial-market indicators, consumer and business surveys, and the expectations of professional forecasters. For our baseline results we use the one-year and ten-year inflation expectations series constructed by the Cleveland Fed. The Appendix discusses results obtained when we use measures of inflation expectations based on the Survey of Professional Forecasters.

Begin with the equation for short-term inflation expectations (*cf1*). Our model posits that short-run inflation expectations in each period are a weighted average of long-term inflation expectations and realized inflation. In the application we also include lags of short-term inflation expectations, which allow for the possibility of gradual adjustment. We accordingly estimate an equation that has short-run inflation expectations depending on four lags of itself, the current value and four lags of our measure of long-run inflation expectations, *cf10*, and current and four lags of actual inflation. Table 4 below summarizes the results.

Table 4. Short-run inflation expectations (dependent variable = *cf1*)

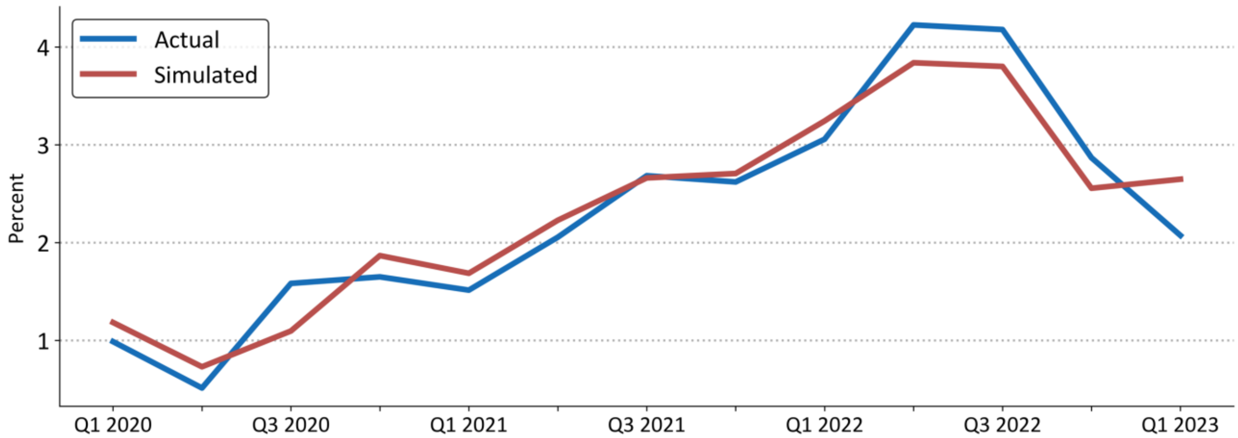
Independent variable	cf1	cf10	gp
Lags	-1 to -4	0 to -4	0 to -4
Sum of coefficients	0.369	0.506	0.124
p-stat (sum)	0.014	0.000	0.001
p-stat (joint)	0.001	0.000	0.000
R-squared		0.910	
No. observations		120	

Note: Sample is 1990Q1 to 2019Q4. *p-value (sum)* is the p-value for the null hypothesis that the sum of coefficients is zero, *p-value (joint)* is the p-value for the joint hypothesis that each of the lag coefficients separately equals zero.

We again impose homogeneity, which in this case implies that the sum of the coefficients of the three variables equal one. (The unconstrained sum of coefficients is 0.99). As noted, this homogeneity restriction, together with a similar restriction on the long-run inflation expectations equation, ensures that, in the long run, a sustained increase in inflation will raise inflation expectations by the same amount. In the short run, however, that relation need not hold, and the fact that current and lagged inflation enter this equation with a small sum of estimated lag coefficients suggests that short-term inflation expectations are relatively well-anchored—that is, all else equal, they are only modestly affected by near-term changes in inflation. However, given the high autocorrelation of short-run inflation expectations, the estimates also imply that sustained inflation gets increasingly reflected in short-run expectations over time.

Like the previous equations, the estimated equation for short-run inflation expectations does a good job of predicting pandemic-era inflation expectations out of sample, as shown by Figure 8. There is no evidence of de-anchoring, defined here as an increase in the short-run effect of inflation on expected inflation: If estimated over the whole sample, including the covid period, estimated coefficients are very similar. For example, the sum of coefficients on inflation is 0.133 in the full sample, compared to 0.124 in the pre-covid sample alone.

FIGURE 8. SHORT-RUN INFLATION EXPECTATIONS, 2020Q1-2023Q1, COMPARED TO PREDICTION OF SHORT-RUN EXPECTATIONS EQUATION



Note: The figure shows predicted and actual short-run inflation expectations, 2020Q1-2023Q1, with predicted values based on the associated equation estimated on the pre-covid sample.

Finally, Table 5 shows our estimated equation for long-run inflation expectations (*cf10*). Following our modeling assumption that long-run inflation expectations evolve as a weighted average of the previous level of long-run expectations and actual inflation, in the estimated equation we allow long-run inflation expectations to depend on four lags of itself and the current value and four lags of realized inflation. The results echo those for short-run inflation expectations. We impose the homogeneity restriction that sum of coefficients is equal to one. The unconstrained sum of coefficients is 0.99, so once again the homogeneity restriction makes no substantial difference to the results.

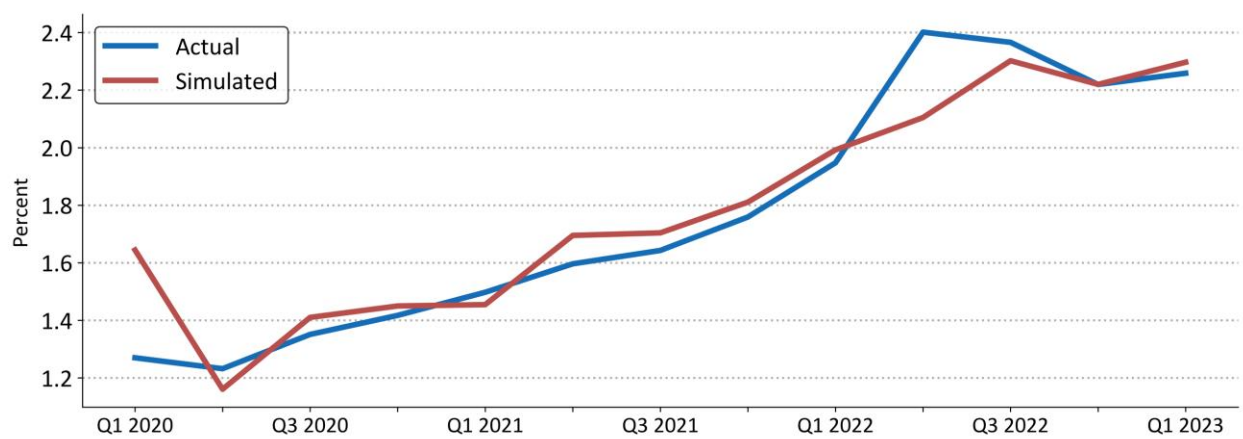
The response of long-run inflation expectations to short-run movements in prices is relatively small, suggesting that long-run expectations are well anchored. In particular, there is no evidence that long-run expectations became de-anchored during the covid period. The sum of coefficients on current and lagged inflation were not much changed, being estimated as 0.031 in the whole sample, compared to 0.025 in the pre-covid sample. The high estimated autocorrelation of long-run inflation expectations implies that a sustained increase in inflation will lead to slowly but steadily rising long-term inflation expectations, which matches the pattern in the covid-era data. See Figure 9.

Table 5. Long-run inflation expectations (dependent variable = *cf10*)

Independent variable	cf10	gp
Lags	-1 to -4	0 to -4
Sum of coefficients	0.975	0.025
p-stat (sum)	0.000	0.208
p-stat (joint)	0.000	0.004
R-squared	0.936	
No. observations	120	

Note: Sample is 1990Q1 to 2019Q1. *p-value (sum)* is the p-value for the null hypothesis that the sum of coefficients is zero, *p-value (joint)* is the p-value for the joint hypothesis that each of the lag coefficients separately equals zero.

FIGURE 9. LONG-RUN INFLATION EXPECTATIONS, 2020Q1-2023Q1, COMPARED TO PREDICTION OF LONG-RUN EXPECTATIONS EQUATION



Note: The figure shows predicted and actual long-run inflation expectations, 2020Q1-2023Q1, with the prediction based on the associated equation estimated over the pre-covid sample.

Impulse Response Functions

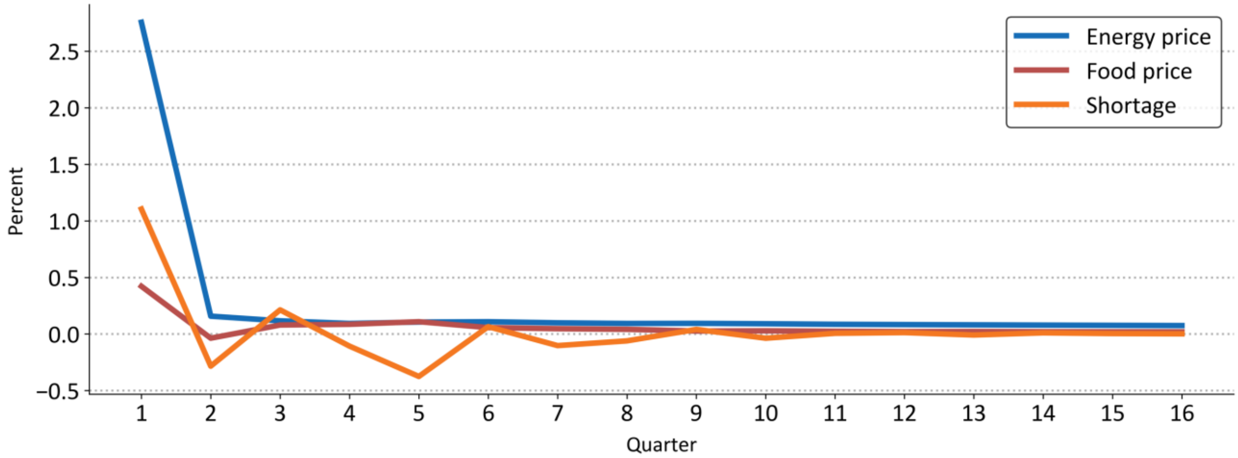
The estimates of this section provide parameter values for the empirical version of our model. The model determines four endogenous variables (price inflation, wage inflation, and short-run and long-run inflation expectations) given initial conditions and five exogenous variables (the vacancy-to-unemployment ratio, the relative prices of food and energy, the shortage indicator, and trend productivity.)

The estimated model can be used to calculate impulse response functions (IRFs) that take into account both the simultaneity and lagged relationships among wages, prices, and inflation expectations. For example, we can estimate the dynamic effects of a shock to a particular equation or of a change in any of the exogenous variables, taking a general equilibrium and dynamic perspective. Estimated impulse responses using the full model capture not only the direct effects of a given shock (e.g., as reflected in the estimated coefficients of the shocked variable in each of the equations) but also the knock-on effects in all subsequent periods. For example, an increase in the relative price of energy affects price inflation directly, but it also motivates workers to try to maintain their real wages (the catch-up effect) and increases both short-run and long-run inflation expectations, each of which feeds into wage inflation and subsequently into price inflation over time.

In Section 2, using the simple model and starting from the steady state, we showed the responses of price inflation to (i) a positive, permanent shock to the price equation (Figure 1) and (ii) a positive, permanent shock to labor market tightness (Figure 2). We conducted these exercises using two sets of hypothetical parameters, in the process confirming the intuition that the persistence of inflation in the face of a shock is typically less when the catch-up effect is small (workers are unable to regain much of the purchasing power lost to unexpected inflation) and inflation expectations are well anchored. With the full model, now including estimated parameters and unrestricted lags, we can repeat those exercises. As before, we start from a steady state and consider one-standard-deviation positive shocks to each of three price shocks—the relative price of energy, the relative price of food, and the shortage index—and to the vacancy-to-unemployment ratio. The standard deviations used for the shocks are calculated using data from 2020Q1 to 2023Q1.[11] The results are given in Figure 10 for the three price shocks and and Figure 11 for the vacancy-to-unemployment ratio below.

[11] The standard deviations are respectively 32 percent for the quartely rate of change of the relative price of energy (which varied for 45 percent to -52 percent during the period) at an annual rate, 3.2 percent for the rate of change of the relative price of food (which varied from 8.9 percent to -1.3 percent), 11.6 for the shortage index (which varied from 10 to 48), and 0.5 for the vacancy-to-unemployment ratio (which varied from 0.26 to 1.91).

FIGURE 10. RESPONSE OF INFLATION TO SHOCKS TO THE RELATIVE PRICE OF ENERGY, THE RELATIVE PRICE OF FOOD, AND THE SHORTAGE INDEX



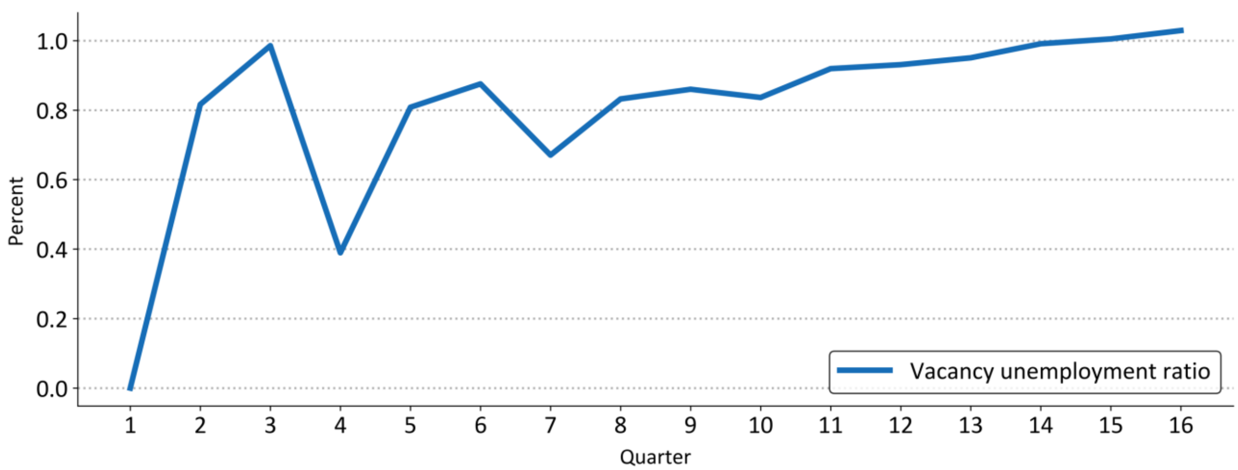
Note: The figure shows the full-model, dynamic responses of inflation to a one-standard-deviation positive shock to relative energy prices, relative food prices, and the shortage variable. It may be compared to the hypothetical responses of inflation under alternative parameter assumptions in Figure 1.

Figure 10 is striking, in that the effects of the three price shocks on inflation are quite short-lived, even more so than in the simulation of the analytical model under weak feedback parameters (Figure 1). The effects mostly disappear in the quarter following the shock, although the short burst of inflation together with not fully anchored inflation expectations yields, in the case of an increase in the price of energy, a small sustained increase in inflation of about 0.1 percent. This long-term effect reflects the fact that, as discussed earlier, inflation is indeterminate in this model, and its steady-state level depends on the behavior of inflation in the past.

The short-lived response of inflation to various price shocks reflects our findings that real wage rigidity (the catch-up effect) is limited, and that short-run and long-run inflation expectations appear to be reasonably well anchored, adjusting very slowly to actual inflation. This anchoring likely reflects the credibility of the Fed's commitment to return inflation to its target level over time. Figure 10 is good news for policy makers, as it suggests that, as price shocks fade or even partly reverse, their effects on inflation quickly (although not fully) disappear. These results are also in sharp contrast to what happened in the 1970s, a time when inflation expectations were much less anchored, and because of automatic cost-of-living adjustments and other mechanisms, catch-up effects were presumably much stronger. As a result, inflation due to price shocks (notably oil and food price shocks, in the 1970s) was very persistent, despite the fact that on the whole the labor market was not particularly tight during that decade.

Figure 11 shows a full-model simulation of how inflation responds over time to a persistently tight labor market, modeled as a permanent one-standard deviation increase in the ratio of vacancies to unemployment. The jagged initial response reflects the fact that both the level and the change in the vacancy-to-unemployment ratio affect inflation. Once these short-run effects fade, inflation increases slowly but steadily, reflecting the effects of a tight labor market on wages (which in turn affect prices) and the feedback of realized inflation to short-run and long-run inflation expectations. In this simulation, inflation has risen about 0.7 percent after 6 quarters, 1.0 percent after 12 quarters, and keeps increasing at about 0.15 percent per year from then on. This pattern is very similar, even quantitatively, to the weak feedback case we showed in Figure 2. In general, the takeaway is that persistent labor market pressure leads to ever-increasing inflation. The rate of increase in our estimated model is relatively low, reflecting a weak estimated catch-up effect and well-anchored inflation .expectations. Yet, as inflation expectations are not fully anchored, extended labor market tightness can lead to significant additional inflation.

FIGURE 11. RESPONSE OF INFLATION TO SHOCKS TO THE VACANCY TO UNEMPLOYMENT RATIO.

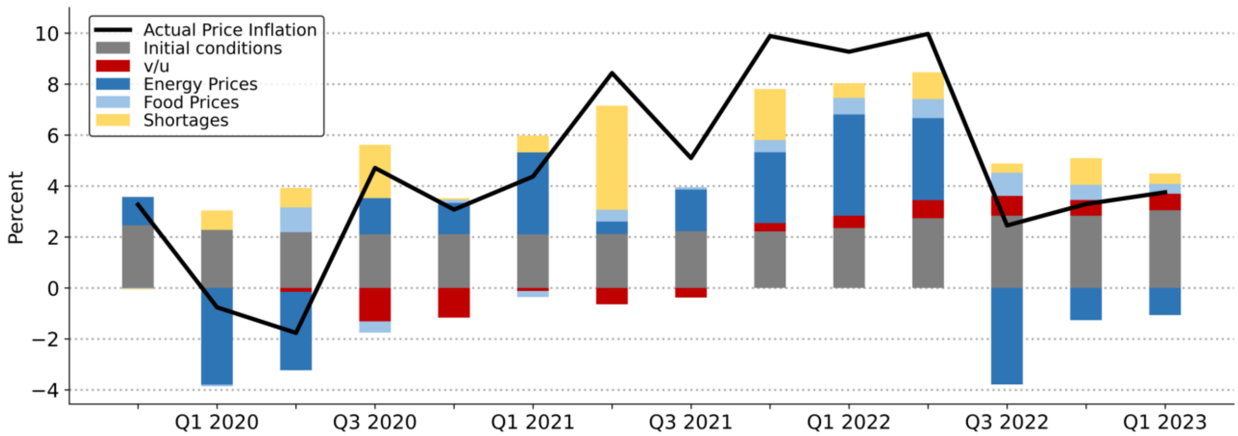


Note: The figure shows the full-model, dynamic responses of inflation to a one-standard-deviation positive shock to vacancy-to-unemployment ratio. It may be compared to the hypothetical responses of inflation under alternative parameter assumptions in Figure 2.

Quantifying the sources of the pandemic-era inflation

With the estimated model in hand, we can calculate the impulse response functions of any endogenous variable to shocks to both (i) the residuals associated with the four structural equations and (ii) the exogenous variables. As we have seen, these estimated impulse responses capture both the direct and indirect (general equilibrium) effects on each endogenous variable, in both the current period and in the future, of any exogenous shocks. Moreover, because the model is linear, the IRFs of each endogenous variable, including the responses to the equation residuals, sum exactly to realized value of the endogenous variable at each date. Consequently, the estimated model and the calculated IRFs for historical shocks can be used to decompose the variation in any endogenous variable into its sources, taking fully into account dynamic and general equilibrium effects.

FIGURE 12. THE SOURCES OF PRICE INFLATION, 2020Q1 to 2023Q1



Note: The figure shows a decomposition of the sources of inflation, 2020Q1 to 2023Q1, based on the solution of the full model and the implied impulse response functions. The continuous line shows actual inflation, and the total net heights of the bars are the model's forecast of inflation in each period, given initial conditions through 2019Q4 and excluding the effects of equation residuals. The grey portion of each bar shows the contribution of pre-2020 data (and also include the contributions of productivity shocks). Colored segments of each bar show the general equilibrium, fully dynamic contribution of each exogenous variable to inflation in that period, as implied by the estimated model.

Using this approach, Figure 12 shows the estimated sources of inflation from 2020Q1 to 2023Q1. For comparison, the continuous line shows actual inflation. (The inflation data are quarterly, at annualized rates, and thus more jagged than the annualized series we often see.) Figure 12 does not show the contributions to inflation of shocks to the residuals of the model equations, both to avoid clutter and because the residuals by definition do not have a clear structural interpretation. Consequently, the sum of the estimated sources of inflation in each quarter (the net heights of the bars) does not exactly equal realized inflation, the difference being the omitted effects of the equation residuals.

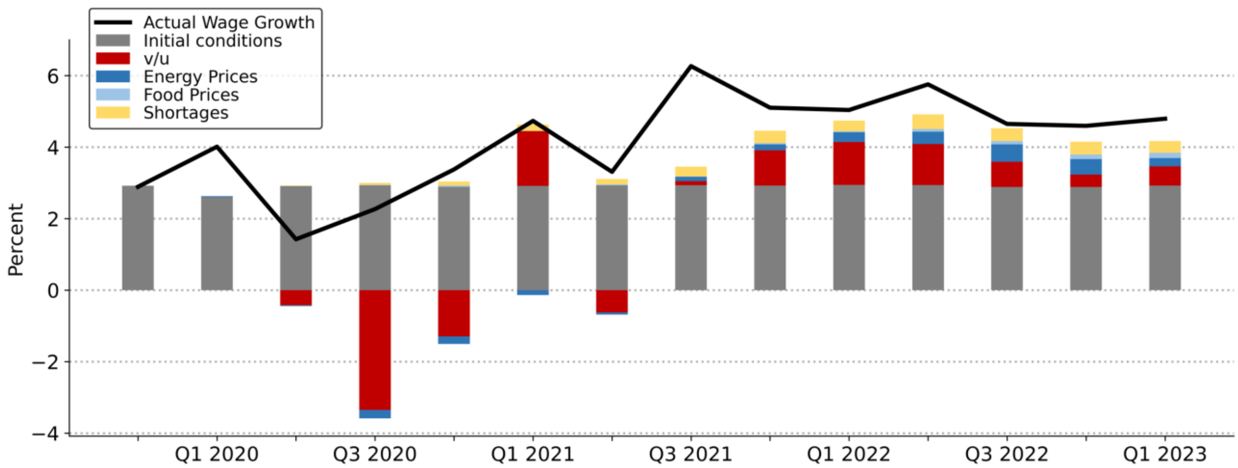
The decomposition underlying Figure 12 takes as given data prior to 2020Q1. The implications of the constants in the equation, plus the dynamic effects of pre-covid shocks, plus the actual behavior of the productivity variable (whose dynamic effects we do not analyze) are put together in an "initial conditions" category, shown in the figure by grey bars. The figure shows the contribution of initial conditions to be roughly constant over time, suggesting that, absent the pandemic-era shocks considered here, inflation would have likely remained stable at around 2 percent or a bit higher into 2023.

Initial conditions aside, the colored components of the vertical bars in Figure 12 show the full dynamic contributions to inflation, in each quarter, of each of the four exogenous variables. Shocks to the rate of change of the relative price of energy and food are constructed as deviations of the values of those variables from zero. Shocks to the shortage and the vacancy-to-unemployment ratio variables are constructed as the actual values of those variables minus their values in 2019Q4.

Figure 12 yields several conclusions. First, the contributions of food and (especially) energy price shocks to the pandemic-era inflation were large. Energy price shocks in particular account for much of the rise of overall inflation in late 2021 and the first half of 2022, and the for the decline in inflation in the second half of 2022. The large and extended contributions of commodity price shocks to inflation shown in Figure 12 are not inconsistent with our earlier finding that price shocks tend to have transitory effects on inflation, as both energy and food prices rose continuously over much of the period (see Figures 4 and 5), which our procedure interprets as a series of positive shocks. Second, the combination of increased demand for durables and shortages associated with disrupted supply chains was the dominant source of inflation in 2021Q2, and the effects of supply chain problems, both direct and indirect, remained significant through the end of our sample period. Third, and importantly, the contribution to inflation of tight labor-market conditions—the leading concern of many early critics of U.S. monetary and fiscal policies—was quite small early on, and indeed was negative in 2020 and early 2021 as labor markets suffered from the effects of the pandemic recession. However, over time, as the labor market has remained tight, the traditional Phillips curve effect has begun to assert itself, with the high vacancy-to-unemployment ratio becoming an increasingly important, though by no means dominant, source of inflation.

To get a better understanding of the role of labor market tightness, we can use the same approach to decompose wage inflation into its sources (Figure 13). Again, the contribution of "initial conditions" is very stable, at around 3 percent per year, roughly the rate of nominal wage growth consistent with 2 percent price inflation. Price shocks (energy, food, shortages) contribute less to wage growth than to price inflation, but even at the beginning of 2023 the direct and indirect effects of shocks to prices still explain about two-thirds of the excess of wage growth over that predicted by the initial conditions, with the vacancy-to-unemployment ratio explaining about a third of excess wage growth.

FIGURE 13. THE SOURCES OF WAGE INFLATION, 2020Q1 to 2023Q1



Note: The figure shows a decomposition of the sources of nominal wage growth, 2020Q1 to 2023Q1, based on the solution of the full model and the implied impulse response functions. The continuous line shows actual wage growth, and the total (net) heights of the bars are the model's forecast of wage growth in each period, given initial conditions through 2019Q4 and excluding the effects of equation residuals. The grey bar shows the contribution of pre-2020 data (and also includes the contributions of productivity shocks). Colored segments of each bar show the general equilibrium, fully dynamic contribution of each exogenous variable to wage growth in that period, as implied by the estimated model.

The retrospective evaluation of how policymakers assessed the economy in early 2021, around the time of the passage of the American Rescue Plan, is thus more complicated than sometimes portrayed. At least for the short run, policymakers were initially more right than wrong in arguing that tight labor markets would not generate high inflation, although in focusing on unemployment rates and total employment rather than the vacancy-to-unemployment ratio they did underestimate labor market tightness. As we have seen, the initial sources of the inflation were primarily shocks to prices given wages, including large energy price shocks and the surprisingly persistent shortages of cars and other durable goods. By raising inflation expectations, and to a smaller extent by creating a catch-up effect, these shocks ultimately affected wages as well as prices. However, over time a very tight labor market has begun to exert increasing pressure on inflation, pressure which our model predicts will grow over time. Over the longer run, then, the critics who worried about an overheated economy leading to inflation may be able to claim some vindication.

Model-based projections

Some insight into the future, as well as into the workings of the model, can be obtained by projecting the model forward, under specified assumptions about the future paths of the four exogenous variables. We briefly look at some projections in this section. However, we do so very cautiously, for at several reasons.

First, beyond the usual statistical uncertainty surrounding the parameter estimates and the specification of the model itself, there is also a great deal of uncertainty about the future course of the exogenous variables in the model. A full analysis would consider alternative scenarios with differing assumptions about energy prices and other variables, which we do not attempt here. Instead, we interpret the simulations described below as conditional projections, not unconditional forecasts.

Second, all else equal, our model is designed to project inflation and wage growth conditional on the state of the labor market, as measured by the vacancy-to-unemployment ratio (v/u). Since we know the past realizations of v/u, we were able to use the model in the previous section to estimate the portion of historical price and wage inflation stemming from tight labor markets. However, the model takes v/u as given and provides no insight about the particular fiscal and monetary policies that would be needed to achieve a given state of the labor market in the future. In addition, we know that the Beveridge curve, the downward-sloping relation between job vacancies and unemployment, shifted dramatically during the pandemic (Blanchard, Domash, and Summers 2022), obscuring the relationship of the vacancy-to-unemployment ratio and other measures of labor market tightness, including unemployment. We return to this point below.

Finally, for the purposes of projection the "natural" or steady-state value of the vacancy-to-unemployment ratio, v/u^*, is important. Specifically, absent new shocks, in our model bringing down wage inflation requires a period in which v/u is below its steady-state value. The steady state of v/u implied by our model depends on the parameters of the wage and price equations and is not tightly estimated. For consistency with the decomposition exercises of the previous section, and following the assumption made by Blanchard, Domash, and Summers, for these projections we assume that v/u^*

equals 1.2, its value in 2019Q4, the last full quarter before the pandemic, a period when inflation appeared stable.[12]

With these substantial caveats, we can use the model to project the course of price inflation and wage growth, starting in 2023Q2, with initial conditions determined by the actual data for the prior four quarters. We assume that food and energy prices grow for the next few years at a rate equal to nominal wage growth, so the growth rates of the relative prices *grpe* and *grpf* are both equal to zero; that supply chains have largely repaired, so that the shortage variable takes an index value of 10 (on a scale in which its highest monthly value is 100);[13] and that productivity growth is 1 percent, close to its in-sample average. Equation residuals are set to zero. As in the rest of the paper, we use the price equation estimated over the full sample, including the covid period, and base the estimates for the other three equations on pre-covid data.

We consider three projections, based on differing assumed trajectories of the labor market. Specifically, in our simulations we assume that macro policy brings down v/u over eight quarters, beginning in 2023Q2, to one of three terminal values: 1.8 (approximately the current value of v/u); 1.2 (the value that prevailed immediately before the pandemic, which we have assumed is the steady-state or "natural" value of v/u); and 0.8. Obviously, lower values of v/u require tighter monetary and fiscal policies, all else equal. The value of v/u after eight quarters is not important for the points we want to make, so we simply assume that it remains constant thereafter. The results of the projections are shown in Figure 14. The three curves in the figure show the projected path of inflation under each of the assumed terminal points for the vacancy-to-unemployment ratio (the first observation in each trajectory is actual inflation in 2023Q1). As before, we use the CPI to measure inflation (not the PCE deflator, which the Fed targets) and the ECI to measure the nominal wage.

The qualitative lesson of Figure 14 is straightforward and would generalize for alternative steady-state values of v/u. All else equal, and not surprisingly, allowing v/u to remain near current levels does not bring inflation down in our projections. Indeed, because an extended period of inflation raises long-term inflation expectations, it leads to slowly increasing inflation. In contrast, in our projections, reducing the vacancy-to-unemployment ratio to its steady-state level over the next eight quarters brings CPI inflation down to about 2.7 percent, which, adjusting for historical differences between CPI and PCE inflation, is within striking distance of the Fed's target. A more aggressive policy,

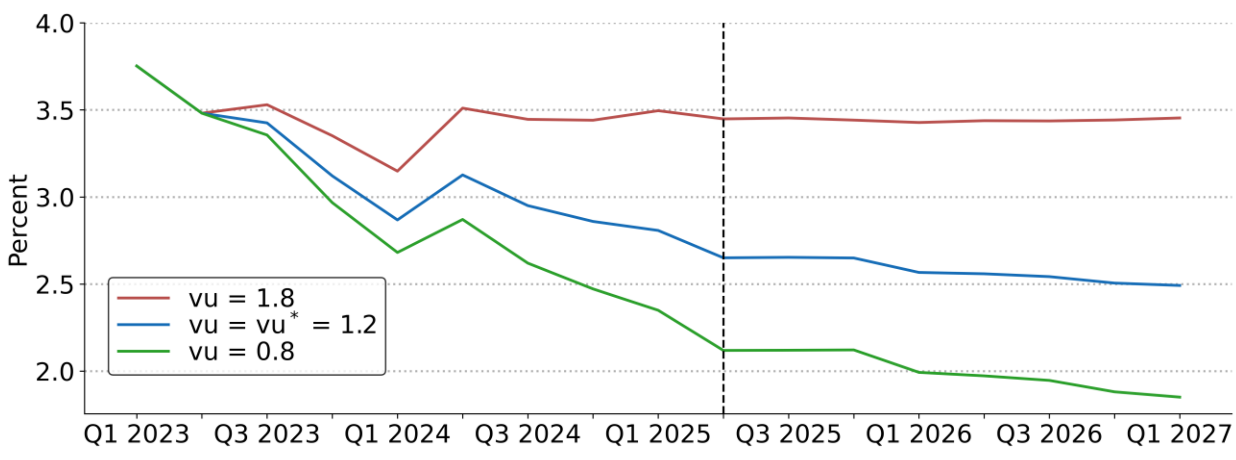
[12] We adjust the constant in the estimated wage equation so that the model delivers a steady-state value of v/u^* equal to 1.2.

[13] The realized values of *shortage* in the four quarters preceding the start of the simulation are 33, 18, 24, 22.

which brings v/u down to 0.8 in eight quarters, is projected to reduce CPI inflation to close to 2 percent by the end of that period. In the latter case, the projections show continuing declines in inflation for a constant level of v/u; the implication is that this more restrictive policy should ultimately be reversed.

One would like to know the unemployment rates associated with the three alternative paths. Unfortunately, that depends on a factor outside the model, namely, the future evolution of the Beveridge curve (see the debate between Blanchard, Domash, and Summers 2022 and Figura and Waller 2022). As we have discussed, during the pandemic the Beveridge curve shifted upward, implying that, for reasons not fully understood, the job-worker matching process had become less efficient. If that shift were to be fully reversed, then a decline in v/u to a level below its natural rate of 1.2, together with an unemployment rate above the implied natural rate of 3.6 percent (the actual unemployment rate in late 2019) could bring down inflation over time without a significant increase in unemployment (an "immaculate disinflation"). If, in the other extreme case, the Beveridge curve were to remain at its position as of early 2023, then the unemployment rate associated with v/u equal to 1.2—that is, the implied natural rate of unemployment—would be about 4.3 percent.[14] As implied by the figure, reducing inflation to target in that case would require an unemployment rate above that level for a period of time.

FIGURE 14. INFLATION PROJECTIONS UNDER ALTERNATIVE PATHS FOR v/u



Note: The figure shows projected inflation in the model if v/u is brought down to the specified terminal level over eight quarters. The value for 2023Q1 reflects actual data.

[14] Blanchard, Domash, and Summers show that the unemployment rate associated with a given v/u is proportional to $\left(\frac{v}{u}\right)^{-0.6}$. We calculate the natural rate by inferring the coefficient of proportionality from current data on unemployment and vacancy-to-unemployment rates.

IV. Conclusion

The pandemic-era inflation was a complicated phenomenon, that involved both multiple sources and complex dynamic interactions. Ultimately, as many have recognized, the inflation reflected strong aggregate demand, the product of easy fiscal and monetary policies, excess savings accumulated during the pandemic, and the reopening of locked-down economies. The strength of aggregate demand led to a (belatedly recognized) tightening of the labor market, as reflected in record high ratios of job openings to unemployed workers. However, at least initially, the arguments that the tighter labor market would not create much inflation, so long as the labor market tightness was temporary, were in fact correct. Although the Phillips curve was operative, inflation expectations did not de-anchor and there was little evidence of a wage-price spiral, in that workers did not achieve nominal wage gains sufficient to compensate them for unexpected price increases (a weak catch-up effect). Our decomposition of inflation shows that tight labor markets alone made only a modest contribution to inflation early on.

Instead, initially, the inflation reflected primarily developments in product markets. To the extent that excessive aggregate demand set off the inflation, it did so primarily by raising prices given wages, through its contribution to higher commodity prices (which reflected other forces as well, including the war in Ukraine) and by increasing the demand for goods for which supply was constrained. The effects of stronger aggregate demand on labor markets were less important.

The good news for policymakers is that the indirect effects of the price shocks were smaller than they might have been. In particular, inflation expectations, especially short-run expectations, rose enough to put upward pressure on wages and prices but generally remained reasonably well anchored. Although shocks to prices given wages have played a central role in the pandemic-era inflation, in the absence of strong indirect effects or renewed shocks, the portion of inflation accounted for by these shocks should largely (if not fully) dissipate over time, even without policy action.

However, even as the effects of price shocks have waned, the effects of tight labor markets have begun to cumulate. Our decomposition shows that, as of early 2023, tight labor market conditions still accounted for a minority share of excess inflation. But according to our analysis, that share is likely to grow and will not subside on its own. The portion of inflation which traces its origin to overheating of labor markets can only be reversed by policy actions that bring labor demand and supply into better balance. .

What are the lessons of all this for macroeconomics? The pandemic was extraordinarily disruptive, making forecasting and policymaking difficult. Nevertheless, we don't think that the recent experience justifies throwing out existing models of wage-price dynamics. We were able to simulate the pandemic-era inflation using a simple and rather traditional model of the interactions of wages, prices, and inflation expectations. That said, our results show that inflation can be a complicated phenomenon. Policymakers must be alert to the possibility that inflationary pressures can come from product markets as well as labor markets, for example, through unexpected changes in input costs or shifts in demand that collide with inelastic sectoral supply curves. Moreover, through various mechanisms, inflationary pressures from product and labor markets can interact and be mutually reinforcing. The good news is that, empirically, we find the second-round effects of product-market shocks to be relatively modest, implying that, as the early critics warned, labor-market balance should ultimately be the primary concern for central banks attempting to maintain price stability.

Appendix. Model estimates and robustness checks

Estimates and selected statistics for the four equations of the model are given immediately below. Results from alternative specifications and full estimation results, including estimated coefficients for all lagged values, follow. Price equations are estimated in the sample 1990Q1 to 2023Q1, which includes the covid period, while other equations are estimated on the pre-covid sample, ending in 2019Q4. P-values are given for both (i) the hypothesis that the sum of a set of coefficients is zero and (ii) the joint hypothesis that each of the coefficients applying to a given right-side variable are zero.

Numbers in parentheses indicate included lags, e.g., (0 to -4) says that the contemporaneous value and four lags of the variable are included in the regression. Variable mnemonics used in the reporting of regression results are given below (see also Table 1 in the text).

TABLE A1. VARIABLE MNEMONICS USED IN THIS APPENDIX

WAGE EQUATION
gw = change in the log nominal wage (ECI)
cf1 = one-year inflation expectations (Federal Reserve Bank of Cleveland)
spf1 = one-year inflation expectation (Survey of Professional Forecasters)
v/u = vacancy-to-unemployment ratio
catch-up = the excess of the actual log price level over the expected log price level
gpty = 8-quarter moving average productivity trend

PRICE EQUATION (additional variables)
gp = gcpi = change in the log nominal price level (CPI)
gpce = change in the log nominal price level (PCE)
grpe = change in the log of CPI energy prices relative to the aggregate wage
grpf = change in the log of CPI food prices relative to the aggregate wage
shortage = index of Google searches for " shortage"

INFLATION EXPECTATIONS EQUATIONS (additional variables)
cf10 = ten-year inflation expectations (Federal Reserve Bank of Cleveland)
spf10 = long-run inflation expectations (ten-year inflation forecast from Survey of Professional Forecasters)

TABLE A2. ESTIMATION WITH PCE INFLATION RATHER THAN CPI INFLATION

Dependent variable: gw

Independent variable	gw	v/u	catch-up	cf1	gpty
Lags	-1 to -4	-1 to -4	-1 to -4	-1 to -4	-1
Sum of coefficients	0.345	0.655	0.774	0.008	0.068
p-stat (sum)	0.050	0.016	0.092	0.000	0.258
p-stat (joint)	0.226	0.037	0.404	0.003	0.258
R-squared			0.594		
No. observations			120		

Dependent variable: gpce

Independent variable	gpce	gw	grpe	grpf	shortage	gpty
Lags	-1 to -4	0 to -4	0 to -4	0 to -4	0 to -4	-1
Sum of coefficients	0.501	0.499	0.038	0.086	0.014	-0.104
p-stat (sum)	0.001	0.001	0.002	0.133	0.442	0.116
p-stat (joint)	0.001	0.004	0.000	0.237	0.018	0.116
R-squared			0.844			
No. observations			133			

Dependent variable: cf1

Independent variable	cf1	cf10	gp
Lags	-1 to -4	0 to -4	0 to -4
Sum of coefficients	0.375	0.527	0.098
p-stat (sum)	0.031	0.001	0.016
p-stat (joint)	0.001	0.000	0.000
R-squared		0.883	
No. observations		120	

Dependent variable: cf10

Independent variable	cf10	gp
Lags	-1 to -4	0 to -4
Sum of coefficients	0.971	0.029
p-stat (sum)	0.000	0.129
p-stat (joint)	0.000	0.006
R-squared	0.932	
No. observations	120	

TABLE A3. ESTIMATION WITH SURVEY OF PROFESSIONAL FORECASTERS INSTEAD OF CLEVELAND FED FORECASTS

Dependent variable: gw

Independent variable	gw	v/u	catch-up	spf1	gpty
Lags	-1 to -4	-1 to -4	-1 to -4	-1 to -4	-1
Sum of coefficients	0.233	1.154	0.087	0.767	0.154
p-stat (sum)	0.205	0.002	0.285	0.000	0.024
p-stat (joint)	0.494	0.001	0.441	0.001	0.024
R-squared			0.636		
No. observations			120		

Dependent variable: gp

Independent variable	gp	gw	grpe	grpf	shortage	gpty
Lags	-1 to -4	0 to -4	0 to -4	0 to -4	0 to -4	-1
Sum of coefficients	0.335	0.665	0.066	0.126	0.018	-0.143
p-stat (sum)	0.037	0.000	0.000	0.050	0.281	0.027
p-stat (joint)	0.066	0.000	0.000	0.050	0.000	0.027
R-squared			0.947			
No.observations			132			

Dependent variable: spf1

Independent variable	spf1	spf10	gp
Lags	-1 to -4	0 to -4	0 to -4
Sum of coefficients	0.854	0.113	0.033
p-stat (sum)	0.000	0.031	0.067
p-stat (joint)	0.000	0.000	0.000
R-squared		0.950	
No.observations		120	

Dependent variable: spf10

Independent variable	spf10	gp
Lags	-1 to -4	0 to -4
Sum of coefficients	0.969	0.031
p-stat (sum)	0.000	0.002
p-stat (joint)	0.000	0.029
R-squared	0.969	
No. observations	120	

TABLE A4 FULL ESTIMATION RESULTS

Dependent variable: gw

Using gcpi		Using gpce		Using spf	
gw (-1)	0.16	gw (-1)	0.14	gw (-1)	0.08
	(0.10)		(0.10)		(0.10)
gw (-2)	0.12	gw (-2)	0.08	gw (-2)	0.10
	(0.10)		(0.10)		(0.10)
gw (-3)	0.17*	gw (-3)	0.15	gw (-3)	0.12
	(0.10)		(0.10)		(0.10)
gw (-4)	0.00	gw (-4)	-0.03	gw (-4)	-0.06
	(0.10)		(0.10)		(0.10)
cf1 (-1)	0.34**	cf1 (-1)	0.38***	spf1 (-1)	-0.11
	(0.14)		(0.13)		(0.40)
cf1 (-2)	-0.03	cf1 (-2)	0.00	spf1 (-2)	0.22
	(0.15)		(0.14)		(0.46)
cf1 (-3)	0.20	cf1 (-3)	0.27*	spf1 (-3)	0.35
	(0.16)		(0.15)		(0.45)
cf1(-4)	0.03	cf1(-4)	-0.01	spf1(-4)	0.30
	(0.16)		(0.15)		(0.39)
magpty (-1)	0.03	magpty (-1)	0.07	magpty (-1)	0.15**
	(0.06)		(0.06)		(0.07)
vu(-1)	3.77*	vu(-1)	3.31*	vu(-1)	3.38*
	(1.98)		(1.94)		(1.96)

vu (-2)	-1.81	vu (-2)	-1.69	vu (-2)	-0.67
	(3.63)		(3.58)		(3.57)
vu. (-3)	-3.64	vu. (-3)	-3.58	vu. (-3)	-3.77
	(3.66)		(3.61)		(3.60)
vu (-4)	2.38	vu (-4)	2.74	vu (-4)	2.21
	(2.10)		(2.07)		(2.10)
Catchup (-1)	-0.01	Catchup (-1)	-0.11	Catchup (-1)	0.12
	(0.08)		(0.13)		(0.08)
Catchup (-2)	0.01	Catchup (-2)	0.13	Catchup (-2)	0.04
	(0.08)		(0.15)		(0.09)
Catchup (-3)	-0.00	Catchup (-3)	-0.05	Catchup (-3)	-0.07
	(0.08)		(0.14)		(0.09)
Catchup (-4)	-0.02	Catchup (-4)	0.04	Catchup (-4)	-0.00
	(0.07)		(0.11)		(0.08)
Constant	-0.27	Constant	-0.93*	Constant	-0.75***
	(0.20)		(0.50)		(0.24)
R-squared	0.583	R-squared	0.594	R-squared	0.636
No. observations	120	No. observations	120	No. observations	120

Dependent variable: gp = (gcpi or gpce)

Using gcpi		Using gpce		Using spf	
gcpi (-1)	0.04	gpce (-1)	0.03	gcpi (-1)	0.04
	(0.11)		(0.09)		(0.11)
gcpi (-2)	0.18*	gpce (-2)	0.23**	gcpi (-2)	0.18*
	(0.10)		(0.09)		(0.10)
gcpi (-3)	0.23**	gpce (-3)	0.29***	gcpi (-3)	0.23**
	(0.11)		(0.09)		(0.11)
gcpi (-4)	-0.11	gpce (-4)	-0.04	gcpi (-4)	-0.11
	(0.10)		(0.08)		(0.10)
Gw	0.37***	gw	0.21**	gw	0.37***
	(0.09)		(0.10)		(0.09)
gw (-1)	0.18	gw (-1)	0.08	gw (-1)	0.18
	(0.11)		(0.11)		(0.11)
gw (-2)	0.04	gw (-2)	0.24**	gw (-2)	0.04
	(0.11)		(0.11)		(0.11)
gw (-3)	0.04	gw (-3)	-0.04	gw (-3)	0.04
	(0.11)		(0.11)		(0.11)
gw (-4)	0.05	gw (-4)	0.00	gw (-4)	0.05
	(0.10)		(0.11)		(0.10)

magpty	-0.14**	magpty	-0.10	magpty	-0.14**
	(0.06)		(0.07)		(0.06)
grpe	0.09***	grpe	0.04***	grpe	0.09***
	(0.00)		(0.00)		(0.00)
grpe (-1)	0.00	grpe (-1)	0.03***	grpe (-1)	0.00
	(0.01)		(0.00)		(0.01)
grpe (-2)	-0.01	grpe (-2)	-0.01	grpe (-2)	-0.01
	(0.01)		(0.01)		(0.01)
grpe (-3)	-0.02**	grpe (-3)	-0.02***	grpe (-3)	-0.02**
	(0.01)		(0.01)		(0.01)
grpe (-4)	0.01	grpe (-4)	-0.01	grpe (-4)	0.01
	(0.01)		(0.00)		(0.01)
grpf	0.11***	grpf	0.03	grpf	0.11***
	(0.04)		(0.03)		(0.04)
grpf (-1)	-0.02	grpf (-1)	0.03	grpf (-1)	-0.02
	(0.04)		(0.03)		(0.04)
grpf (-2)	-0.00	grpf (-2)	-0.04	grpf (-2)	-0.00
	(0.04)		(0.03)		(0.04)
grpf (-3)	-0.00	grpf (-3)	-0.01	grpf (-3)	-0.00
	(0.04)		(0.03)		(0.04)
grpf (-4)	0.04	grpf (-4)	0.07**	grpf (-4)	0.04
	(0.04)		(0.03)		(0.04)
Shortage	0.11***	Shortage	0.04*	Shortage	0.11***
	(0.02)		(0.02)		(0.02)
Shortage (-1)	-0.03	Shortage (-1)	0.04**	Shortage (-1)	-0.03
	(0.02)		(0.02)		(0.02)
Shortage (-2)	0.00	Shortage (-2)	0.01	Shortage (-2)	0.00
	(0.02)		(0.02)		(0.02)
Shortage (-3)	-0.03	Shortage (-3)	-0.04**	Shortage (-3)	-0.03
	(0.02)		(0.02)		(0.02)
Shortage (-4)	-0.02	Shortage (-4)	-0.04*	Shortage (-4)	-0.02
	(0.02)		(0.02)		(0.02)
Constant	-0.11	Constant	-0.27	Constant	-0.11
	(0.16)		(0.20)		(0.16)
R-squared	0.947	R-squared	0.844	R-squared	0.947
No. observations	133	No. observations	133	No. observations	133

Dependent variable: cf1/spf1

Using gcpi		Using gpce		Using spf	
cf1 (-1)	0.30***	cf1 (-1)	0.25***	spf1 (-1)	0.63***
	(0.09)		(0.10)		(0.09)
cf1 (-2)	-0.23**	cf1 (-2)	-0.21**	spf1 (-2)	0.17
	(0.10)		(0.10)		(0.11)
cf1 (-3)	0.18*	cf1 (-3)	0.15	spf1 (-3)	0.21*
	(0.10)		(0.10)		(0.11)
cf1 (-4)	0.12	cf1 (-4)	0.19**	spf1 (-4)	-0.15*
	(0.07)		(0.09)		(0.09)
cf10	1.20***	cf10	1.23***	spf10	0.67***
	(0.14)		(0.16)		(0.15)
cf10 (-1)	-0.47**	cf10 (-1)	-0.40	spf10 (-1)	-0.04
	(0.23)		(0.25)		(0.18)
cf10 (-2)	0.02	cf10 (-2)	-0.14	spf10 (-2)	-0.58***
	(0.23)		(0.26)		(0.19)
cf10 (-3)	0.14	cf10 (-3)	0.20	spf10 (-3)	-0.11
	(0.23)		(0.25)		(0.18)
cf10 (-4)	-0.38**	cf10 (-4)	-0.36*	spf10 (-4)	0.18
	(0.17)		(0.20)		(0.15)
gcpi	0.04***	gpce	0.09***	gcpi	0.03***
	(0.01)		(0.02)		(0.01)
gcpi (-1)	0.10***	gpce (-1)	0.08***	gcpi (-1)	0.02***
	(0.01)		(0.03)		(0.01)
gcpi (-2)	0.00	gpce (-2)	-0.01	gcpi (-2)	-0.01
	(0.02)		(0.03)		(0.01)
gcpi (-3)	0.01	gpce (-3)	-0.01	gcpi (-3)	-0.00
	(0.02)		(0.03)		(0.01)
gcpi (-4)	-0.02	gpce (-4)	-0.05**	gcpi (-4)	-0.01
	(0.02)		(0.03)		(0.01)
R-squared	0.910	R-squared	0.883	R-squared	0.950
No. observations	120	No. observations	120	No. observations	120

Dependent variable: cf10/spf10

Using gcpi		Using gpce		Using spf	
cf10 (-1)	0.85***	cf10 (-1)	0.82***	spf10 (-1)	0.70***
	(0.09)		(0.09)		(0.09)
cf10 (-2)	-0.05	cf10 (-2)	-0.06	spf10 (-2)	0.26**
	(0.12)		(0.12)		(0.11)
cf10 (-3)	0.20	cf10 (-3)	0.25**	spf10 (-3)	0.00
	(0.12)		(0.12)		(0.11)
cf10 (-4)	-0.03	cf10 (-4)	-0.05	spf10 (-4)	-0.00
	(0.09)		(0.09)		(0.09)
Gcpi	0.03***	gpce	0.05***	gcpi	0.01
	(0.01)		(0.01)		(0.00)
gcpi (-1)	0.01	gpce (-1)	-0.02	gcpi (-1)	0.01**
	(0.01)		(0.02)		(0.00)
gcpi (-2)	-0.01	gpce (-2)	-0.00	gcpi (-2)	0.01*
	(0.01)		(0.01)		(0.00)
gcpi (-3)	-0.00	gpce (-3)	-0.01	gcpi (-3)	0.00
	(0.01)		(0.01)		(0.00)
gcpi (-4)	-0.00	gpce (-4)	0.01	gcpi (-4)	0.01*
	(0.01)		(0.01)		(0.00)
R-squared	0.936	R-squared	0.932	R-squared	0.969
No. observations	120	No. observations	120	No. observations	120

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