HONG KONG MONETARY AUTHORITY

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AN ASSESSMENT OF INFLATION-AT-RISK IN THE US

Key points

- *The COVID-19 pandemic has cast considerable uncertainty on the US inflation outlook. It affected both the demand and the supply sides, triggered unprecedented policy easing, and galvanised US efforts to decouple itself from global supply chains. While downside risks to inflation are currently preoccupying the Federal Reserve and the financial market, there are some market concerns about upside risks from aggressive policy easing and de-globalisation.*

- *Using the "Inflation at Risk" (IaR) methodology developed by researchers at the Federal Reserve (Lopez-Salido et al. (2020)), which links current macrofinancial conditions to the distribution of future inflation, this study investigates tail risks to US inflation. Taking into account structural drivers of inflation such as the rise in E-commerce and global trade, we forecast the probabilities of one-year-ahead core CPI inflation, as well as longer-term inflation under different scenarios of policy accommodation and de-globalisation, which helps us quantify the risk of inflation running significantly above target and better understand the potential driving forces behind.*

- *In the near term, the chance of a surge in inflation is limited even in the presence of aggressive policy easing and brisk loan growth, primarily reflecting the highly negative output gap and well-anchored inflation expectations. However, in the longer run when the US economy has recovered from the pandemic-induced recession, IaR suggests that should policy easing, strong loan growth and/or lower global trade be sustained, they could translate into material upside risks to inflation. This study therefore highlights the need for the fiscal and monetary authorities to keep inflation anchored, and serves as a reminder of the potential stagflationary impact of de-globalisation.*

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I. INTRODUCTION

The US economy plunged into recession in March 2020, as lockdown measures to contain the COVID-19 pandemic disrupted production and wreaked havoc in the services sector. The immediate impact of the pandemic has mostly been disinflationary, as the negative supply shock due to disrupted production was met with an even greater decline in demand. The negative demand shock, coupled with other structural disinflationary factors that have been in force before the pandemic (such as the rise in E-commerce and outsourcing), raised concerns of a prolonged period of too-low inflation.

However, *upside* risks to inflation over the longer term should not be overlooked. Many consequences of the pandemic, including outsized fiscal policy easing, the Fed's unprecedentedly large balance sheet that could potentially translate into strong money and credit growth, and emergent de-globalisation trends, could individually and collectively increase inflation risks going forward. Against this background, this study empirically assesses the probabilities of one-year-ahead core inflation, and longer-term inflation under different scenarios of policy accommodation and de-globalisation.

This memorandum proceeds as follows. Section II provides an assessment of the current US inflation situation. Section III lays out the empirical framework on forecasting the probabilities of high inflation under different scenarios. Sections IV and V respectively elaborate on the forecasting of inflation in the near term, and the settings of several scenarios for examining longer-run inflation risks. Section VI provides policy implications and concludes.

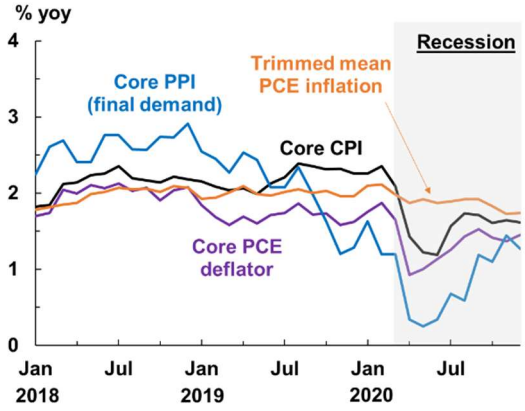
II. LATEST INFLATION SITUATION IN THE US

Various measures of inflation slowed markedly after the COVID-19 pandemic pushed the US economy into recession in March, reflecting the outbreak's immediate disinflationary impact (Chart 1). The slowdown in inflation has been quite broad-based, considering that even price measures based on central tendency, such as the Dallas Fed's trimmed mean PCE inflation rate (orange line), also decelerated in tandem.[1]

[1] Trimmed mean PCE inflation is an alternative measure of "core" inflation. It is constructed by deleting a fixed proportion of extreme price changes within the PCE basket (hence different items may be excluded from calculation from month to month), rendering this measure less susceptible to idiosyncratic prices changes and more indicative of the broader inflation trend.

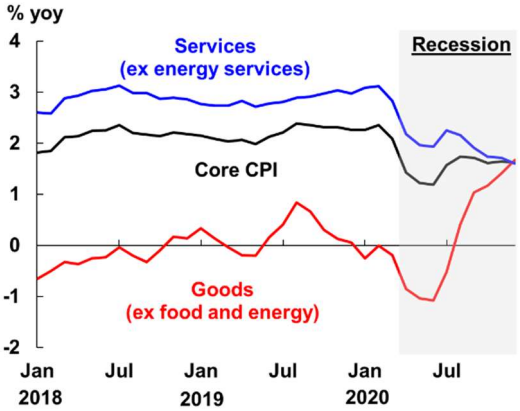
Chart 2 shows the breakdown of core CPI inflation, the subject of this study. It shows that, while core goods inflation (red line) has been picking up more recently[2], overall core inflation (black line) remained below pre-pandemic levels, held down by weakening core services inflation (blue line) which comprised the bulk of the CPI basket and was more heavily affected by social distancing measures, given the more contact-intensive nature of the services sector.

Chart 1: Selected indicators of inflation in the US



Source: CEIC.

Chart 2: Core CPI inflation by major component



Source: CEIC.

In the very near term, while inflation may rise in the coming months due to the base effect, risks to the inflation outlook remain tilted to the downside, particularly given the threats from mutated variants of COVID-19 and the relatively slow progress in inoculating the population against the coronavirus. As the US is being hit with another wave of COVID-19 infections, social distancing and lockdown measures have been tightened in many states since November 2020, which have already been weighing on consumer spending more recently. Indeed, conceivably reflecting its concern over too-low inflation, the Federal Reserve adopted an average inflation targeting framework in August 2020, signalling a "low for longer" monetary policy.

That being said, there are some market concerns about *upside* risks to inflation over the longer term. In response to the pandemic-induced recession, the Treasury and the Federal Reserve unleashed unprecedented fiscal, monetary and liquidity measures to support the economy and forestall disorderly tightening of financial conditions.[3] Corporates, in anticipation of challenging times ahead,

[2] Analysts generally attribute the pickup in core goods inflation to pent-up demand for goods consumption after the March lockdown.

[3] Notable fiscal policy responses included (1) the Coronavirus Preparedness & Response Act, (2) the Families First Coronavirus Response Act, (3) the Coronavirus Aid, Relief, and Economic Security Act (CARES Act), (4) the Paycheck Protection Programme and Healthcare Enhancement Act, and (5) the

rushed to build up cash buffers by drawing down credit lines and tapping the debt market aggressively, leading to surging bank credit and corporate indebtedness. Disruptions to global logistics and a more acrimonious US-China relationship also motivated efforts to reduce US reliance on global supply chains. Each of these recent developments could be potent drivers of inflation risks in the US going forward.

III. ESTIMATING THE PROBABILITIES OF HIGH INFLATION IN THE US

3.1 Introduction to the "Inflation at Risk" methodology

This paper employs the quantitative framework developed by two researchers at the Federal Reserve (Lopez-Salido et al. (2020)), known as "Inflation at Risk" (IaR), to assess the risks of a significant pickup or decline in US inflation over different time horizons.[4] While standard econometric techniques such as ordinary least squares (OLS) may be used to predict future inflation, they can only provide an estimate of the conditional mean of the variable of interest (US CPI inflation in our case), while for surveillance purposes it is often much more useful to characterise the variable's entire probability distribution.

The IaR methodology involves two steps (see Annex). First, we estimate quantile regressions of future CPI inflation against a set of explanatory variables (details to be provided in the next sub-section). Second, the estimated percentiles are used to fit a probability distribution of future inflation. In essence, instead of predicting the mean of inflation as in OLS, IaR predicts the entire probability distribution of future inflation and examines how the distribution would shift along with the explanatory variables. In this way, IaR allows us to make statements in the form of

Consolidated Appropriations Act. The IMF estimated that the total (i.e. above- and below-the-line) fiscal expenditure arising from these measures amounted to as much as 16.7% of GDP. At the same time, by virtue of the authority vested under Section 13(3) of the Federal Reserve Act, the Fed implemented various lending programmes and liquidity facilities in response to intensified stresses in several segments of financial markets.

[4] The idea of "Inflation at Risk" could be further traced back to the "Growth at Risk" framework introduced by the IMF. The term "at-risk" originates from the concept of "value-at-risk", which measures the left (right) tail risks of a significant decline (surge) in a financial variable, commonly defined as the 5th (95th) percentile of the forecasted distribution. Presad et al. (2019) provides an introduction to "Growth at Risk" and how this tool can be used for macro-surveillance purposes.

"N quarters from now, inflation is expected to exceed / fall below x% year-on-year with a probability of y%, given the assumed initial values of the explanatory variables"

A benefit of IaR is that it allows us to examine more extreme scenarios. Indeed, given that US inflation has been fairly stable since the Great Moderation, standard regression techniques may not be able to uncover the tail risks to inflation. IaR, on the other hand, can capture potential non-linearities of the response of inflation to changes in the underlying macrofinancial determinants.

3.2 Determinants of inflation in IaR

Following the inflation forecasting literature, we use the following popular set of cyclical and structural explanatory variables in the quantile regressions for future inflation.[5] The inclusion of selected structural factors of inflation helps us better capture the notion of a "flat Phillips curve", i.e. reduced responsiveness of inflation to resource slack in the post-GFC era, which should allow our model to generate more realistic predictions of future inflation than by considering cyclical factors alone. By "shocking" one or more of these variables based on assumptions of future policy developments, we can conduct scenario analysis on how changes to these variables would affect the probability distribution of future inflation.

Cyclical factors

- *Inflation expectations*: Theoretical and empirical research finds that the public's expectations of future inflation have a strong influence on actual inflation — in other words, higher inflation expectations tend to translate into higher actual inflation. This study uses the mean 4-quarters-ahead expected headline CPI inflation from the Philadelphia Fed's Survey of Professional Forecasters (SPF) as a proxy of inflation expectations.[6]

- *Fiscal balance*: Net government surplus (+) / deficit (-) as a percentage of nominal GDP. A more positive fiscal balance indicates a tighter fiscal policy stance, which tends to dampen inflationary pressure.

[5] The sample period of the quantile regressions is between Q1 1983 and Q4 2020 (both quarters inclusive). We choose this starting point because economists generally regard the early 1980s as the beginning of the "Great Moderation", a regime shift towards reduced macroeconomic volatility.
[6] We do not use the expected core CPI inflation rate because data for this indicator are available only from 2007 onwards.

- *Broad money*: Outstanding broad money supply (M2) as a percentage of nominal GDP. A larger stock of broad money supply indicates more accommodative monetary conditions, which could be more inflationary.

- *Bank credit*: Outstanding loans by private depository institutions as a percentage of nominal GDP. This variable is included to examine whether a surge in bank loans (such as in case the banking sectors' excess reserves were to be suddenly released into the real economy as loans) could result in higher inflation risks, above and beyond the impact from existing money stocks.

- *Output gap*: Deviation of actual output from potential output, expressed as percentages of potential output, as estimated by the Congressional Budget Office (CBO). A more negative output gap suggests the presence of greater resource slack, which tends to weigh on inflation.

- *Import price deflator:* The year-on-year change in the implicit price index for imports of goods and services, included to capture the impact of imported inflation.

- *Effective Fed funds rate (EFFR)*: A proxy of the Fed's (conventional) monetary policy stance. A lower EFFR suggests an easier monetary policy.

- *Actual inflation*: Since inflation tends to be rather persistent (i.e. it has a high degree of positive autocorrelation), current core CPI inflation can be a useful predictor of future core CPI inflation.

Structural factors

- *E-commerce in retail sales:* The year-on-year change in the share of E-commerce (predominantly online shopping) in overall retail sales, intended to control for the possibility of greater retail market competition having a dampening effect on goods inflation (i.e. "Amazonisation").

- *Global merchandise trade*: The sum of global exports and imports of goods (as a share of global nominal GDP), intended to capture the extent of globalisation, which is commonly thought to represent a secular disinflationary force.

Notably absent from the list of "structural factors" is technological progress, which has been a key driver of the global disinflationary trend over the past few decades. Nonetheless, this factor is eventually excluded in our model due to two considerations:

1. In some sense, the E-commerce variable has already partly captured the pace of technological progress, given that the improvement in computer technologies and the rising Internet penetration rate play a pivotal role in supporting the growth of the online shopping industry.

2. There is no clear consensus on how best to measure technological progress. For instance, the estimation of Total Factor Productivity (TFP) is sensitive to the specification of production functions, and relies on the availability of time-series data on capital stock, which can only be obtained by estimation (e.g. the perpetual inventory method). Alternative measures of technological progress, such as hedonic pricing or patent data, also come along with their unique challenges.[7] On a more practical level, many of these measures of technological progress are not readily available at quarterly frequencies, and could therefore be difficult to be incorporated into our IaR model.

IV. ASSESSING INFLATION TAIL RISKS IN THE NEAR TERM

4.1 Empirical settings

This section examines risks to the near-term US inflation outlook. We apply IaR to estimate the probability distribution of 4-quarters-ahead year-on-year change in core CPI inflation, using the latest actual data available up to Q4 2020 (green column, Table 1). To put these figures into perspective, their most recent 20-year (2000 – 2019) averages are also provided for comparison (grey column, Table 1).[8]

[7] The hedonic pricing approach (see, for example, Saviotti (1985)) attempts to break down observed price changes of a commodity into "pure price effect" and "quality / technological change effect". However, this approach implicitly assumes a competitive market, but in reality technological products are typically sold in monopolistically competitive markets where producers can charge a markup. Meanwhile, patent statistics allows for measurement of technological advances even before the actual emergence of new products / services, but is subject to a number of limitations for use as a time-series indicator, such as requiring the assumption that the quality of an average patent remains stable over time. See Basberg (1987) for a review of literature.

[8] With the exceptions of (1) growth in the share of online shopping in retail sales and (2) global trade / GDP ratio.

Table 1: Values of the underlying factors of IaR

	Latest (Q4 2020) value	Long-run (2000 – 2019) average
Inflation expectations	2.1%	2.2%
Fiscal balance / GDP	-30.0%[#]	-4.2%
M2 / GDP	88.5%	58.0%
Bank credit / GDP	54.4%	51.4%
Output gap	-2.9%	-1.6%
Import price deflator	-1.1%	1.2%
EFFR	0.1%	1.8%
Core CPI inflation	1.6%	2.0%
E-commerce in retail sales	26.1%[+]	NA[&]
Global trade / GDP	43.0%	NA[&]

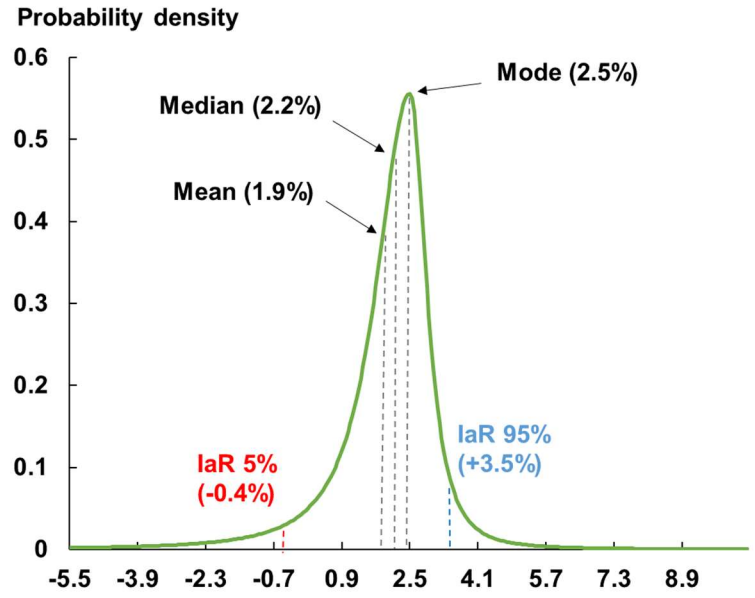
Notes:
[#] Actual value in Q2 2020. In our specification, we introduced a two-quarter lag on the fiscal balance variable to achieve a better statistical fit.
[&] Given that global trade and E-commerce are indicators of structural development, it is not meaningful to consider their historical averages.
[+] Latest value as of Q3 2020.
Sources: CEIC and HKMA staff calculations.

The figures in Table 1 suggest the presence of two opposing forces to the US inflation outlook. On one hand, the US economy is now facing a larger-than-average negative output gap (-2.9% vs. -1.6%), which can be expected to dampen inflationary pressure in the near term. On the other hand, fiscal deficit, money supply and bank credit are now well above their long-run averages because of the pandemic (items 2 – 4, Table 1), raising market concerns over upside risks to future inflation. Nonetheless, expected inflation (latest: 2.1%) remains close to the Fed's target and long-run averages (2.2%), testament to well-anchored inflation expectations.

4.2 Empirical findings

Chart 3 shows the estimated probability distribution of 4-quarters-ahead core CPI inflation, using actual data available up to Q4 2020. It shows that core inflation is expected to come in at around 2% (mean: 1.9%; median: 2.2%) in Q4 2021, and the distribution is somewhat left-skewed, with about 6.4% probability of core CPI inflation falling below zero. Considering the leftmost and rightmost 5th percentile, the corresponding 5% and 95% IaR are -0.4% and 3.5% respectively (i.e. there are 5% probability for inflation to fall below -0.4% or rise above 3.5% respectively).

Chart 3: Predicted probability distribution of 4-quarters-ahead (i.e. Q4 2021) core CPI inflation, based on actual data up to Q4 2020



Source: HKMA staff estimates.

Generally speaking, our findings suggest that upside risks to US inflation are likely to be limited in the near term, even in the presence of well-above-average money supply, bank loans and fiscal deficits (please refer to the relevant rows in Table 1). These benign findings could be explained by several factors, including: (1) well-anchored inflation expectations, (2) the highly negative output gap currently experienced by the US economy, and (3) historical experience suggesting that inflation is usually not responsive to money or loan growth in the short run, especially when inflation is running low (reflected by the 10th and 25th percentile regression coefficients associated with M2 and bank loans, as shown in Annex).

V. ASSESSING INFLATION TAIL RISKS IN LONGER RUN UNDER VARIOUS SCENARIOS

5.1 Setting of baseline case and scenarios

In this section, we repeat the IaR exercise as in Section IV, but with three major differences. First, instead of using the most recent actual values as starting points, we use the historical averages of each explanatory variable, as a broad-brush attempt to characterise the state of the US economy under "normal"

circumstances. Second, we consider five scenarios involving varying degrees of policy accommodation and / or de-globalisation to investigate their potential impact on US inflation. Third, because the short-run impact of changes in structural variables (such as global trade) is quite small, we lengthen the forecasting horizon from four quarters to eight quarters, doing so would also better capture the longer-term prospect for inflation. With these changes in mind, we describe the baseline case and the five scenarios to be considered:

- Baseline: Projection of 8-quarter-ahead core CPI inflation (% yoy) using the historical averages of each explanatory variable as starting points (with the exceptions of global trade and growth of E-commerce in retail sales, where their latest actual observations in 2020 are used here, as an implicit assumption that the degree of globalisation and the prevalence of online shopping will maintain their current scale going forward). The assumed values for each explanatory variable are provided in Table 2.

Table 2: Values of the underlying factors of IaR in baseline case

Variable	Assumed value	Justification
Inflation expectations	2%	Assuming the Fed is successful at anchoring the public's inflation expectations at its target
Fiscal balance / GDP	-4.2%	Long-run (2000 – 2019) average
M2 / GDP	58.0%	Long-run (2000 – 2019) average
Bank credit / GDP	51.4%	Long-run (2000 – 2019) average
Output gap	-1.6%	Long-run (2000 – 2019) average
Import price deflator	1.2%	Long-run (2000 – 2019) average
EFFR	2.5%	FOMC's longer-run expectations
Core CPI inflation	2.0%	Long-run (2000 – 2019) average
E-commerce in retail sales	26.1%	Latest (Q3 2020) value[#]
Global trade / GDP	43.0%	Latest (2020) value[#]

(#) Note: Given that global trade and E-commerce are indicators of structural development, it is not meaningful to consider their historical averages in this context.
Sources: CEIC and HKMA staff calculations.

- Scenario 1 (*Accommodative monetary policy*): Same as baseline, except we assume a more accommodative monetary policy stance. Specifically, we assume the M2/GDP ratio to stay at the pre-COVID high of **72.4%** in Q1 2020, during which the effective Fed funds rates averaged **1.35%**. In comparison, the baseline values of M2/GDP and EFFR are 58.0% and 2.5% respectively.

- Scenario 2 (*Scenario 1 plus strong growth in bank loans*): In addition to the assumptions in Scenario 1, we further assume bank loans to grow at the robust pace as in Q1 2020 (+4.9% qoq), during which companies aggressively drew down their existing credit lines to build up cash buffer in anticipation of recessions ahead. Such a quarterly loan growth rate implies a bank loan / GDP ratio of **61.1%**, as opposed to the baseline of 51.4%.

- Scenario 3 (*Scenario 2 plus accommodative fiscal policy*): On top of the assumptions in Scenario 2, we further assume the continuation of a highly accommodative fiscal policy. More specifically, we assume that the US government will maintain its existing level of spending on COVID-related emergency support, except that it does not renew the Paycheck Protection Programme. This would imply a fiscal balance of -**12.2%** of GDP, somewhat smaller than the actual FY2020 deficit of -14.9% but still significantly larger than the baseline of -4.2%

- Scenario 4 (*Scenario 3 plus unanchored inflation expectations*): Building upon Scenario 3, this scenario further assumes that the inflation expectations become unanchored, possibly due to the Fed's persistently large balance sheet and the lack of a credible path towards restoring fiscal discipline. More specifically, we assume the 1-year-ahead inflation expectations to rise to **4.8%** (the 90th percentile of SPF results in Q3 2008), as opposed to the baseline of 2.0%.

- Scenario 5 (*Scenario 4 plus de-globalisation*): In addition to all assumptions incorporated into Scenario 4, we assume global trade (as % of global GDP) to fall from the baseline value of 43% in 2020 to **29.3%** in 1991 (the lowest in our sample period), as a crude approximation of what might happen to global trade should heightened US-China trade tensions result in a generalised US decoupling from global supply chains. Table 3 summarises the values of underlying factors in the baseline case and in the scenarios.

Table 3: Summary of values of the underlying factors of IaR (in baseline case and scenarios)

	Baseline (Copied from Table 2 for easy reference)	Scenario 1 (Easy monetary policy)	Scenario 2 (Scenario 1 + Loan expansion)	Scenario 3 (Scenario 2 + Fiscal expansion)	Scenario 4 (Scenario 3 + Unanchored inflation expectations)	Scenario 5 (Scenario 4 + De-globalisation)
M2 / GDP	58.0%	72.4%	72.4%	72.4%	72.4%	72.4%
EFFR	2.5%	1.35%	1.35%	1.35%	1.35%	1.35%
Bank credit	51.4%	51.4%	61.1%	61.1%	61.1%	61.1%
Fiscal balance	-4.2%	-4.2%	-4.2%	-12.2%	-12.2%	-12.2%
Inflation expectations	2%	2%	2%	2%	4.8%	4.8%
Global trade / GDP	43.0%	43.0%	43.0%	43.0%	43.0%	29.3%
(Variables not subject to shocks)						
Output gap	-1.6%	-1.6%	-1.6%	-1.6%	-1.6%	-1.6%
Import price deflator	1.2%	1.2%	1.2%	1.2%	1.2%	1.2%
Core CPI inflation	2%	2%	2%	2%	2%	2%
E-commerce growth	26.1%	26.1%	26.1%	26.1%	26.1%	26.1%

Note: Boxes shaded in purple denote variables that have been changed compared with the preceding scenario.
Source: HKMA staff estimates.

5.2 Empirical findings

Table 4 shows our findings on the baseline case and the five scenarios, assuming the US economy has returned to "more normal" conditions. While our baseline case suggests that longer-run core CPI inflation is expected to remain broadly consistent with the Fed's mandate of price stability (mean: 2.2%, median: 2.3%), the scenarios show that persistent monetary expansion, credit growth and fiscal expansion can each increase the longer-term upside risks to US inflation materially.

Focussing on the last (orange) row of Table 4, even only maintaining a large money stock (scenario 1) could push up the probability of inflation overshooting 3% from 16% in the baseline case to over 30% in scenario 1. Applying the same argument, we see that strong bank loan growth, fiscal expansion, unanchored inflation expectations and de-globalisation can each be a potent driver of inflation, highlighting the need for fiscal and monetary authorities to remain nimble in timing their exits from the extraordinary policy accommodation. These findings also underpin the utmost importance in keeping

inflation expectations well-anchored, and reflect the role of anchored inflation expectations in contributing to the low inflation over the past few decades.

Finally, by comparing scenarios 4 and 5, we infer that, on an incremental basis, the inflationary risks from a de-globalisation shock could be highly significant, both in terms of the central tendency of inflation (e.g. mean and median) and also in terms of the right-tail risks (Q90% and Q95%).

Table 4: Summary statistics of probability distributions of future inflation in baseline case and in scenarios

	Baseline	Scenario 1 (Monetary expansion)	Scenario 2 (Scenario 1 + Loan expansion)	Scenario 3 (Scenario 2 + fiscal expansion)	Scenario 4 (Scenario 3 + unanchored inflation expectations)	Scenario 5 (Scenario 4 + de-globalisation)
Q5%	-0.43	1.07	1.59	1.92	3.24	4.57
Q10%	1.08	1.62	2.24	2.62	3.89	5.17
Mean	2.21	2.73	3.39	3.76	4.98	6.29
Median	2.25	2.63	3.39	3.84	4.99	6.26
Q90%	3.38	3.92	4.59	4.92	6.14	7.47
Q95%	3.93	4.67	5.24	5.42	6.74	8.08
Prob. of deflation	3.55	1.87	1.64	1.50	0.73	0.41
Prob. of inflation > 3%	16.02	31.20	69.48	83.70	95.85	98.52

Notes: Q5% / Q10% refer to the left tail 5% / 10% "inflation-at-risk", i.e. there is 5% / 10% probability that future inflation will fall below these values. Q90% / Q95% can be interpreted similarly and represent the right tail 5% / 10% "inflation-at-risk" (i.e. inflation exceeding these values).

Source: HKMA staff estimates.

VI. CONCLUSION

The COVID-19 pandemic has resulted in significant uncertainties over the US inflation outlook. While the present inflation situation is dominated by the negative demand shock, there are some concerns that several recent developments, including the unprecedented policy easing, brisk loan growth and threats to globalisation, could each impose upside risks to the inflation outlook. This paper estimates the probability of significant pickup in core CPI inflation one year ahead, as well as in the longer run under various assumed scenarios of policy accommodation and de-globalisation. We find that the near-term inflation outlook remains benign thanks to well-anchored inflation expectations and because of the negative output gap. In the longer term where the US economy has emerged out of recession, we find that inflation can rise significantly under the tail scenario of persistent policy accommodation and/or sharp de-globalisation trend. This study highlights the need for the fiscal and monetary

authorities to remain vigilant in order to keep inflation anchored, and serves as a reminder of the potential stagflationary impact of de-globalisation.

REFERENCE

Basberg, B. L. (1987). *Patents and the Measurement of Technological Change: A Survey of the Literature*. Research policy, 16(2-4), 131-141.

Lopez-Salido, D., & Loria, F. (2020). *Inflation at Risk.* Finance and Economics Discussion Series 2020-013. Washington: Board of Governors of the Federal Reserve System.

Prasad, M. A., Elekdag, S., Jeasakul, M. P., Lafarguette, R., Alter, M. A., Feng, A. X., & Wang, C. (2019). *Growth at risk: Concept and Application in IMF Country Surveillance*. IMF Working Paper, 19/36.

Saviotti, P. P. (1985). *An Approach to the Measurement of Technology based on the Hedonic Price Method and Related Methods*. Technological Forecasting and Social Change, 27(2-3), 309-334.

Annex: Technical note on the IaR framework

The inflation-at-risk (IaR) framework involves two main steps. The first step is to run quantile regressions of future inflation rate conditional on a selected set of explanatory variables. In the second step, the estimated percentiles obtained from the first step are used to derive the T-skew distribution of the future inflation.

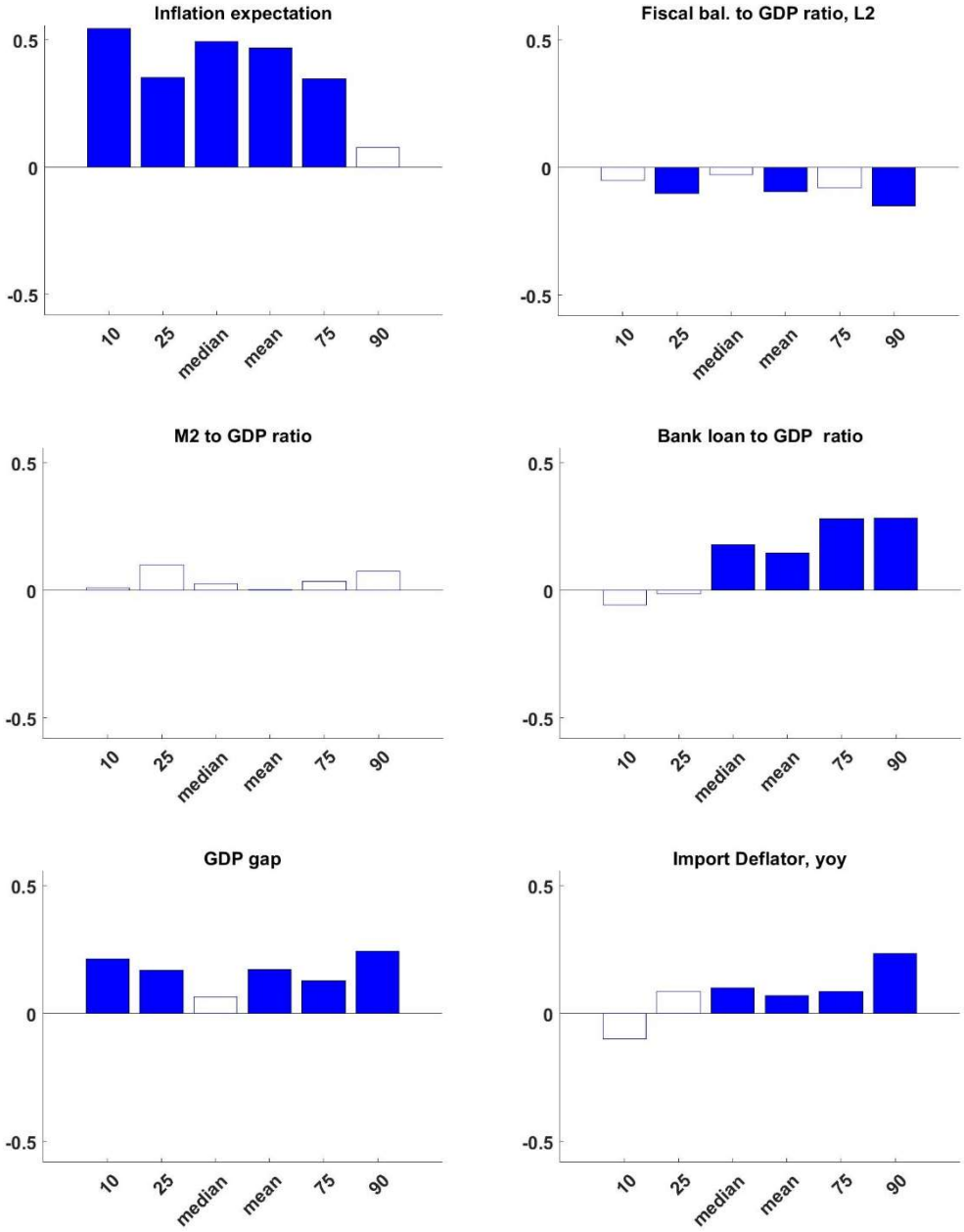
As a first step, conditional quantiles of *n*-period-ahead core CPI inflation are forecasted using quantile regressions, without making any distributional assumptions:

$$Q\left(y_{t+n}, \tau \mid \{X_{i,t}\}_{i \in P}\right) = \alpha^{\tau} + \sum_{i \in P} \beta_i^{\tau} X_{i,t},$$

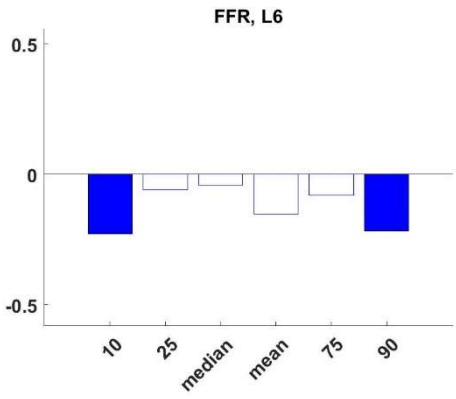
where y_{t+n} is the *n*-period-ahead core CPI inflation, $Q(y_{t+n}, \tau \mid \{X_i\}_{i \in P})$ is conditional quantiles at the level τ, and $\{X_{i,t}\}_{i \in P}$ is a set of variables that have forecasting power on inflation.

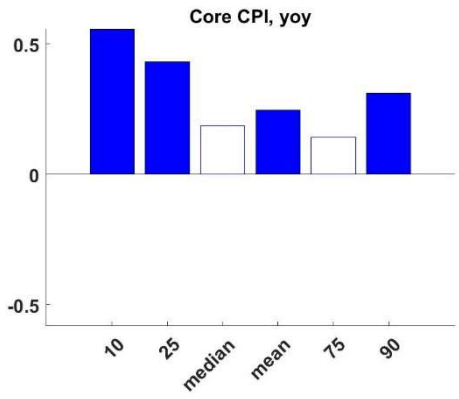
After running the quantile regression for $\tau = \{0.05, 0.1, 0.25, 0.4, 0.5, 0.6, 0.75, 0.9, 0.95\}$, the estimated quantiles are then fitted to the cumulative distribution function (cdf) of a parametric t-skew distribution (which has been proven useful to model tail events), and the results characterise the probability distribution of *n*-quarter-ahead CPI inflation. Since we are focusing on *upside risks* to inflation, the *right* tail of the inflation distribution will be of interest (i.e. 90% and 95% quantiles, meaning that inflation can be above these levels with 10% and 5% probability respectively). The charts on the next page shows the estimated coefficients from the quantile regressions.

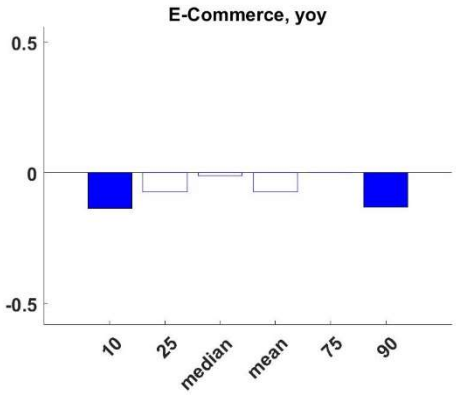
Quantile regression coefficients[9]

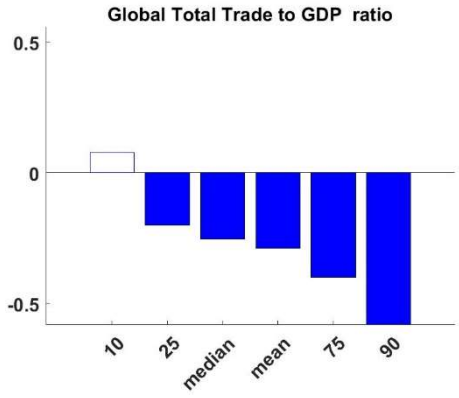


[9] Notes: For the charts in this section, the x-axis shows various quantiles (and the mean). A point estimate that is significant at 10% level is shown by a solid bar, and by a hollow one otherwise. All coefficients are normalised by the regressors' standard deviation and should be interpreted as the marginal effect when the regressor changes by one standard deviation. In each title, we use Ln to denote that a variable is lagged by n period.)


FFR, L6
0.5
0
-0.5
10
25
median
mean
75
90


Core CPI, yoy
0.5
0
-0.5
10
25
median
mean
75
90


E-Commerce, yoy
0.5
0
-0.5
10
25
median
mean
75
90


Global Total Trade to GDP ratio
0.5
0
-0.5
10
25
median
mean
75
90