The COVID Inflation Shock, Monetary Policy Gradualism, and Lingering Supply Chain Effects

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Abstract: Monetary policymakers face difficult tradeoffs when inflation is above target. In this paper, we argue that central banks should generally move slowly in combatting inflation when the sources of that inflation are ambiguous (such as in the aftermath to a pandemic), when long-term inflationary expectations remain well-anchored (as they have), and inflation is not overly excessive (e.g., when it is below a double-digit range on an annual basis). The lags with which various forces drive inflation are highly uncertain, and the risk of inflation becoming embedded when it is above target (the argument for moving faster) can be outweighed by the risk of "breaking things" (the argument against moving faster), especially when inflation remains in the single digits. We present new empirical evidence on one particular source of lags in the inflation process: lingering effects from supply chain disruptions at the height of COVID. We show that lagged effects from COVID-era supply chain disruptions were still an important driver of elevated inflation in 2022, likely because price adjustments to changing supply conditions take time. We estimate that the lingering impact of heightened COVID-era delivery times explains up to 70 percent of elevated core inflation in Q4 2022. The possibility that lagged effects from supply chain disruptions are still working their way through the system advises a *"*wait-and-see*"* approach for the Fed, especially

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in the wake of tighter fiscal policy and recent banking sector turmoil (the latter of which in turn may be at least partially linked to the speed of the monetary policy tightening to date).

I. Introduction

The debate over the causes and severity of the US inflation shock – and the appropriate monetary policy response – has ebbed and flowed in recent years. In the early stages of COVID, amid unprecedented shut-downs in the economy and a global fear factor that saw oil prices go negative in April 2020, the focus of monetary policy was to provide as much accommodation as possible and support fiscal stimulus.[2] That emphasis was encouraged in part by the decade of below-target inflation in the run-up to the pandemic (Exhibit 1), which made it seem almost unthinkable that inflation could rise in a material way. These perspectives reached their apex with the introduction of Flexible Average Inflation Targeting (FAIT) in August 2020, a new policy framework that allowed for inflation overshoots in an attempt to make up for periods of below-target inflation.

In 2021, inflation began to rise sharply, with core PCE inflation up from 1.5 percent year-over-year in December 2020 to 5.0 percent one year later. Initial perspectives on this inflation surge were disproportionately that supply disruptions were playing an important role, with delivery times in the manufacturing PMIs lengthening across the board, and much focus on topics such as waiting times for container ships off West Coast ports. These supply disruptions encouraged the view that the rise in inflation was "transitory," and the Fed's Statement of Economic Projections (SEP) forecasts saw inflation return to target relatively quickly. For example, the September 2021

[2] Sylvan Lane, "Powell Urges Congress to Unleash 'Great Fiscal Power' to Defeat Coronavirus, Repair Economy," Text, *The Hill*, April 29, 2020, accessed March 9, 2023, https://thehill.com/policy/finance/495320-powell-urges-congress-to-unleash-great-fiscal-power-to-defeat-coronavirus/.

SEP – when core PCE inflation was running just below 4.0 percent year-over-year -- projected that core PCE inflation in Q4 2022 would fall to 2.3 percent. But others had warned that fiscal stimulus was excessive and that inflation would therefore persist.[3] Actual Q4 2022 core PCE inflation was 4.8 percent, and shifted the narrative to the role that excess demand is playing in keeping inflation high, with some pointing to delayed effects from COVID fiscal stimulus as the principal driver of persistent above-target inflation.[4]

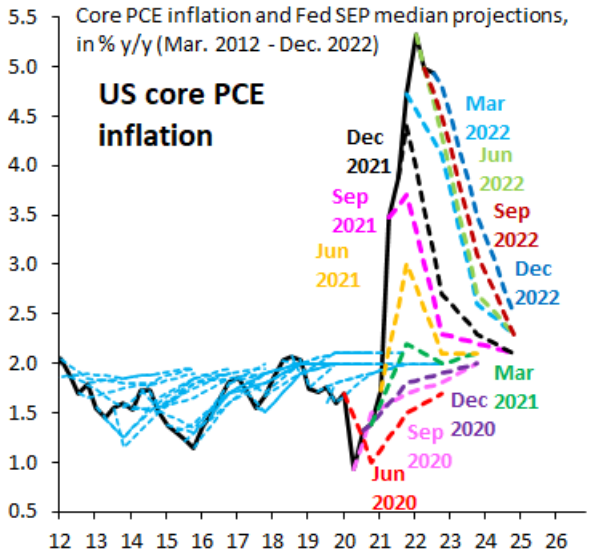

Exhibit 1

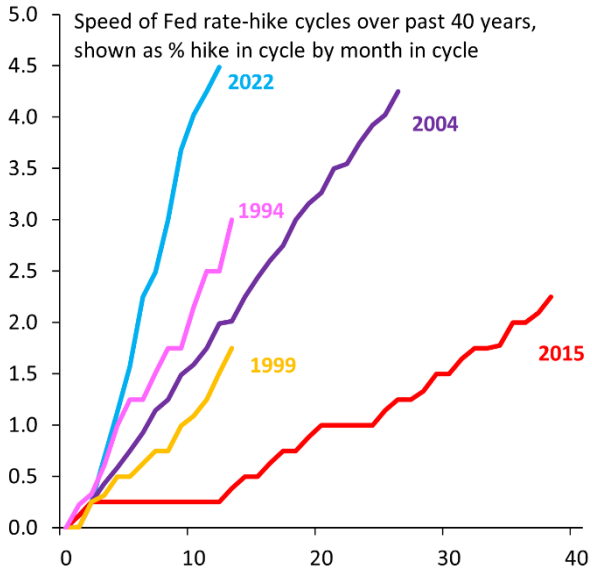

Exhibit 2

After initially standing pat, the Fed pivoted to aggressive rate increases. In 2022, the Fed hiked 425 bps, including highly unusual 75 basis point hikes in June, July, September and November. The speed of this hiking cycle exceeds anything seen in the past 30 years (Exhibit 2)

[3] Lawrence H. Summers, "Opinion | The Biden Stimulus Is Admirably Ambitious. But It Brings Some Big Risks, Too.," *Washington Post*, February 7, 2021, accessed March 9, 2023, https://www.washingtonpost.com/opinions/2021/02/04/larry-summers-biden-covid-stimulus/.
[4] Jason Furman, "Economist Jason Furman Explains How Inflation Snuck Up on Us and What's Ahead in 2022," *RIA Intel*, last modified February 24, 2022, accessed March 9, 2023, https://www.riaintel.com/article/2aucrzsa72lr93ypli4g0/the-big-question/economist-jason-furman-explains-how-inflation-snuck-up-on-us-and-whats-ahead-in-2022.

and raises the question – given the importance of lags not only in monetary policy but also in lagged disinflationary effects from unclogging supply chains – whether Fed tightening has been too much too fast. The underlying question remains the same as in 2021 and 2022: how much of the recent high inflation numbers stems from supply disruptions versus excess demand and – based on this balance – how aggressively the Fed should continue to tighten, especially given the differential costs associated with tightening too rapidly even for the same ultimate shift in financial conditions.[5]

In addition to the possibility that important components of services inflation still reflect the pandemic (e.g., catch-up effects in travel and entertainment), COVID-related chain disruptions likely have lingering price effects even after the supply conditions have eased, mostly because price adjustments are gradual and take time to feed into inflation. Even with delivery times back to normal, it is thus possible that price setting has not yet normalized, as firms adjust gradually back to the status quo ex ante. We find empirical evidence to support the idea that lagged effects from COVID supply chain disruptions may have played an important role in keeping inflation elevated through 2022. In particular, we estimate that lagged effects associated with delivery times may explain between 30 and 70 percent of elevated Q4 2022 core PCE inflation, even allowing for other variables – notably the recently popular vacancies-to-unemployment ratio that is used in the literature to control for the unusually tight labor market post-COVID.[6]

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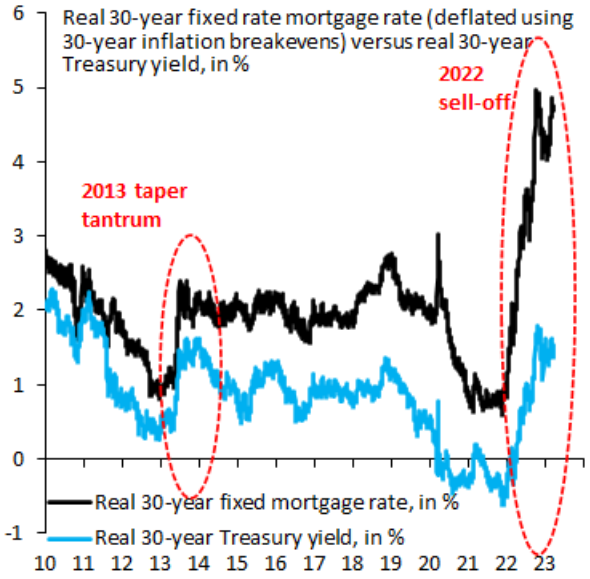
[5] An analogy is to Mohs surgery, in which the surgeons iterate with small increments to address skin cancer rather immediately removing all the relevant skin. The end result is similar, but the incremental approach is preferred because it generally imposes less incidental damage.

[6] We note that interpreting this result is difficult, since it is possible that our lagged terms are picking up excess demand. After all, firms can only sustain higher margins in a strong demand environment. But in part because we control for contemporaneous demand variables, we tend to favor the view that the COVID shock was large and unprecedented enough that lagged supply chain effects are at play.

To the extent that the disinflation associated with COVID-related effects is not over, the implications for Fed policy are immediate. What is nowadays derisively called "immaculate disinflation" could still be in play, since lagged supply chain effects are still working their way through the system. As a result, and especially given recent financial stability concerns, we think the Fed is justified in adopting a "wait-and-see" approach. This will have the benefit of letting lags in the inflation process play out while allowing markets to digest the very rapid pace of monetary tightening in 2022 (Exhibit 3). Furthermore, should inflation not come down as expected, the Fed would still have sufficient time to shift back into hiking mode, given that longer-term inflation expectations tend not to move discontinuously (Exhibit 4) even when shorter-term inflation expectations do.



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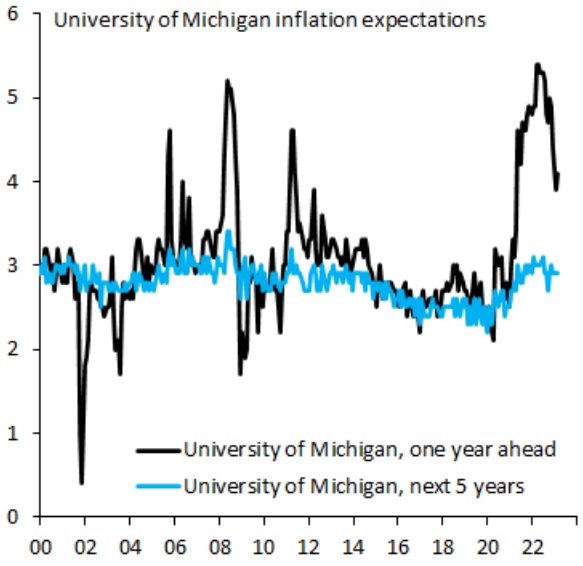


Exhibit 4

II. A Review of Recent Inflation and Supply Chain Trends

a. Inflation Momentum into 2023

Measures of core inflation have remained stubbornly high even as the COVID pandemic is increasingly in the rear-view mirror. In January 2023, core PCE inflation stood at 4.7 percent in year-over-year terms (Exhibit 5), little changed from 5.2 percent in January 2022. Core CPI was 5.5 percent year-over-year in February 2023 versus 6.4 percent a year before (Exhibit 6). This persistence of core inflation has affected the debate over its causes. This section looks at the disaggregated inflation data at high frequency, to discern whether individual components of core PCE and CPI can help inform a view of the underlying causes of the persistent inflation.

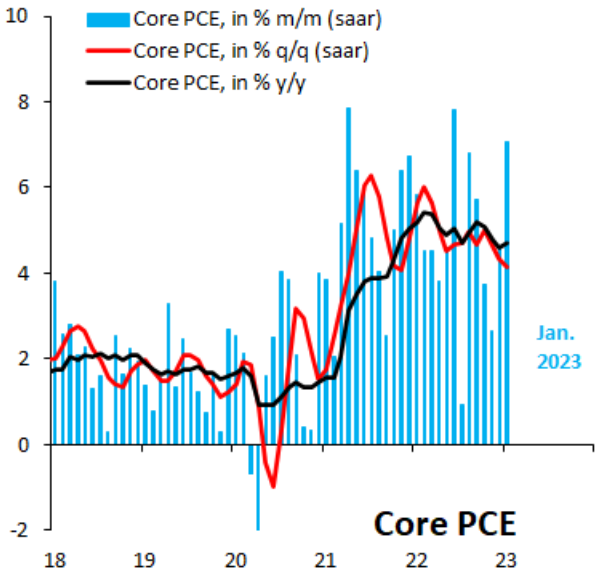


Exhibit 5

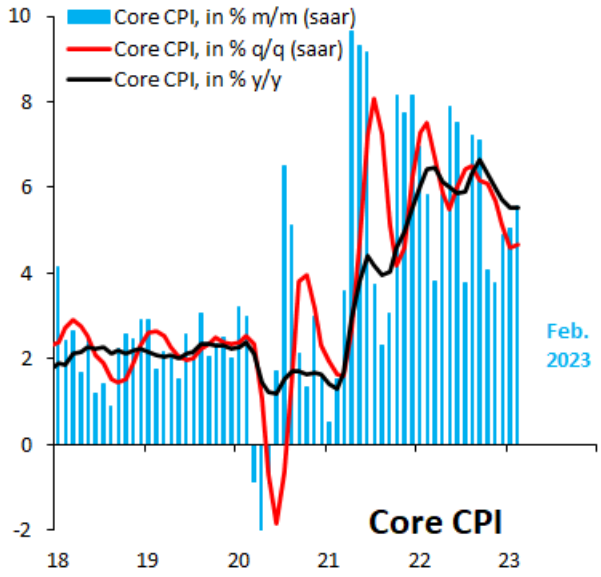


Exhibit 6

We break out core PCE and CPI inflation into key categories that attempt to capture some of the disparate trends in both consumption baskets. In particular, given how idiosyncratic some categories of consumption are, we distinguish between goods inflation, where the pandemic saw households shift to goods consumption when services sectors in the economy were shut down, and

services inflation, where we break out owners' equivalent rent (OER), healthcare and transportation.

Our focus here is on a remaining services inflation category, excluding OER, healthcare and transportation, and covers around 20 percent of the CPI basket and 35 percent of the PCE basket. We see this services category as a good proxy for underlying inflation given the noise and somewhat unusual drivers of other categories. This measure shows little sign that underlying inflation has slowed for either core PCE (Exhibit 7) or core CPI (Exhibit 8).[7]

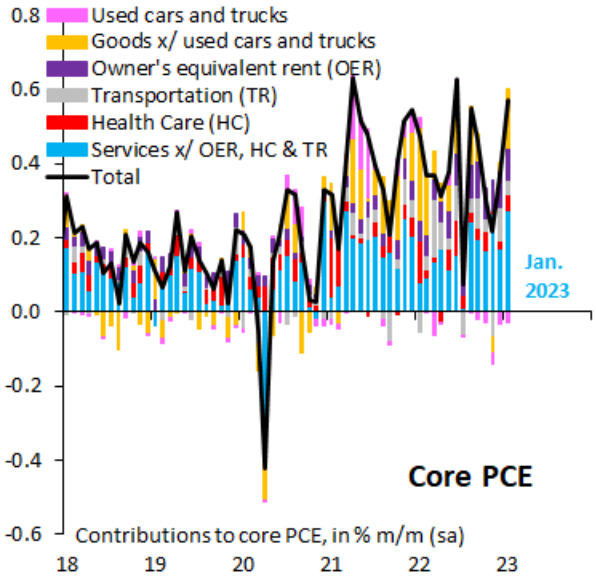


Exhibit 7

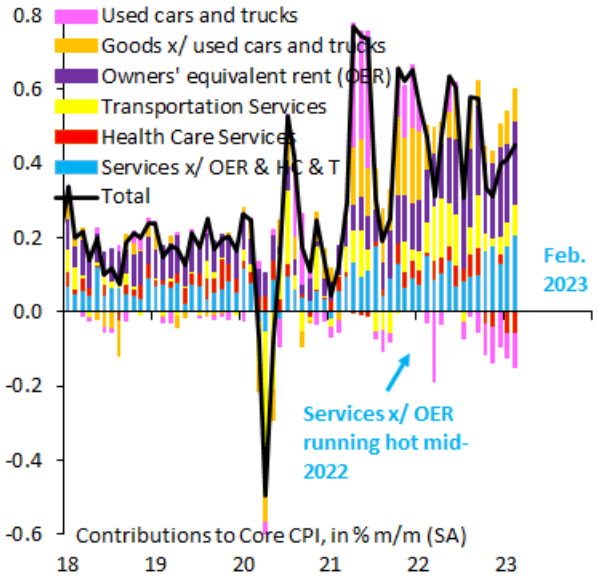


Exhibit 8

One alternative bottom-up perspective is to look at inflation generalization, which is the combined weight of items in the overall PCE and CPI indices with inflation above 2 percent. These

[7] It is possible that start-of-year price resets are muddying the picture in early 2023. These resets are catch-up effects that can be thought of as one-time jumps in the price level, as companies use the start of a new calendar year to adjust prices for higher energy and other costs. These resets do not, therefore, constitute ongoing inflation. That said, there is considerable uncertainty around the magnitude of this start-of-year effect, which will only become clear as 2023 progresses.

indices are typically calculated using year-over-year inflation, which tends to be slower moving and subject to base effects. We calculate these indices for month-over-month, seasonally adjusted annualized inflation, which provides a timelier – albeit noisier – perspective. Exhibit 9 shows our generalization indices for the overall PCE index, while Exhibit 10 shows the same thing for the CPI basket. In both cases, the scale of inflation generalization had declined in the second half of 2022, but the start of 2023 has muddied the picture.

Overall, the inflation picture is therefore quite murky, including from start-of-year price resets but more broadly by ambiguity over the underlying drivers of core inflation. With that ambiguity in mind, we turn to lags in the mapping from the supply chain to prices.

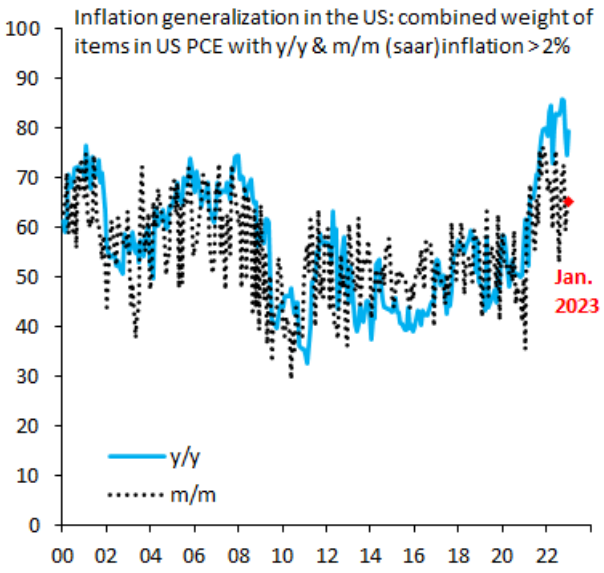


Exhibit 9

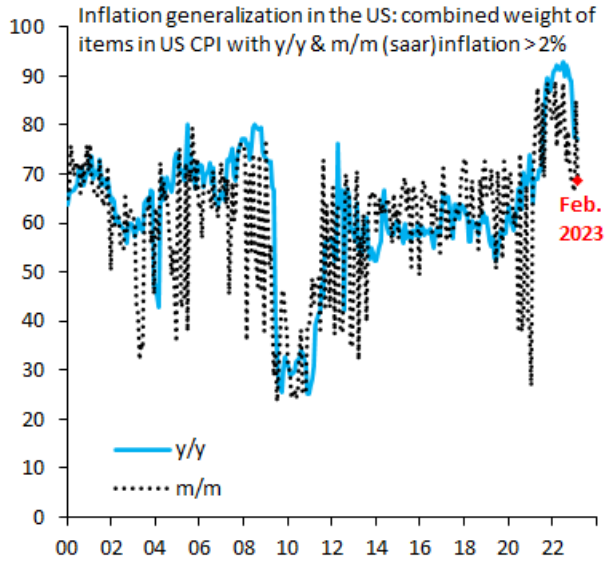


Exhibit 10

b. The COVID Supply Shock: Stretched Delivery Times

When the COVID pandemic engulfed the world in early 2020, it caused severe disruption to global manufacturing. One way to measure this disruption is through delivery times in the global manufacturing PMIs, which are balance of opinion surveys that range from 0 to 100.Numbers

greater than 50 indicate faster deliveries and numbers below 50 indicate slower deliveries. These delivery time indices are available for around 34 countries, which we transform into Z-scores by subtracting their pre-2020 means and dividing by their standard deviations. Exhibit 11 shows delivery time Z-scores during COVID, with China registering a sharp spike in delivery times when COVID first hit, and other advanced countries following somewhat later. In terms of severity, stretched delivery times were comparable to what Japan experienced after the Fukushima nuclear disaster in 2011.

One ambiguity in these indices is that they do not necessarily capture supply disruptions alone as opposed to strong demand: delivery times can rise either because of a supply problem or because demand has risen sharply. Exhibit 12 shows this for the US. When COVID first hit, industrial production fell as factories shut down. There was a commensurate spike in delivery times. Thereafter, industrial production expanded, yet delivery times continued to rise, a possible indication that strong demand – fed by generous fiscal stimulus – was also at play.

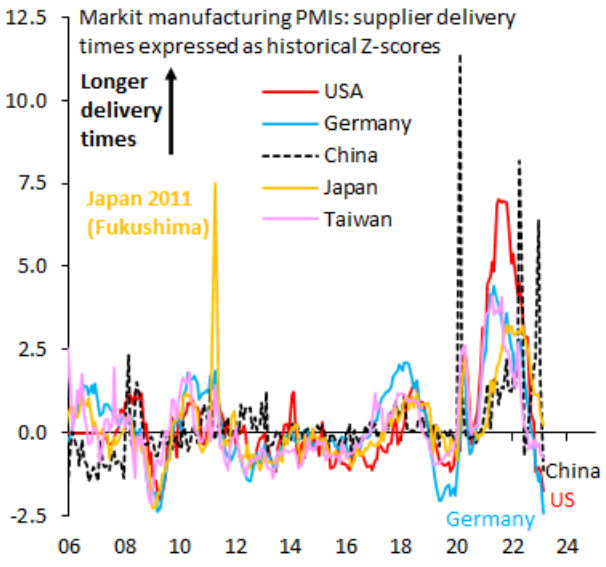


Exhibit 11

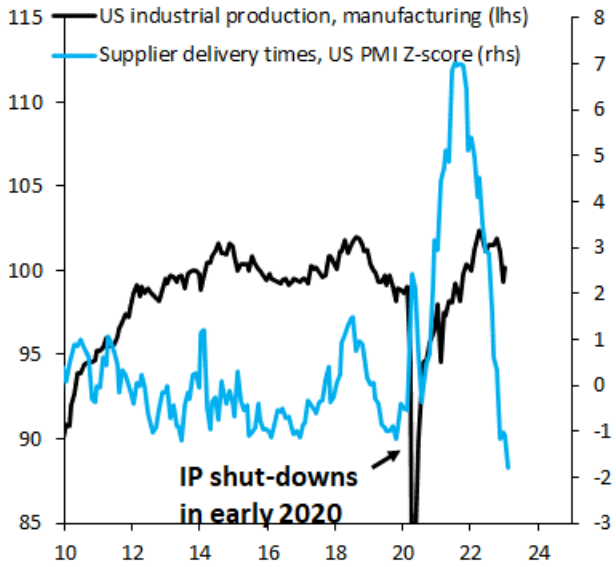
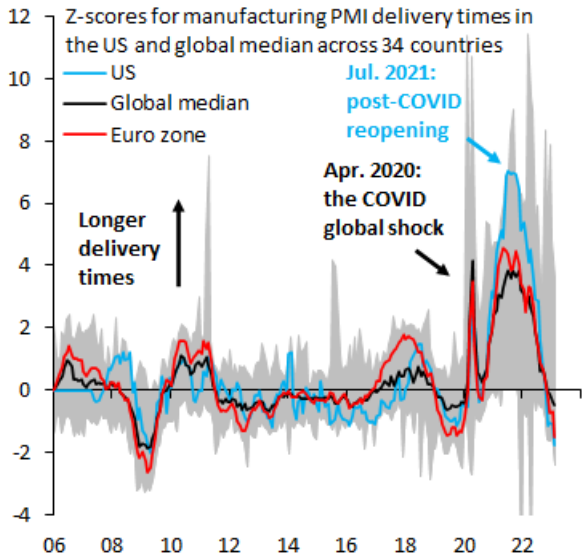


Exhibit 12

Delivery times have normalized since COVID first hit. Exhibit 13 shows that our Z-scores are back to near zero – actually slightly below, indicating falling delivery times – for the US, the Euro zone and for a global median. It is for this reason that many believe the inflationary impact from supply disruptions is over.

A key point of our paper, though, is that the mapping from COVID supply disruptions to inflation may be more complicated than it initially appears. We make similar Z-scores for output prices (Exhibit 14) and input prices (Exhibit 15) in the global manufacturing PMIs. Output prices are what firms charge their customers. Input prices are what they pay for inputs into manufacturing. While input prices have largely normalized – with Z-scores at or below zero – output prices have not normalized and our Z-scores have yet to reach zero. The lagged feedthrough into output prices is a reflection of our broader point.



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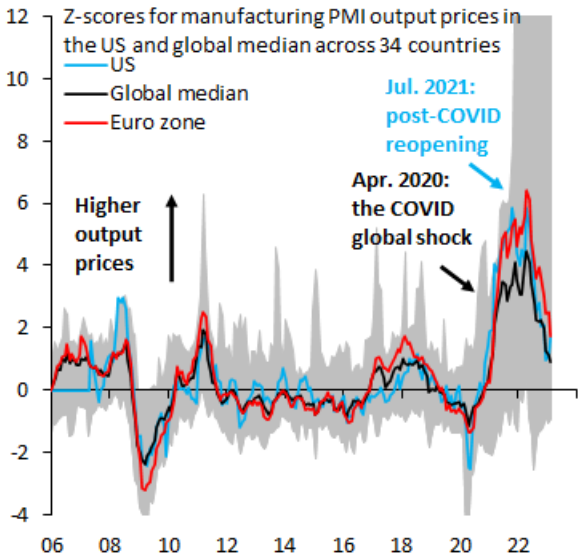

Exhibit 14

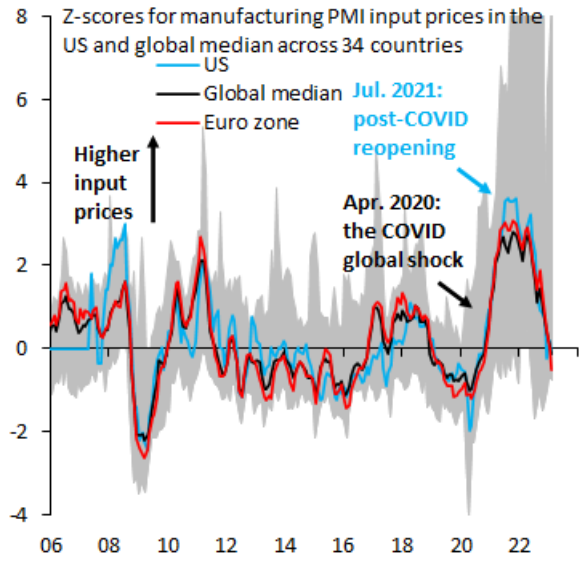

Exhibit 15

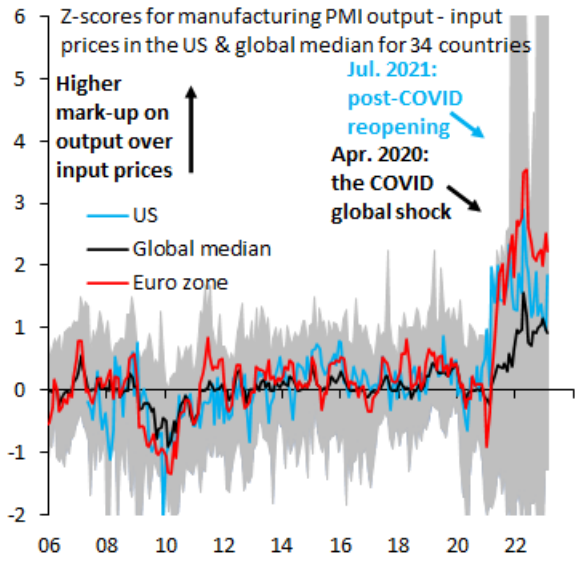

Exhibit 16

III. Empirical Work

We now move to testing empirically whether lingering supply chain disruptions could still be playing a role in ongoing high inflation readings. We embed data on delivery time delays within the existing literature, which estimates Phillips curve regressions that link core inflation to measures of slack such as the output or unemployment gaps and additional metrics that control for the unusually tight labor market in the wake of the pandemic. We perform robustness tests to determine the length of lags with which the delivery times variable enters the inflation process and use rolling regressions to document how sensitive key coefficient estimates are to different sample periods.

a. Existing Phillips Curve Literature on the COVID Inflation Shock

To look at the significance of supply chain issues, and more specifically supplier delivery times, on inflation, we first formulate a standard Phillips curve. Phillips curves are generally modeled with a measure of demand (such as the output gap) along with global variables to capture changes in imports and energy, given that such shocks invariably feed into core inflation via second-round effects.

To explain short-run changes in the inflation rate, many economists look to a measure of labor market slack. The traditional approach would be to focus on the unemployment gap, the difference between the unemployment rate and the noncyclical rate of unemployment. However, for the current pandemic episode, many papers also use JOLTS data for vacancy rates as an alternative measurement of labor market tightness. Papers such as Furman and Powell (2021)[8], Barnichon and Shapiro (2022)[9], Domash and Summers (2022)[10], Ball et al (2022)[11], and most recently Cecchetti et al (2023)[12] all use the vacancies-to-unemployment ratio (v/u) as an additional metric to capture the unusually tight labor market in the wake of COVID.[13] An alternative metric that is used in the literature is the job openings ratio, which is the number of vacancies divided by total employment. We use both metrics in our Phillips curve models, in addition to traditional measures of slack like output and unemployment gaps.

b. Our Phillips Curve Specifications

Our baseline specification models year-over-year core inflation, π_t, as a function of the output gap, $ygap_t$, labor market metrics, $labor_t$, like the vacancies-to-unemployment ratio and the

[8] Furman, Jason, and Wilson Powell III, 2021, "What is the Best Measure of Labor Market Tightness?", Peterson Institute for International Economics, November 22, 2021

[9] Barnichon, Regis and Adam Hale Shapiro. 2022. "What's the Best Measure of Economic Slack?", FRBSF Economic Letter, 2022-04 | February 22, 2022.

[10] Domash, Alex and Lawrence H. Summers (2022), "How Tight are U.S. Labor Markets?", NBER Working Paper 29739, February 2022.

[11] Daniel Leigh, Laurence Ball, and Prachi Mishra, "Understanding U.S. Inflation During the COVID Era," *IMF variables Working Papers* 2022, no. 208 (October 2022): 1, accessed March 9, 2023, https://elibrary.imf.org/openurl?genre=journal&issn=1018-5941&volume=2022&issue=208.

[12] Stephen Cecchetti et al., "Managing Disinflations " (USMPF 2023 PAPER, February 24, 2023), accessed March 9, 2023, http://www.chicagobooth.edu/research/igm/usmpf/usmpf-paper.

[13] The intuition behind the vacancies-to-unemployment ratio is that there is a matching problem, with those who are unemployed not necessarily well-suited to fill existing vacancies. The result is that the large number of vacancies can exert upward pressure on wages – and inflation – which this measure captures.

delivery times variable, $supply_t$, for which we primarily use the PMI component, but also the ISM component, which predominates in the existing literature:

$$\pi_t = \alpha + \beta_1 ygap_t + \beta_2 labor_t + \beta_3 supply_t + \beta_4 USD_t + \beta_5 USD_{t-4} + \beta_6 USD_{t-8} + \beta_7 \pi_t^{oil} + \beta_8 \pi_{t-4}^{oil} + \beta_9 \pi_{t-8}^{oil} + \beta_{10} \pi_{t-4} + \beta_{11} \pi_{t-8} + \varepsilon_t$$

When measuring inflation, we focus on two traditional measures of core inflation: the price index of personal consumption expenditures excluding food and energy (core PCE inflation) and the consumer price index excluding food and energy (core CPI inflation). We use quarterly data when looking at the year-over-year percent change in these indices, and thus when including lags, we include them at yearly intervals.

Turning to labor market indicators, we focus on the unemployment gap ($u - u^*$) as a traditional measure of slack and use the Congressional Budget Office's February 2023 estimates for the noncyclical rate of unemployment.[14] Recent work on alternatives to the unemployment gap are also considered, as mentioned above, including the ratio of vacancies to unemployment and the job openings rate as alternative labor market measures. While JOLTS data are only available starting in Q4 2000, we follow Barnichon (2010) to extend back the history of job openings.[15] Exhibit 17 compares these labor market indicators. While the level of unemployed persons in the United States spiked in Q1 2020, the drop in the number of job openings was significantly smaller. Although unemployment has reverted to pre-pandemic levels, the number of job openings appears to remain significantly above its pre-pandemic path.

[14] "The Budget and Economic Outlook: 2023 to 2033 | Congressional Budget Office." Last modified February 15, 2023. Accessed March 11, 2023. https://www.cbo.gov/publication/58848.
[15] Barnichon, Regis. 2010. "Building a Composite Help-Wanted Index." Economics Letters 109(3), pp. 175–178.

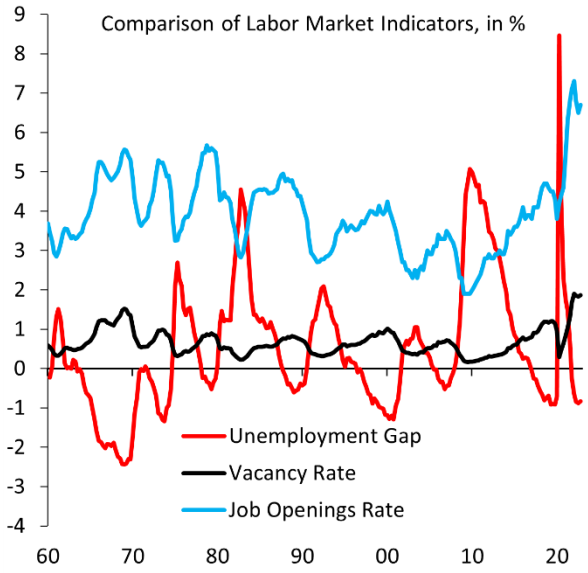

Exhibit 17

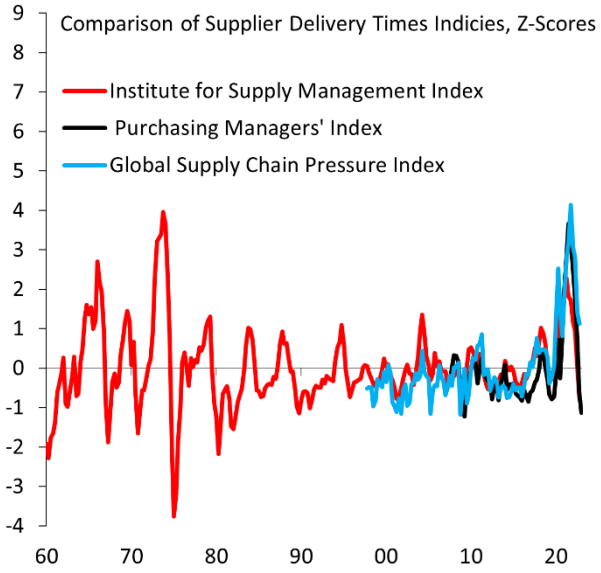

Exhibit 18

As explained in Section II, when measuring supplier delivery times, we focus on Z-scores from the Purchasing Managers Index series on manufacturing suppliers' delivery times as they are available across countries on a consistent basis. When we examine the effects of a lagged supply chain variable, the PMI restricts our sample period to start in Q3 2008. Fortunately, the Institute for Supply Management's manufacturing supplier deliveries index is available over a longer time horizon, allowing us to check our results over a longer period. Additionally, the Federal Reserve Board of New York's Global Supply Chain Pressure Index (GSCPI) is used as another alternative measure.[16] This index was used recently in Ozge et al. (2023) who look at how much recent GSCPI improvements could be driving lower inflation.[17] Exhibit 18 charts all three of these series and shows that they track well together, especially the ISM and PMI data.

[16] Federal Reserve Board of New York. "Global Supply Chain Pressure Index," accessed March 11, 2023, https://newyorkfed.org/research/policy/gscpi.

[17] Ozge Akinci et al., "How Much Can GSCPI Improvements Help Reduce Inflation?," *Liberty Street Economics*, February 22, 2023, accessed March 11, 2023, https://libertystreeteconomics.newyorkfed.org/2023/02/how-much-can-gscpi-improvements-help-reduce-inflation/.

c. Baseline Estimation Results

Exhibit 19 contains our baseline estimation results across specifications. The sample period over which each of these regressions are estimated is the same: Q3 2008 – Q4 2022. The dependent variable in each specification is year-over-year core PCE inflation. Specification (1) regresses year-over-year core inflation in quarter *t* on the delivery times index in the same quarter, the unemployment gap in the same quarter, the year-over-year change in the dollar and lags, the year-over-year change in the WTI oil price and lags, as well as lagged terms for core PCE inflation. This specification is frequently used in the literature, but we believe it is mis-specified. In particular, year-over-year inflation is the compounded inflation rate over four quarters, so it is more accurate to regress year-over-year inflation on the lagged four-quarter moving average of the delivery times index. This is what specification (2) does. This change substantially improves the fit of the model, likely because it correctly aligns the periodicity of year-over-year inflation with the delivery times variable. Specification (3) lags the four-quarter moving average for the delivery times variable by one quarter.

Our tests of successive lags identify one quarter as the optimal lag in terms of maximizing the fit of the regression. This lag turns the coefficient on the contemporaneous delivery times moving average negative and insignificant, so we exclude it from specification (3). Across specifications (1), (2) and (3), the coefficient on the delivery times variable rises from 0.46 to 0.76 and then to 0.90, respectively. Specification (4) swaps out the unemployment gap and uses the job-openings ratio instead. Specification (5) uses the vacancies-to-unemployment ratio in place of the job-openings ratio. Specification (6) uses the CBO output gap measure, in addition to the job-openings ratio. Across these alternative metrics for the labor market and economic slack, the coefficient on the lagged delivery times four-quarter moving average remains highly significant

and economically meaningful. Specification (7) uses the lagged four-quarter moving average for delivery times in the ISM instead of the PMI. Specification (8) uses the New York Fed's GSCPI composite delivery times variable.

Exhibit 19. Regression Results: Importance of Supply Chain Disruptions in Core PCE Y/Y Inflation (Q3 2008 - Q4 2022)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Constant	1.50	2.04	2.34	1.39	1.84	1.68	1.31	2.04
t-stat	*3.35*	*5.94*	*8.06*	*4.95*	*7.46*	*3.83*	*2.99*	*4.58*
PMI	0.46							
t-stat	*5.41*							
PMI (4qma)		0.76						
t-stat		*11.05*						
PMI 4qma,-1)			0.90	0.69	0.79	0.74		
t-stat			*14.17*	*7.80*	*9.74*	*6.73*		
ISM (4qma,-1)							0.93	
t-stat							*5.02*	
GSCPI (4qma,-1)								0.64
t-stat								*4.84*
Unemployment gap (4qma)	-0.08	-0.08	-0.09				-0.01	-0.07
t-stat	*-2.84*	*-2.96*	*-2.97*				*-0.26*	*-1.59*
V/U ratio (4qma)					0.43			
t-stat					*2.43*			
Jobs ratio (4qma)				0.18		0.14		
t-stat				*3.27*		*1.89*		
Output gap (4qma)						0.04		
t-stat						*0.93*		
Dollar	0.06	0.02	0.00	0.01	0.01	0.01	0.04	0.05
t-stat	*5.18*	*2.54*	*0.27*	*1.30*	*1.17*	*0.94*	*3.61*	*4.56*
Dollar (-4)	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.00
t-stat	*0.87*	*1.66*	*1.23*	*1.20*	*0.80*	*1.31*	*0.05*	*0.28*
Dollar (-8)	-0.01	-0.02	-0.02	-0.02	-0.02	-0.02	-0.04	-0.03
t-stat	*-0.59*	*-1.97*	*-2.18*	*-2.36*	*-2.11*	*-2.02*	*-2.62*	*-1.87*
WTI	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01
t-stat	*10.85*	*5.39*	*4.60*	*5.29*	*4.99*	*4.45*	*6.76*	*5.90*
WTI (-4)	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00
t-stat	*0.26*	*-0.84*	*-2.82*	*-1.33*	*-2.37*	*-1.68*	*-3.00*	*-1.18*
WTI (-8)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
t-stat	*1.89*	*0.67*	*0.05*	*-0.49*	*-0.67*	*-0.26*	*-0.97*	*-0.45*
PCE (-4)	0.67	0.42	0.20	0.18	0.17	0.18	0.59	0.13
t-stat	*4.10*	*3.27*	*2.08*	*1.88*	*1.69*	*1.88*	*5.21*	*0.82*
PCE (-8)	-0.52	-0.49	-0.37	-0.28	-0.31	-0.29	-0.38	-0.33
t-stat	*-3.30*	*-3.89*	*-3.19*	*-2.68*	*-2.79*	*-2.73*	*-2.40*	*-2.15*
R2	0.89	0.95	0.97	0.96	0.96	0.97	0.91	0.92
Supply chain ratio	**-8.4**	**29.4**	**73.8**	**41.1**	**53.7**	**47.8**	**25.2**	**65.6**

The key metric in Exhibit 19 is in the bottom row, which shows the contribution to Q4 2022 year-over-year inflation from the delivery times variable. For Specification (1), this contribution is -8.4 percent, meaning that delivery times have fully normalized and – if anything – were pulling down core inflation towards the end of 2022. But as noted previously, this is a function of what we consider a misspecification. The four-quarter moving average in specification (2) has a ratio (that is, the effect of the supply variable on the measured inflation rate) of 29.4 percent, while a one-quarter lag of the four-quarter moving average boosts this ratio to 73.8 percent in specification (3). Across remaining specifications, this ratio fluctuates between 30 and 70 percent. In short, even if the PMI delivery times index have normalized on the surface, they still appear to account for a substantial portion of elevated core inflation through the end of 2022.

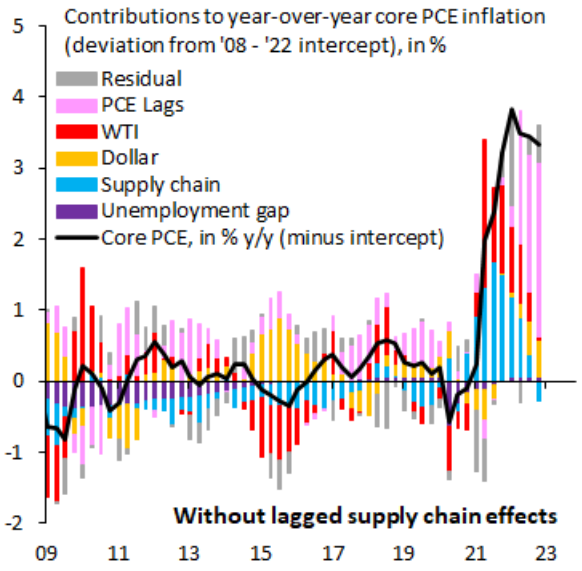

Exhibit 20

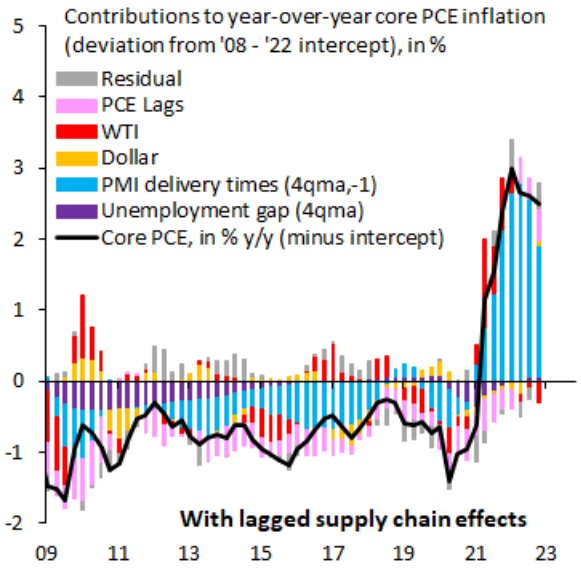

Exhibit 21

Exhibits 20 and 21 show what this looks like graphically. Exhibit 20 shows the contributions from our various right-hand-side variables to year-over-year core PCE inflation in Specification (1) where the PMI delivery times index enters contemporaneously without lags. We show year-over-year core PCE inflation as a deviation from the intercept in our regression. The

chart explains why supply chain disruptions are widely believed to have faded as a driver of core inflation. The impact from stretched delivery times peaked in 2021 and faded to zero towards the end of 2022. The picture looks radically different for specification (3), which is shown in Exhibit 21. The contribution from the delivery times variable explains the bulk of elevated inflation well into 2022, with 70 percent of core PCE inflation linked to the delivery times variable in Q4 2022.

d. Robustness Checks

A key question in the literature is the stability of estimated coefficients. Swings in data were extreme during COVID, which may cause outsized movements in coefficients estimates. To test for coefficient stability, the existing literature has ended the sample period at various points, usually in Q4 2019 before COVID hit. We use rolling regressions with a 15-year time window to examine how variable the coefficients are over time. For the rolling regressions, while our baseline estimation results use a sample period from Q3 2008 – Q4 2022, we use the full sample period of the ISM variable to include as many observations as possible. Similar to Cecchetti et al. (2023),[18] we find that the estimation period in many ways is of greater importance than the exact specification of the Phillips curve.

The lagged ISM variable restricts our estimation period to start after Q1 1963. This time frame captures multiple periods in which delivery times varied. It also includes multiple, large inflation shocks. We run our rolling regressions for the baseline model with year-over-year core PCE inflation as the dependent variable and a lagged four-quarter moving average of the ISM delivery times Z-score and a similar four-quarter moving average for the vacancies-to-unemployment ratio. All other explanatory variables are the same as in specification (3) in Exhibit

[18] Stephen Cecchetti et al., "Managing Disinflations " (USMPF 2023 PAPER, February 24, 2023), accessed March 9, 2023, http://www.chicagobooth.edu/research/igm/usmpf/usmpf-paper.

19, including controls for the oil price, the nominal broad Dollar and persistence in the inflation process. The rolling coefficients for the supply and labor market variables are shown in Exhibit 22 and Exhibit 23, respectively.

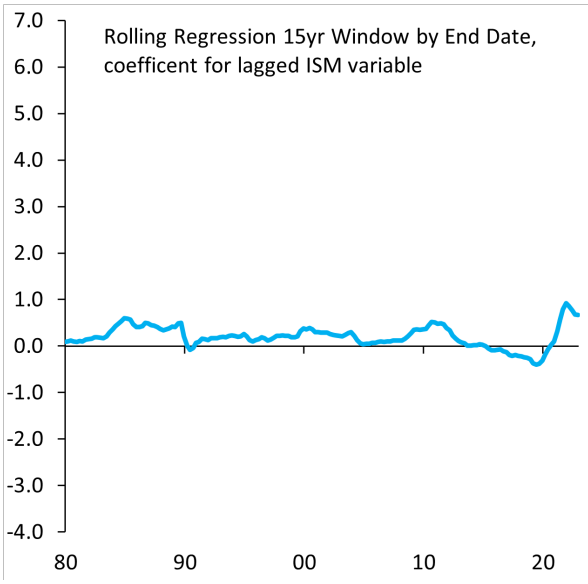

Exhibit 22

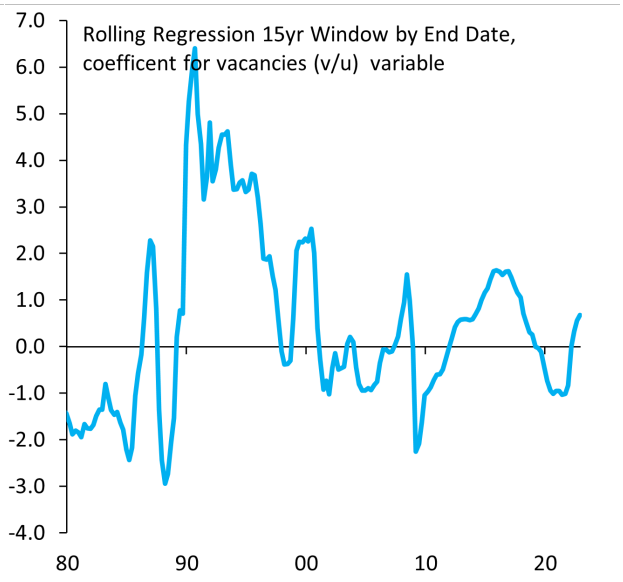

Exhibit 23

Exhibit 22 shows how ending the sample in the period shortly before 2020 results in a much lower coefficient than the historical norm for the supply chain variable, while almost the opposite is true for the labor market variable shown in Exhibit 23. The coefficient for the labor market variable, furthermore, is markedly more variable than that of the supply chain variable. One criticism of our lagged delivery times variable may be that it becomes much larger in the recent inflation period. But this criticism applies just as much to the vacancies-to-unemployment ratio, so we see the time-varying importance of both explanatory variables as a key feature of the COVID shock and not as something that disqualifies them as relevant variables.

Exhibit 24 contains our estimation results across different time periods. The sample period over which each of these regressions is estimated is displayed in the bottom row. As was the case in our baseline results, the dependent variable in each specification is year-over-year core PCE

inflation. Specification 7 is the same as in Exhibit 19. Specification 9 is the same but uses the long sample. The coefficient for the supply chain variable drops in the long sample but remains significant. Importantly, the coefficient on the lagged PCE is higher, partly reflecting the greater role of inflation persistence in the long sample. Specifications 10 and 11 use the vacancies-to-unemployment ratio in place of the unemployment gap, with the former being estimated for the full sample and the latter for a sample ending in Q4 2019. These two estimations show that the vacancies-to-unemployment ratio has a higher coefficient for the shorter sample, overstating the role attributed to labor market tightness in the literature.

Exhibit 24. Regression Results: Importance of Estimation Period in Core PCE Y/Y Inflation

	(7)	(9)	(10)	(11)
Constant	1.31	0.19	-0.16	-0.21
t-stat	*2.99*	*1.43*	*-0.70*	*-0.94*
ISM (4qma,-1)	0.93	0.51	0.45	0.45
t-stat	*5.02*	*3.62*	*2.51*	*2.50*
Unemployment gap (4qma)	-0.01	-0.06		
t-stat	*-0.26*	*-1.35*		
V/U ratio (4qma)			0.49	0.55
t-stat			*1.35*	*1.51*
Dollar	0.04	-0.01	-0.01	-0.01
t-stat	*3.61*	*-0.95*	*-1.06*	*-0.93*
Dollar (-4)	0.00	0.03	0.02	0.02
t-stat	*0.05*	*1.92*	*1.67*	*1.79*
Dollar (-8)	-0.04	-0.04	-0.04	-0.04
t-stat	*-2.62*	*-3.19*	*-3.22*	*-3.12*
WTI	0.01	0.01	0.01	0.01
t-stat	*6.76*	*5.72*	*5.70*	*5.08*
WTI (-4)	-0.01	0.01	0.01	0.01
t-stat	*-3.00*	*1.85*	*2.00*	*2.18*
WTI (-8)	0.00	-0.01	-0.01	-0.01
t-stat	*-0.97*	*-2.85*	*-2.71*	*-2.85*
PCE (-4)	0.59	0.93	0.89	0.93
t-stat	*5.21*	*10.05*	*8.16*	*7.93*
PCE (-8)	-0.38	0.00	0.04	0.01
t-stat	*-2.40*	*0.05*	*0.40*	*0.13*
R2	0.91	0.90	0.91	0.91
Time Period	**Q3 '08 - Q4 '22**	**Q1 '63 - Q4 '22**	**Q1 '63 - Q4 '22**	**Q1 '63 - Q4 '19**

In sum, the estimated coefficient on the delivery times variable becomes much larger and more significant during the COVID shock. But the vacancies-to-unemployment ratio displays similar variability and this variability likely reflects genuine information inherent in the COVID shock.

IV. International Comparison

Returning to the broader point about the underlying causes of inflation, which should inform the stance of monetary policy, the experience of other countries may be informative. Other G10 countries have also experienced a surge in inflation. To the extent that inflation in these countries has tended to co-move with the United States, that would underscore the role of supply factors during COVID, since fiscal stimulus has varied substantially across countries. Indeed, while the manufacturing and shipping disruptions we describe in the sections above have similarly impacted the majority of G-10 countries, there has been significantly more variation across countries in the extent of demand-side factors.

To examine the degree of co-movement in inflation between the United States and the rest of the G10, we regress core year-over-year inflation on a time dummy, to capture the differences in co-movement between the pre-COVID Q1 2006 and Q4 2019 period, and the COVID/post-COVID period between Q1 2020 and Q4 2022. Below we show the summary outputs of the regression (Exhibit 25), which suggest that joint factors in core inflation across the G10 accounted for over a third of the change in inflation over the period. In the pre-COVID period, no similar effect is observed.

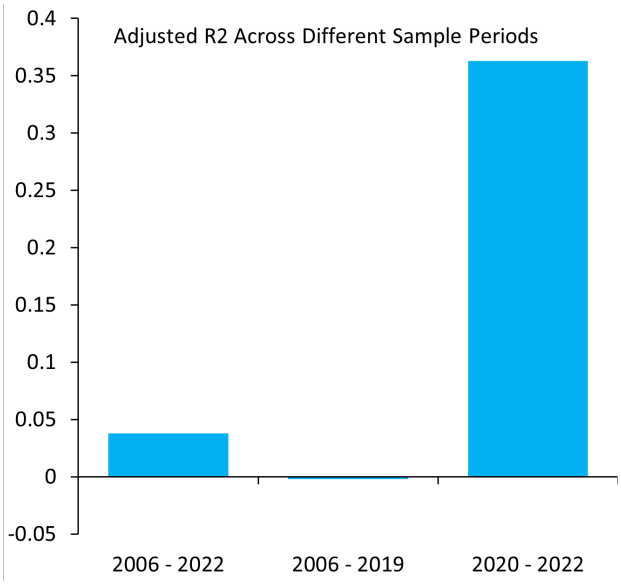

Exhibit 25

Several recent studies corroborate the importance of supply pressures in shaping inflation across the G10. Shapiro (2022) quantifies the impact of supply versus demand factors on PCE inflation, finding that supply factors explain nearly half of the COVID surge in inflation, while demand factors explain around a third of the surge.[19] An OECD study (2022) replicates Shapiro and the San Francisco Fed's methodology across eight countries and finds that supply-driven inflation accounted for roughly half of total inflation on average, but well over half in Denmark, Korea and Sweden.[20] Pasimeni (2022) observes that the attribution of euro area inflation points to pronounced contributions from goods versus services, with the concentration of inflation in high import-content goods tending to favor the hypothesis that a global supply disruption is driving the

[19] Shapiro, Adam Hale. 2022. "Decomposing Supply and Demand Driven Inflation," Federal Reserve Bank of San Francisco Working Paper 2022-18. Available at https://doi.org/10.24148/wp2022-18

[20] OECD, *OECD Economic Outlook, Volume 2022 Issue 2: Preliminary Version*, OECD Economic Outlook (OECD, 2022), accessed March 16, 2023, https://www.oecd-ilibrary.org/economics/oecd-economic-outlook/volume-2022/issue-2_f6da2159-en.

majority of inflation (with as much as 80 percent of producer price increases being driven by supply factors).[21]

Our conclusion from the international experience is consistent with the broader framework above, that the role of supply disruptions in driving inflation has likely been significant, and that in the face of uncertainty about the impact and timing of how the end of those disruptions affect disinflation, monetary policy tightening should proceed gradually rather than rapidly.

V. Review of Prior US Inflation Episodes

Our empirical analysis is constrained by the availability of data like the manufacturing PMIs, which start for the United States only from 2007. We therefore here provide a longer historical overview, looking at past high inflation episodes since around World War I. Exhibit 26 presents annual CPI inflation from 1914 through 2022. The U.S. has experienced at least six major bursts of inflation over this period: 1) the aftermath of World War I; 2) the years after World War II; 3) the years during the Korean War; 4) the oil shock in the early 1970s; 5) the oil shock in the early 1980s; and 6) the current COVID inflation spike. In every prior episode, inflation subsided within a few years. This section investigates why inflation fell and what this might tell us about the current episode.

[21] Paolo Pasimeni, "Supply or Demand, That Is the Question: Decomposing Euro Area Inflation," *Intereconomics* 57, no. 6 (December 16, 2022): 384–393, accessed March 16, 2023, https://link.springer.com/10.1007/s10272-022-1092-z.

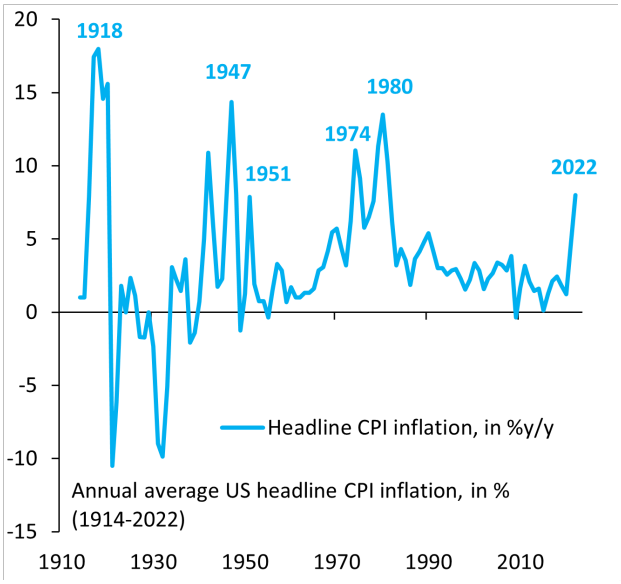

Exhibit 26

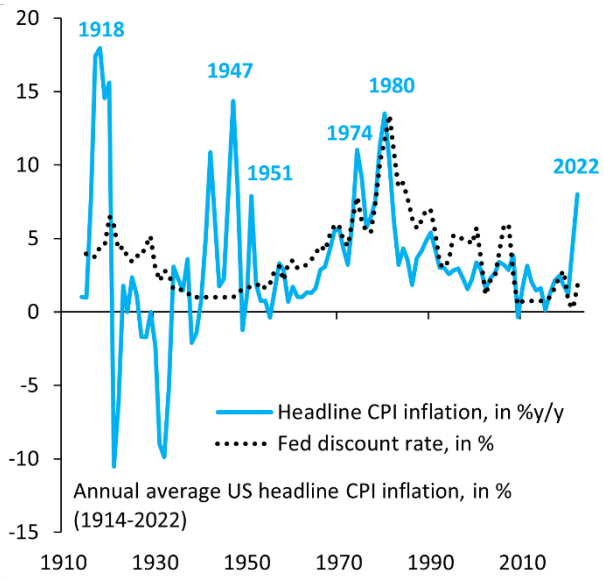

Exhibit 27

Arguably, the episodes most favorable to our perspective are the post-WWII and Korean War ones. This is because inflation subsided then without aggressive interest rate hikes, though changes to reserve requirements were implemented to cool demand. We consider neither episode a particularly useful gauge for post-COVID high inflation, however. The composition of the CPI basket has shifted substantially towards services since then, which makes the behavior of inflation during those episodes quite different from what can be seen today. During the oil shocks in the late 1970s and early 1980s, services inflation was roughly comparable as a driver to today (Exhibit 28). However, those episodes had highly unstable inflation expectations (Exhibit 29), unlike toay, and those stabilized only after the Volcker disinflation.

In short, the historical experience is not particularly informative for the monetary policy choices facing the United States in the post-pandemic era.

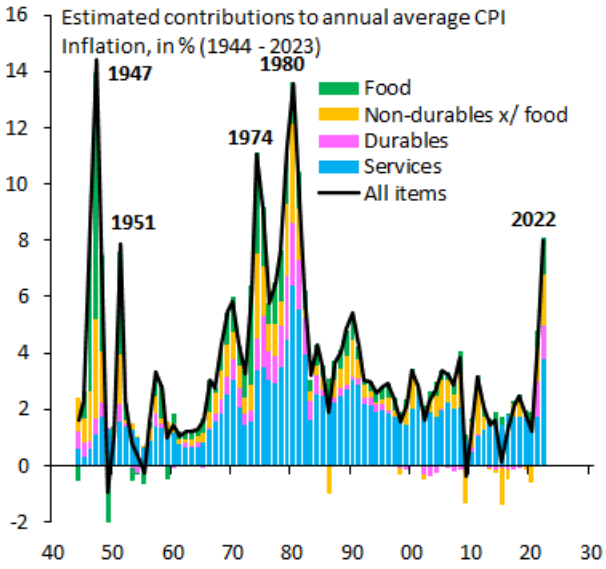

Exhibit 28

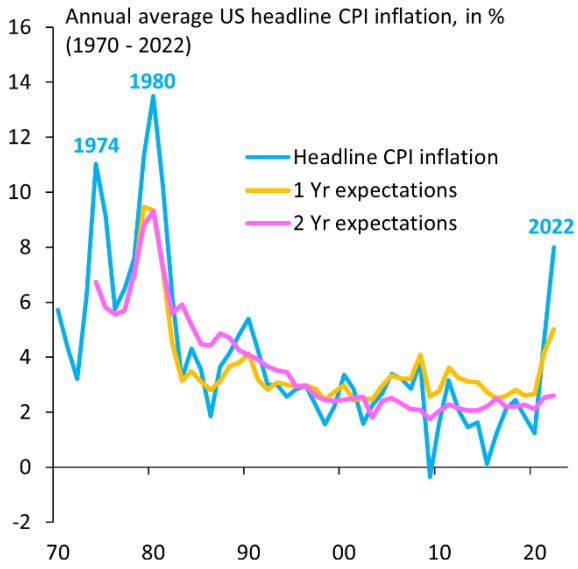

Exhibit 29

VI. Other factors in favor of gradualism

Several other factors point toward gradualism in monetary policy tightening. One is the long and variable lags involved. In response to the surge in US inflation, the Fed has hiked rates eight times over the past year and Fed Chair Powell has reaffirmed the Committee's commitment to remaining restrictive until there is a material fall in inflation towards the Fed target. Commentary from the Fed has emphasized that the committee will take into account "the cumulative tightening of monetary policy, the lags with which monetary policy affects economic activity and inflation, and economic and financial developments" in order to determine the appropriate monetary stance.

Across economic studies, estimates of the lag between monetary tightening and inflation impact are significantly dispersed, with estimates ranging from two quarters to more than eight quarters for the full impact of monetary tightening to flow through to inflation. Newer studies, which Fed Chair Powell (vaguely) referenced during the December 2022 FOMC Q&A, suggest that the lags have shortened materially due to financial conditions responding faster to rate hikes. Miranda-Agrippino & Ricco (2021) found that while prices do not fully adjust on impact when

there is a monetary tightening, they slide down over a few months to reach a trough within the first six months of a monetary policy shock. [22] A recent Kansas City Fed study (Doh & Foerster, 2022) found that since the Global Financial Crisis, the peak response of inflation is larger and happens after four quarters owing to changes in financial market conditions and the transmission mechanism of monetary policy.[23]

Older studies estimate the lag to be much longer. A 2002 Bank of England study (Batini & Nelson, 2002) which examined data from the UK and US for the period 1953–2001 on money growth rates, inflation, and interest rates, found that it takes over a year before monetary policy actions have their peak effect on inflation. [24] Meanwhile, Bernanke et al. (1999) found a two-year lag between policy actions and their main effect on inflation.[25]

Below we show what these varied lags imply about how much of the tightening so far has flowed through to inflation. We make the simplifying assumption that the impact of the rate hikes is linear and, for the chart on the right, we adjust the impact using the magnitude of the rate hikes as a proportion of total rate hikes. Across this range of lag estimates, a significant portion of the Fed's rate hikes have *not* flowed through to inflation so far, from as little as a quarter to as much as three-quarters to-date. Should the reduction in supply pressures begin to translate into a

[22] Miranda-Agrippino, Silvia, and Giovanni Ricco. 2021. "The Transmission of Monetary Policy Shocks." *American Economic Journal: Macroeconomics*, 13 (3): 74-107.DOI: 10.1257/mac.20180124

[23] Doh, Taeyoung and Andrew Foerster, 2022. "Have Lags in Monetary Policy Transmission Shortened?," Economic Bulletin, Federal Reserve Bank of Kansas City, issue December , pages 1-3, December.

[24] Batini, N., and Nelson, E., (2002). The lag from monetary policy actions to inflation: Friedman revisited. International Finance 4, 381-400.

[25] Bernanke, Ben S., Thomas Laubach, Frederic S. Mishkin, and Adam S. Posen. *Inflation Targeting: Lessons from the International Experience*. Princeton University Press, 1999. https://doi.org/10.2307/j.ctv301gdr.

significant fall in inflation in coming months, the Fed may find that it has over-tightened as the remainder of the rate hike impacts on inflation (and on output) flow through with a lag.

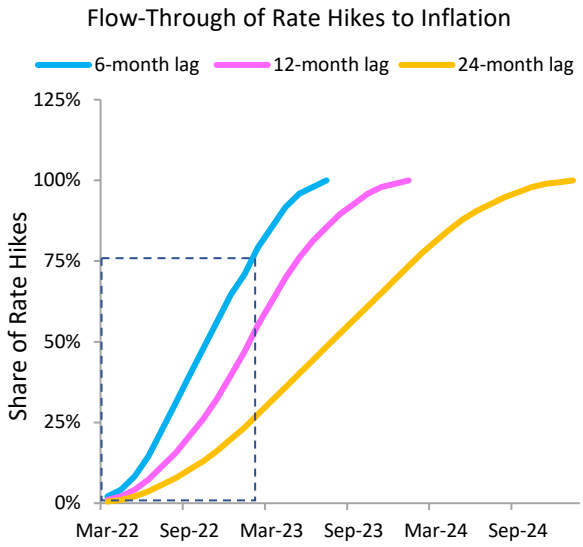

Exhibit 30

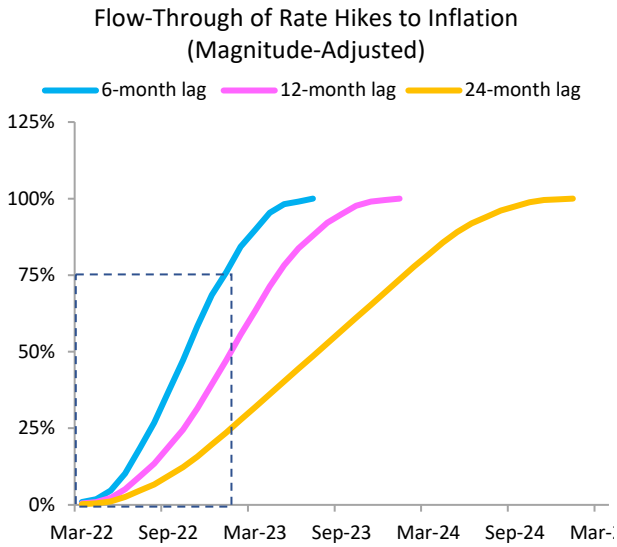

Exhibit 31

A second factor is that the Fed is tightening against a backdrop of waning fiscal stimulus and a high likelihood of a muted fiscal impulse given near-term risks. The charts below show the Brookings measure of fiscal impact on GDP growth. As the US has moved past pandemic stimulus, fiscal policy has turned from a material support, particularly to consumption, to a drag. Of particular importance to the inflation debate is the fading effect of unemployment insurance benefits on consumption. This is likely to be compounded by near-term risks related to the debt limit, as heightened uncertainty around the outcome could lead to more muted government spending as the summer 2022 X date approaches, and the risks of default further tighten financial conditions, which have already tightened materially over the past year. The combined impact of supply-related inflation pressures easing and demand from fiscal support starting to fade will likely result in a material drop in inflation, even without the monetary interventions that are still working their way through the economy.

A final factor tilting toward gradualism is the emerging banking sector crisis. Although one can logically separate the financial stability objectives and tools from the price stability ones, in practice they are linked and impossible to divide neatly into different categories. Put simply, in the face of extreme stress in parts of the banking system, the Fed should tilt further towards going slowly enough in its fight against inflation to avoid "breaking things."

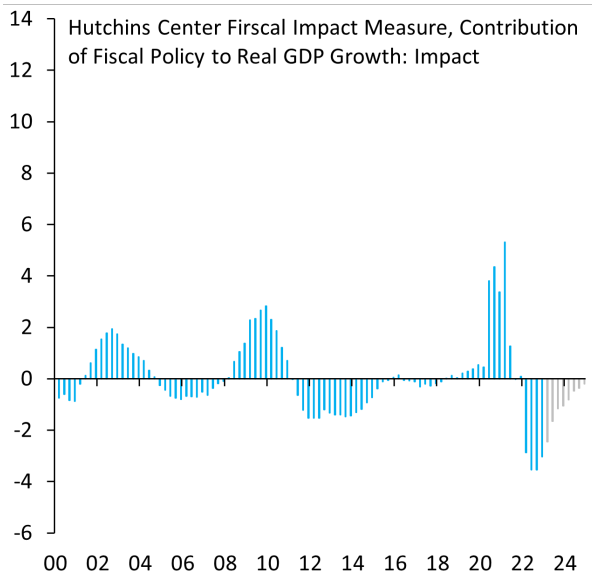

Exhibit 32

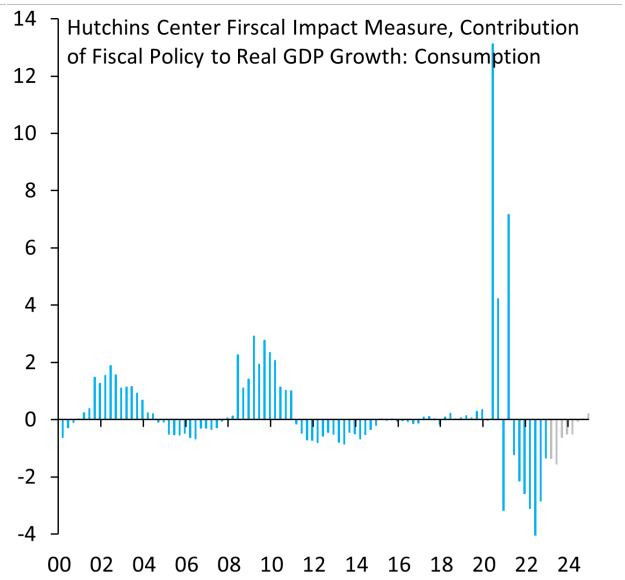

Exhibit 33

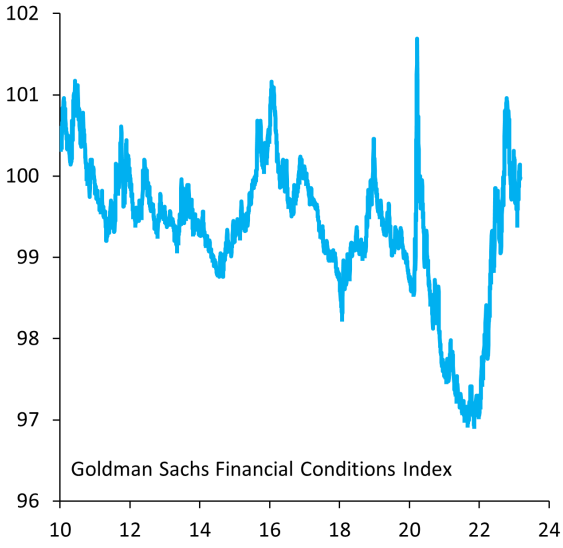

Exhibit 34

VII. Conclusion

In the face of high inflation, how quickly should monetary policymakers adjust to a given terminal rate? Going rapidly may help bring inflation down more quickly. But going rapidly also can pose higher adjustment costs, since the monetary policy shock is more severe and economic actors have less time to adjust.

Our core argument is that when inflation remains in single digits (admittedly a qualitative judgement rather than an empirical one), when the sources of inflation are ambiguous (such as following the pandemic), and when long-term inflationary expectations remain well-anchored (such as they have), going gradually on tightening is better than going faster. Furthermore, we show that there are lags in the empirical relationship between inflation and stretched delivery times, with between 30 and 70 percent of elevated core PCE inflation towards the end of 2022 still attributable to lingering supply chain effects, so that the normalization of supply chains will continue being a disinflationary force in 2023.

The impact of lags in monetary policy, tighter fiscal policy, and the banking crisis also all point toward a "wait-and-see" approach to further hikes. Should further tightening from the Fed be needed, there will be ample time to shift back into hiking mode, given that inflation expectations have not displayed discontinuous moves during the pandemic or in the years before.

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