US Economics Research

US economic tipping points model: Stress testing a stall

- **With mounting evidence of decelerating US payroll employment, we use the *tipping point framework* we introduced in March to investigate the likelihood of the US economy experiencing a stall. The model uses payrolls to estimate the probability of being in various business cycle phases, including "rapid expansion", "expansion", "stall", and "recession", where a stall must precede a recession. We characterize stalls as periods of heightened recession vulnerability.**
- Our view is that slipping into a stall significantly boosts recession risks. According to the model, the probability of experiencing some sort of recession within four quarters is about 10x higher in the stall phase (56%) than in the expansion phase (4.9%).
- Our model places the stall probability in Q3 2019 at about 3% – even when we adjust historical data to reflect downward "benchmark" revisions to payroll employment scheduled for February. Given this small likelihood, the probability of a recession within four quarters is less than 10%.
- However, estimates using only available data do not account for further deterioration in payrolls, which is widely anticipated. To represent this, we use our model to simulate stall probabilities using alternative trajectories of payroll employment through 2020. These simulations show that not much additional slowing is needed to substantially raise recession vulnerability. If private nonfarm payrolls gradually slow to 100k/m by end-2020, as is our baseline scenario, the stall probability rises to nearly 30% by end-2020. In scenarios in which payrolls slow more rapidly, such as to 50k by mid-2020, the probability rises to as much as 85% by end-2020.

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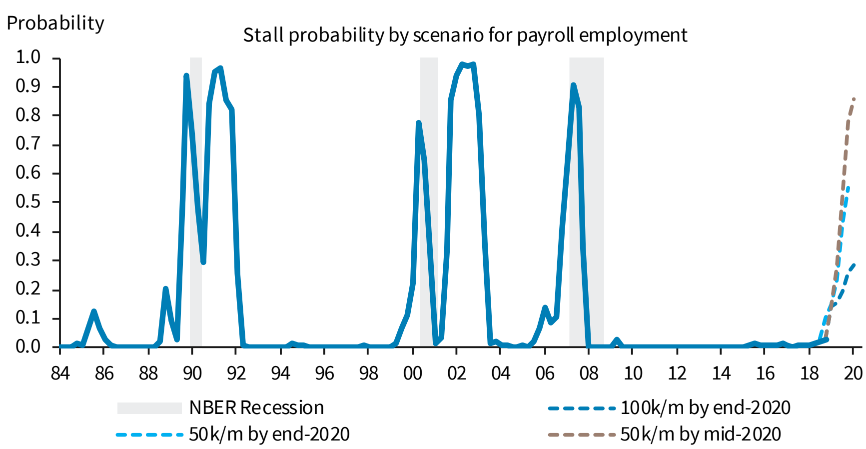
FIGURE 1
Stall risks would intensify with greater deceleration in payroll employment



Source: Barclays Research

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Slowing US payrolls: Soft landing or recession?

One of the most remarkable features of the current US expansion has been the steady expansion of US payrolls. Since the early stages of the recovery, US payrolls have largely increased at a monthly pace of about 200k per month (Figure 2), more than sufficient to push down the unemployment rate even with the steady net inflow of workers into the economy and rebound in participation rates of prime-age workers. Private payrolls have risen in every month since March 2010, a string of 115 consecutive months, the longest such stretch dating to the beginnings of the establishment survey in 1939. This influx has helped anchor the expansion, propelling further gains in aggregate demand through rising household income and spending.

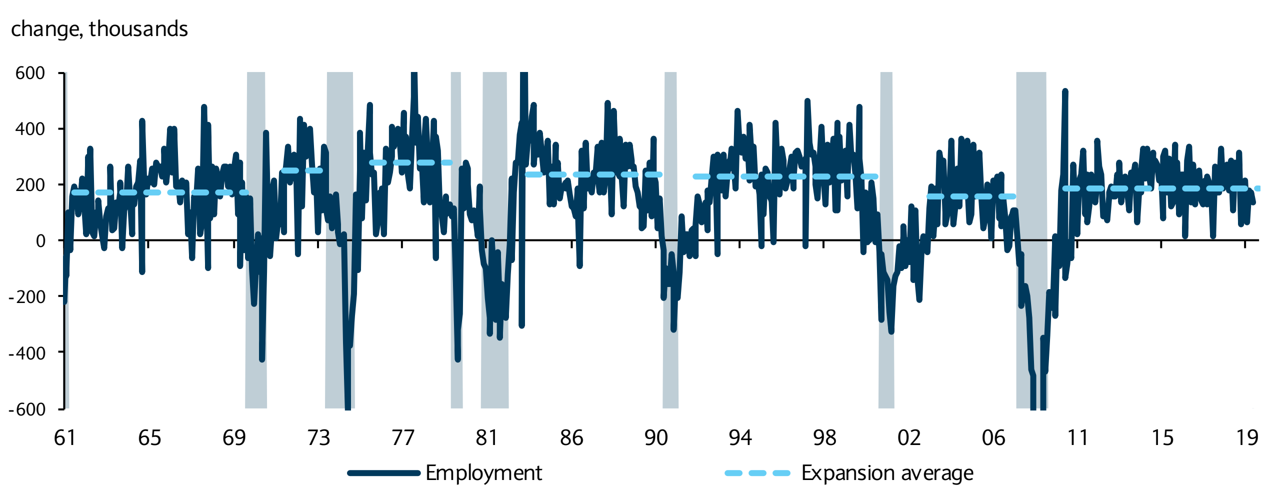
More recently, payrolls gains have shown signs of slowing, with the three-month moving average in September 2019 (157k) down appreciably from the currently published average pace in 2018 (223k) and 2017 (179k). There appears to be widespread consensus among economic forecasters that this slowing will continue given the pressures on aggregate demand from softer global growth, fading fiscal stimulus, trade policy uncertainty, and potential limitations on the supply of additional workers with the unemployment rate (3.5% in September) already at a five-decade low.

In *Recession risk: Labor market data and economic tipping points*, we introduced a new model for assessing US risks that is based on the view that labor market indicators provide strong signals about economic turning points. This is not only a view that we hold, but also one that has been shared in the past by Federal Reserve staff and FOMC participants. The approach of this model is to use data on monthly payroll gains to estimate the probability of being in various business cycle phases, including “rapid expansion”, “expansion”, “stall”, and “recession”, imposing a key restriction that a recession must be preceded by a stall. Assessing the likelihood of the economy being in each of these phases is useful, because recession risks vary notably depending on the phase of the business cycle. (See Box 1, which discusses our modelling approach and its merits in more detail.)

One limitation of our previous work was that it was mainly focused on assessing near-term recession risks, providing little insight about how risks are likely to evolve given projected trends in employment. This is particularly relevant at present, with expectations of further

FIGURE 2

Steady employment growth equals steady expansion



Source: Bureau of Labor Statistics; Barclays Research deceleration in employment in the coming quarters. In this piece, we extend our model framework to assess the risks of stall and recession if reasonable projections for employment growth were to materialize, thereby producing a more complete view of how stall and recession risks are likely to evolve over the medium term.

Among the major new takeaways of our analysis are the following:

- **A stall significantly raises the probability of transitioning into a recession.** Indeed, once the US economy is in the stall phase, the probability of transitioning to a recession within a four-quarter horizon (56%) is about 10x higher than the probability than if the economy is currently in an expansion (4.9%). Faltering employment momentum after a long expansion should not be taken lightly.

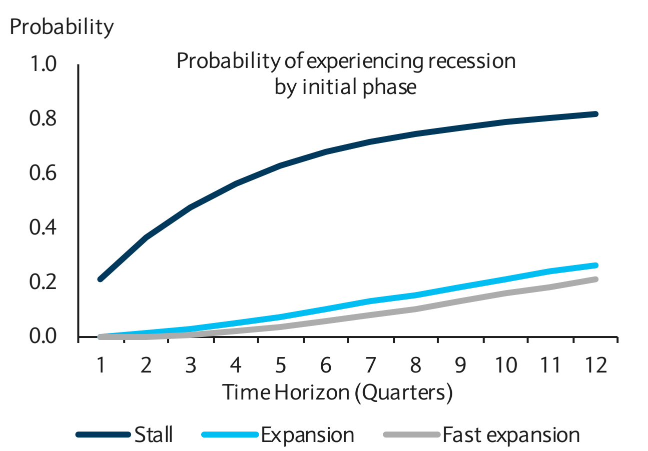
- **Our baseline, which includes slower employment growth, points to risk of a stall.** In our baseline projection, in which monthly payroll employment gains slow to 100k by end-2020, our tipping point framework sees the probability of being in a stall rising to nearly 30% in Q4 2020 from about 3% in Q3 2019.

- **Modestly slower employment gains than in our baseline significantly raise the probability of stall.** Stall risks rise substantially if the slowing in payrolls is more rapid, larger in magnitude, or both, relative to our baseline. For instance, in a scenario in which monthly payroll gains descend to 50k by mid-2020 and then stabilize, our model thinks that the probability of being in a stall would approach 85% in H2 20. Given the historical tendency for stall outcomes to transition to recession, any sharper slowing in employment gains relative to our baseline is likely to cause us concern. The opposite is also true; employment outturns above our baseline point more clearly to an economy that remains in expansion following a short lull.

- **Our preferred estimates incorporate upcoming benchmark revisions to payrolls, which point to higher stall risks.** The BLS has indicated that in February 2020 it will be marking down its estimates of payroll employment from April 18 to March 19 by about 40k/m to reflect more accurate source data (see *Upcoming benchmark revisions imply a significant slowing of US payrolls from early 2018*). Incorporating the preliminary estimate of these revisions into the historical data tends to boost our estimates a fair bit.

FIGURE 3

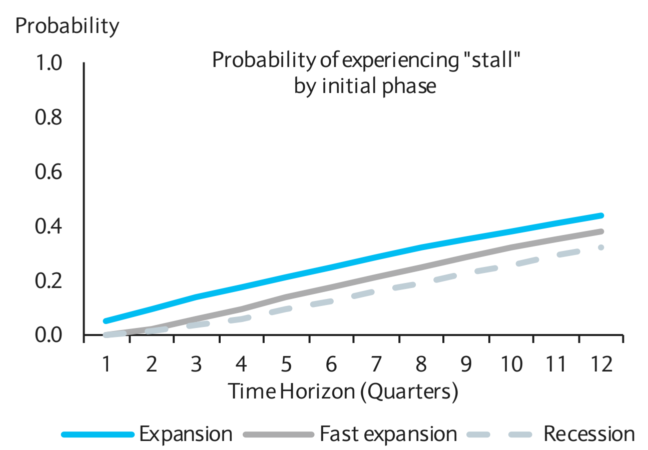
The probability of experiencing a recession varies considerably across initial states of the economy



Note: Probability of transitioning from the given state of the business cycle to recession, over a given number of quarters. For example, if the economy is currently in stall, it is about 56% likely to enter into some sort of recession within four quarters. Source: Barclays Research

FIGURE 4

The model places a relatively low probability on transitioning to a stall from other phases, over medium-term horizons



Note: Probability of transitioning from the given state of the business cycle to stall, by time horizon. For example, if the economy is now in expansion, the likelihood of at least visiting the stall state within the next ten quarters is about 40%. Source: Barclays Research

Our analysis begins by discussing why it is helpful to distinguish between the stall and expansion phases in terms of identifying recession risk. Next, we describe how our model interprets risks using available data through Q3 2019. Finally, we perform some scenario analysis using the model, describing the probability of entering into stall under reasonable alternative projections for payroll growth. Finally, we offer some concluding thoughts.

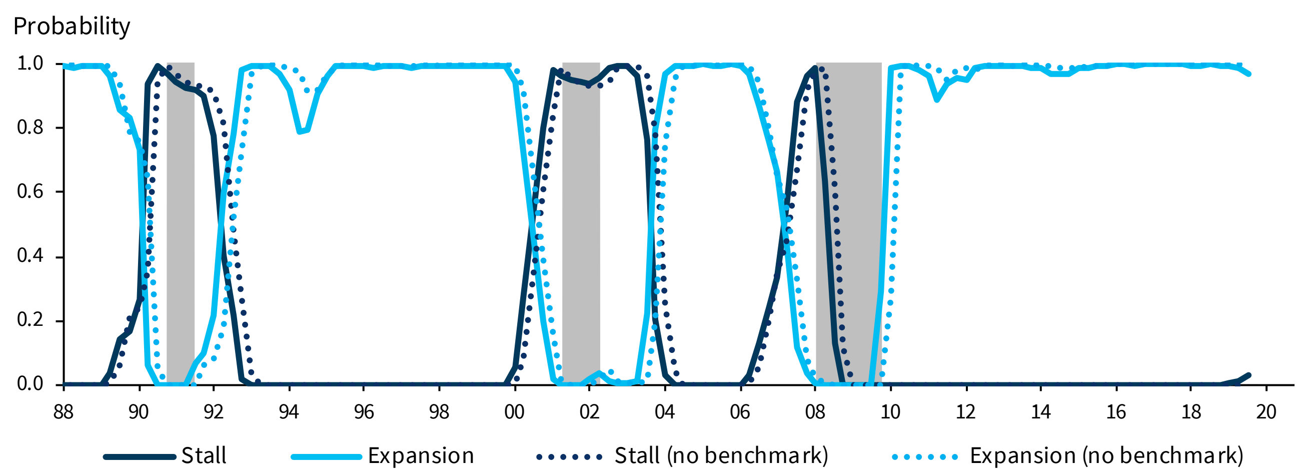
The stall phase and heightened recession vulnerability

We define a stall phase as a state in which the economy has lost some underlying momentum, but the signal from the bulk of incoming data would suggest the economy continues to grow. With this definition in mind, one of the key merits of our approach, relative to most recession probability models, is that it allows us to better distinguish between periods when the economy is clearly expanding versus when it may be losing momentum and, therefore, has increased vulnerability to adverse shocks. In our view, the stall phase identified by our model identifies such periods of vulnerability.

According to our framework, being in a stall phase substantially raises the probability of entering into recession both in the near and medium term. This point is illustrated in Figure 3, which shows the probability of visiting the recession phase within each of the given time horizons shown, starting from the stall phase or from either of the expansion phases. (For a horizon of one period, these probabilities are taken directly from the estimated transition matrix; otherwise, the probabilities are calculated using the procedure described in the Appendix.) As one can see, being in a stall substantially raises the probability of experiencing a recession. For example, for a horizon of four quarters, the probability of visiting the recession phase when starting from the stall state is 56.2%, compared with 4.9% when starting from the expansion state. For a horizon of eight quarters, the probability of experiencing some sort of recession after having entered into stall is 74.4%, compared with 15.4% when starting from the expansion phase. Vulnerability to a recession is much higher in the stall phase because stall is a precondition for a recession, and the model places a relatively low probability on experiencing a stall when it is in other phases (Figure 4).

FIGURE 5

Given available data through Q3 2019, our model currently places low likelihood on the US economy being in a stall



Note: Estimates apply two-sided smoothing. Solid lines include adjustments for upcoming BLS benchmark revisions to previous employment data. The dashed lines use published data without such adjustments. Source: Barclays Research

Note that our model has little to say about whether a recession, if it occurs, will be shallow or deep. Once the economy enters the recession phase, it is expected to transition to other phases according to the probabilities embedded in the estimated transition matrix. Although the model is calibrated so that the mean duration matches the average historical duration in the data (3.7 quarters), the distribution of durations is quite wide, with probabilities diminishing at longer horizons.

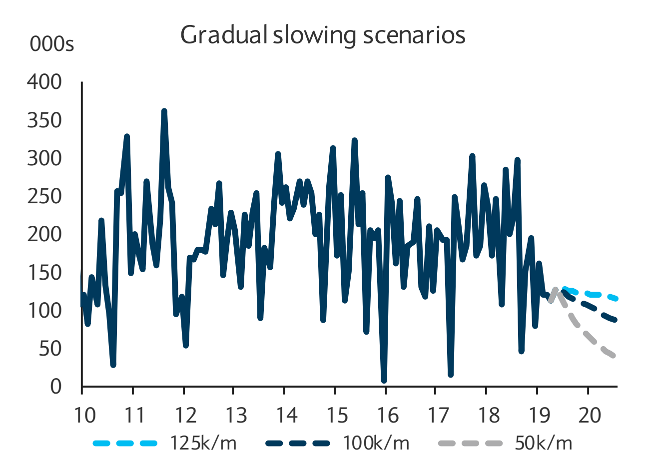
Using available data, our model sees low stall and recession probabilities

Figure 5 shows the evolution of the model's estimates of the economy being in an expansion or stall given available data through Q3 2019, where we run separate versions of the model with (the solid lines) and without (the dashed lines) adjustments for the benchmark revisions. Even though the model indicates that the likelihood of being in a stall has risen a little of late with the recent slowing of monthly payrolls, it currently places the likelihood of being in a stall at only 3%. That is, given the relatively modest slowing in employment growth seen to date, the model does not yet see enough evidence to conclude that these outcomes are inconsistent with what it would expect in an expansion. Intuitively, this is because recent developments are not necessarily inconsistent with historical experience, as it is not uncommon for transitory influences (such as adverse weather, strikes, etc.) to temporarily push payroll growth below the range of outcomes that is generally consistent with an expansion. In light of the ebbs and flows of employment growth seen over the several long expansions in post-WWII experience, the model needs more than just a few months of soft employment to conclude the economy is transitioning to a stall phase. Instead, it needs to see an accumulation of low-growth outcomes that are more consistent with a stall than an expansion.

Given the low stall likelihood in Q3 2019 and the transition probabilities for the expansion phase shown in Box 1, the model concludes that the probability of transitioning by end-2020 to a stall is about 24% and to a recession is less than 10%.[1] However, one reasonable criticism of this inference is that the model does not account for further deterioration in payrolls that we, and a number of other forecasters, anticipate.

FIGURE 6

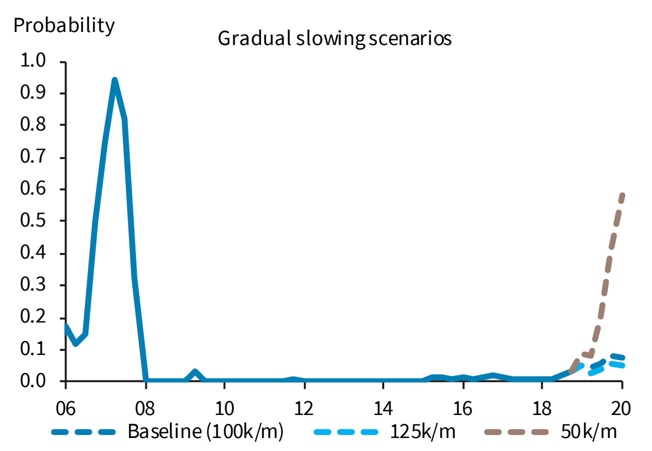
Our "gradual slowing" scenarios have payrolls slowly descending to given levels through Q4 2020



Note: Currently published estimates. Source: Barclays Research

FIGURE 7

The probability of stall is sensitive to relatively small changes in our assumptions about the pace of deceleration



Note: Model uses currently published estimates. Source: Barclays Research

[1] According to the model estimates, this probability is approximately 9.0%. This probability can be determined by multiplying the probabilities that the model places on being in each phase by the probabilities of transitioning to recession shown in Figure 2, where the recession probability once already in recession is 1.0.

Stress testing a stall

Gradual slowing scenarios

A potential shortcoming of the aforementioned probabilities is that, given its inference about the current state, the model infers probabilities of transitioning to stall or recession based on unconditional forecasts formed from broad historical experience. Hence, it ignores available information that might improve the forecast about where we are headed. This is a meaningful risk because, as mentioned above, payroll employment is widely expected to decelerate going forward: the consensus of private forecasters, as reported by Bloomberg, currently sees payrolls slowing to 110k per month by Q4 2020.

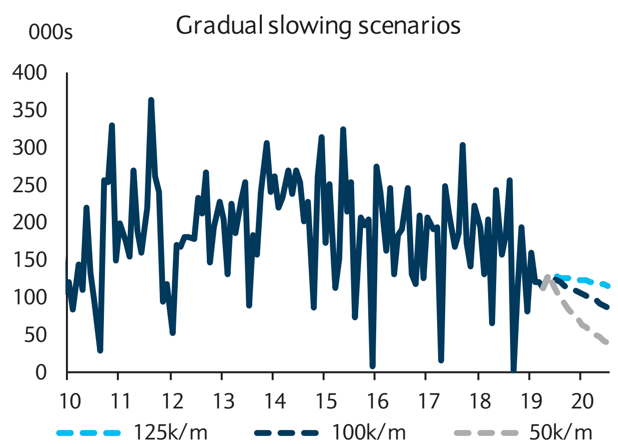
Anticipated slowing of this magnitude would surely affect the probability that we would place on a stall or recession – the question is, by how much? To help quantify these risks, we simulate our model using some alternative scenarios for the evolution of payrolls through 2020. These scenarios include the following three cases, all of which allow for only gradual deterioration in monthly payroll gains:

1. A relatively **optimistic scenario** in which private nonfarm payrolls continue to increase at an average monthly pace of 125k in Q4 2020 – close to their current level.
2. Our **baseline forecast** scenario, which foresees that monthly payrolls gradually step down to an average pace of 100k in Q4 2020.
3. A more **pessimistic scenario**, which sees monthly payroll gains winding down to an average of 50k in Q4 2020.

Figure 6 and Figure 8 show the trajectory of payroll gains under these scenarios, with and without the benchmark revisions. In all cases, the trajectory of payroll gains is situated toward the lower end of the distribution over the expansion, with more pessimistic outcomes further toward the lower tail. As illustrated, payroll growth has slowed to rates consistent with the pessimistic scenario on more than one occasion during the current recovery; however, in all of these instances, the forces behind this slowing proved transitory as labor markets quickly snapped back. This includes the European Debt Crisis early in the recovery period; in this episode, when private employment only dropped below 100k for two months and payroll growth was only dampened for three months in total. Hence, the pessimistic scenario should

FIGURE 8

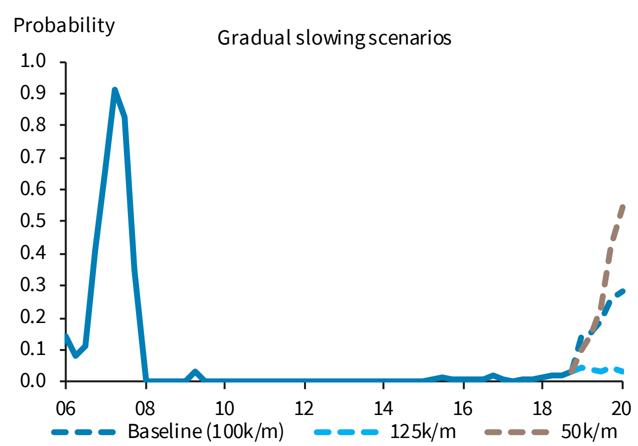
Benchmark revisions provide more substantial evidence of persistent slowing in payrolls over the past year or so…



Note: Estimates adjusted for anticipated benchmark revisions. Source: Barclays Research

FIGURE 9

…leading our model to infer somewhat higher stall risks – especially in our baseline scenario



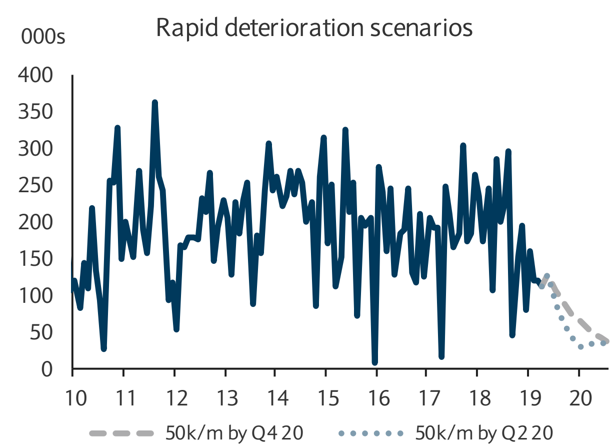
Note: Uses adjusted historical estimates. Source: Barclays Research be viewed as presenting the model with stronger evidence that the economy is transitioning to a lower-growth state. When calibrating these scenarios, we assume, in all cases, that the labor force participation rate remains flat at its current (Q3 2019) level, thereby ruling out additional influences on the evolution of the labor force beyond those from projected growth in the working-age (16 years and over) population.[2]

Figure 7 shows the evolution of stall probabilities in these three "gradual slowing" scenarios, as calculated from a simulation without benchmark revisions.[3] Not surprisingly, stall risks ascend over the course of 2020 in all but the first scenario. In this first "relatively optimistic" scenario, the model does not see any additional signs of deterioration relative to current outcomes. Because current outcomes are only on the low side of payroll gains seen so far in the expansion, the probability of stall does not change appreciably through end-2020. Clearly, the model extracts a somewhat stronger signal from the additional deceleration in our baseline scenario, with the stall probability ratcheting up to about 6% by Q2 2020 and to 8% by end-2020. In our more pessimistic scenario where payroll gains slow to 50k by end-2020, the stall probability increases to 26% in Q2 2020 and to 64% in Q4 2020.

However, the upcoming downward benchmark revisions are somewhat of a game changer with regard to the probability of stall. Estimates using the adjusted data, shown in Figure 9Figure 9, show that the model puts a considerably higher probability on the possibility of a stall after seeing evidence of persistent slowing from the benchmark revisions – especially in our baseline scenario. In that case, the probability of stall ascends to 19% in Q2 2020 and then further to 28% in Q4 2020. Probabilities of stall also rise appreciably in the more pessimistic scenario, with the probability now rising to 23% in Q2 2020 and then to 55% by end-2020. One interpretation of the difference in model estimates is that the framework is attempting to reconcile the degree of slowing as well as its duration; it interprets the gradual slowing in employment over several years as more indicative of stall than a modestly sharper slowdown over a shorter period.

FIGURE 10

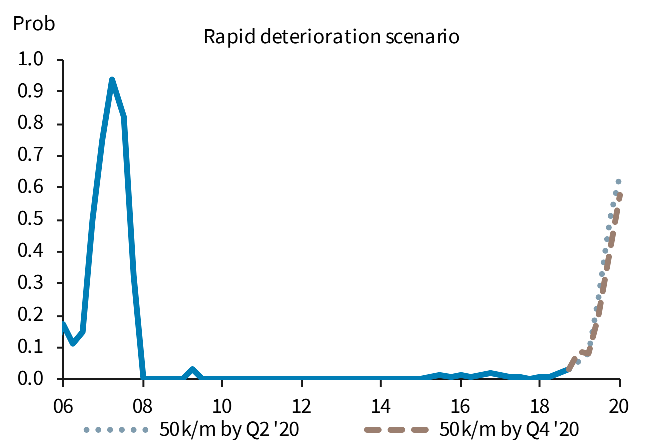
Our "rapid deterioration" scenario has monthly payrolls descending to 50k sooner…



Source: Barclays Research

FIGURE 11

…and this makes the model somewhat more certain about a stall by Q3 2020



Source: Barclays Research

[2] Our employment growth indicator in each quarter is calculated by dividing nonfarm payroll employment (from the Bureau of Labor Statistics' Establishment Survey) by an eight-quarter moving average of the labor force (from the Household Survey). Hence, all else equal, assuming a falling participation rate would tend to raise our employment growth indicator and lower probabilities of stall and recession, whereas assuming a rising participation rate would tend to lower our indicator and raise probabilities of stall and recession.

[3] Note that we calculate these probabilities using a one-sided filter that does not update historical probabilities in light of information seen later in the sample. When we use a smoothing procedure, the model has a strong tendency to revise up stall probabilities in prior periods after seeing slowing in subsequent periods. We do not view this smoothing to be appropriate, in the current setting, because the model then puts too much weight on our various assumptions about payroll growth as it revisits the probabilities it has assigned using available historical data.

In both of these figures, the strong signal taken in the pessimistic scenario is reflected in the cumulative differences in employment gains relative to the baseline. All told, cumulative employment gains in the pessimistic scenario are about 480k smaller than in the baseline scenario. Clearly, over the 15-month horizon, this amounts out to only about 30k jobs per month relative to our baseline outlook. However, in this case, the model takes a strong signal from the difference because it occurs at a critical juncture, when employment growth is approaching the lower end of the range of outcomes that would be consistent with an expansion and entering within the range of outcomes that the model would view as consistent with stall. Within this range, the model's inferences about the state of the economy can be very sensitive to relatively small changes.

Rapid deterioration scenario

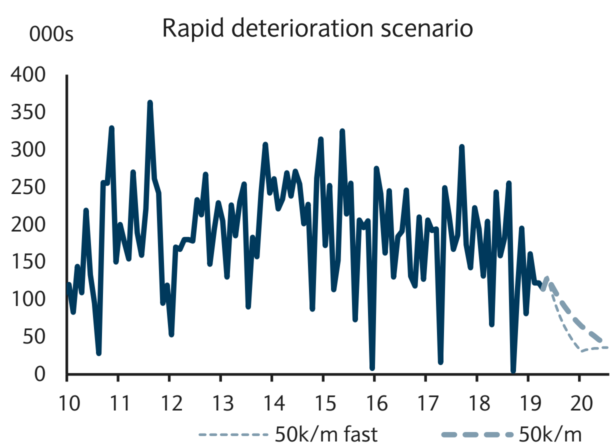
To consider how the model would react to evidence of more pronounced slowing, we use this scenario:

1. **A rapid deterioration scenario**, where monthly payroll gains fall to an average of 50k in Q2 20 – two quarters sooner than the pessimistic scenario above – and then level out in H2 20. Through the end of 2020, this scenario generates only about half of the cumulative employment gains assumed in our baseline.

Assumed monthly payrolls gains in this scenario – shown in Figure 10 using currently published estimates and in Figure 12 with adjustments for the benchmark revision – consistently come in at the very lower end of the distribution of expansionary outcomes from early 2020 onward. Figure 11 and Figure 13 compare the evolution of stall probabilities in this rapid deterioration scenario with those from our more pessimistic case (scenario 3) with more gradual slowing. Not surprisingly, with the more rapid downturn of payrolls in this scenario, the model is quicker to infer with high likelihood that a transition to the stall phase has occurred, with the stall probability reaching 64% by Q4 2020 in the simulation using currently published estimates. Moreover, when the model is presented with evidence of persistent slowing from the benchmark revisions, it extracts a much stronger signal about stall risks, with the stall probability rising to 85% by end-2020. Hence, slowing in payrolls of this magnitude would seemingly make the economy particularly vulnerable to a recession – though, as always when the economy flirts with the stall phase, a recession would not be a foregone conclusion.

FIGURE 12

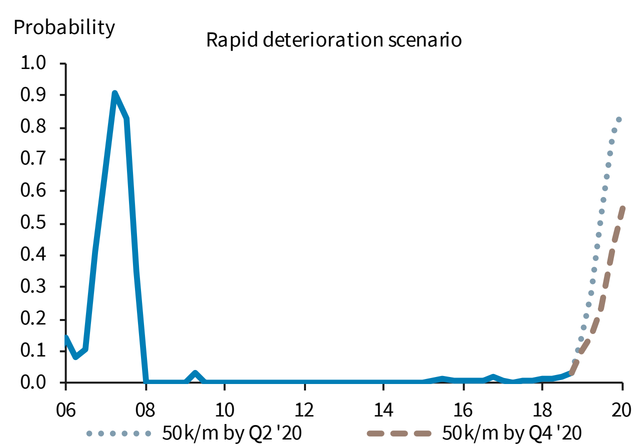
When we adjust our "rapid deterioration" scenario to account for the upcoming benchmark revisions….



Note: Historical estimates are adjusted for the benchmark revision.
Source: Barclays Research

FIGURE 13

…the probability of stall increases significantly – to about 85% by Q4 2020



Note: Model uses adjusted estimates. Source: Barclays Research

Box 1. Generating recession probabilities with employment data

A frequent critique of our tipping point framework is that employment is not a leading economic indicator and, as a result, cannot provide a forward-looking signal about recession risk. Although we agree employment is a coincident economic indicator, we do not think this diminishes its usefulness in understanding the likely evolution of the business cycle.

Employment data send a strong signal about the current position of the US economy in the business cycle. Evidence supports classifying employment as a coincident economic variable, as opposed to a leading or lagging indicator. For instance, the Conference Board includes four variables in its *Coincident Economic Index*: employment, personal income (less transfer payments), industrial production, and manufacturing and trade sales, with the factor loading on nonfarm employment exceeding the remaining three variables combined. In addition, the NBER relies heavily on nonfarm employment when dating recessions. Finally, our own research on estimating the output gap indicates that employment data play a much more pivotal role in the estimation of the business cycle than traditional output measures like GDP and GDI. In our view, this is the case, in part, because shocks to the latter are influenced by fluctuations in productivity growth (from measurement error and other sources) that tend not to persist.

Identification of the current state of the economy is only one part of the procedure. As we discussed in *Recession risk: Labor market data and economic tipping points*, 14 March 2019, we use nonfarm employment scaled by the labor force to place the US economy in any one of four phases, or regimes, of the business cycle: rapid expansion, expansion, stall speed, and recession. To improve identification in the face of long-run changes to aggregate supply from demographics and population ageing, we scale employment by the labor force. Our framework then uses the evolution of this employment-to-labor force ratio to place a probability, in each quarter over the sample period, that the economy in each of the four possible phases of the business cycle. As a by-product of this process, it also characterizes the distribution of the employment ratio in each state, under the assumption that outcomes are normally distributed in each phase.

Knowing the state of the economy today helps indicate where it is likely to move next. To gain an understanding of which phase the economy is in today, our model forms a probabilistic understanding of where the economy has been and where it may go. These dynamics are captured in a transition probability matrix (shown below), which contains the probability that the economy will transition from each phase of the business cycle to each other phase. This includes the likelihood that the economy will *remain* its current phase next quarter. This persistence differs across phases. Based on quarterly data from 1960 to the present, economic expansions are very persistent; when the US economy enters into an expansion, it tends to stay there. This is much less true when the economy in stall, recession, or rapid expansion. Moreover, when the economy is in stall, it is four times more likely to slip into recession in the next quarter than return to expansion. Hence, knowing when the economy may be slipping into a stall contains important information about the *risk* of transitioning to recession.

Table: Estimated transition probabilities using employment data

Transition probabilities using employment growth indicator (%)				
from \ to	rapid expansion	expansion	stall	recession
rapid expansion	49.5	50.5	0.0	0.0
expansion	2.4	92.7	4.9	0.0
stall	0.0	5.0	74.2	20.7
recession	0.0	26.7	0.0	73.3

Note: From model run that adjusts historical estimates for benchmark revisions. Source: Barclays Research

Concluding thoughts

Taking stock, these results seem to be broadly consistent with our existing views about the balance of risks surrounding the outlook, which, for some time now, we have been characterizing as being weighted to the downside. In light of this consistency, we place the likelihood of recession in 2019 at close to zero, and the likelihood of recession in 2020 at about 30%. Qualitatively, these findings would support the rationale for precautionary easing outlined by the Federal Reserve, with cuts intended to forestall outcomes in which monthly payroll gains slip into a range where the probability of stall is high.

When the economy is approaching a turning point, there seems to be a fine line between paths of payroll gains for which the model infers a relatively low stall probability and paths for which it infers a high probability. Moreover, this sensitivity is well within the range of measurement uncertainty. As our simulations with and without the benchmark revisions illustrate, it is not unusual for historical revisions to mark down monthly payrolls by enough to trigger meaningful changes in how the model assesses the probability of a stall. Even if payroll estimates regarding these turning points are unbiased, this nonlinearity provides some basis to believe that the model will understate the true likelihood of a stall (and vulnerability to recession), on average, around these points. We take this as food for thought as we assess risks to the outlook in the coming months.

Finally, our results might be interpreted as being consistent with the view that economic expansions become more difficult to sustain as they age – provided that this aging coincides with slowing employment growth. In our view, this would be a natural outcome of a prolonged expansion, as the economy gradually goes through its unemployed or discouraged workers. If this is the case, then there may be some cause for precautionary easing by the Federal Reserve in the latter stages of the business cycle, when payroll gains are losing momentum. This would be especially true in instances, such as now, when productivity growth appears insufficient to sustain gains in household income and spending – thereby making the economy more vulnerable to adverse shocks.

Appendix: Calculating probabilities of a recession (and other states) within a given time horizon

In this appendix, we describe formulas that we use to calculate probabilities of transitioning to the recession state (or any other model state), conditional on being in some initial state.

Let the four states of the model be represented by the letters f (fast expansion), e (expansion), s (stall), and r (recession). Our formulas work from the estimated 4x4 matrix of Markov transition probabilities, which we denote by M, with rows representing the initial state and columns representing the state in the following period. The individual elements of this matrix can be denoted as $m_{i,j}$, where i, j can each take any of the values F, E, S and R. So, for instance, $m_{E,S}$ would represent the probability of transitioning from an expansion this period to a stall phase next period, and so on.

Letting $P(t|t)$ denote the 4x1 vector of the probabilities of being in each of the four states, at time t, based on the model's assessment using information available at time t. This vector is composed of elements $p_F(t|t)$, $p_E(t|t), p_S(t|t)$, and $p_R(t|t)$ that represent the probability that the model places on being in each state. Using these probabilities, we can use the transition matrix calculate the vector of probabilities of being in each of the states in the following period conditional on currently available information at time t, as

$$P(t+1|t) = M' \cdot P(t|t).$$

Furthermore, we can iterate this formula to find the probabilities at time horizon $n > 0$, as

$$P(t+n|t) = (M')^n \cdot P(t|t).$$

Although this formula is straightforward, it calculates probabilities of being in each of the four states at a given time horizon rather than the likelihood of having visited some state at least once within that horizon. Among other things, this distinction can be important for assessing recession risks, being mindful of the fact that within a multi-period horizon, paths are possible in which the economy has transitioned in and then out of a recession phase – perhaps even multiple times.

To lay some notational groundwork, let $P^j(n)$ denote a column vector of probabilities of visiting state j at least once within the coming n periods, conditioned on knowing with certainty the current phase of the economy. The probabilities for each initial state i are arranged across the rows of the vector. So, for instance, $P^R(4) = [p_F^R(4), p_E^R(4), p_S^R(4), p_R^R(4)]'$ would represent the vector of probabilities of being in recession in at least one of the following four periods, starting with certainty from each of the four phases shown in the rows.

Note that we focus on calculating probabilities under cases in which we are certain about the initial state, because these are key building blocks for determining the probability of visiting that state when we are uncertain about the current state. Specifically, if we currently can only place a probability on currently being in any each of the possible states, we can still then calculate a probability of visiting some state j within n periods, conditional on currently available information, using the calculation $P(t|t)' \cdot P^j(n)$. So, for instance, we can calculate the probability of visiting the recession state within n periods as

$$p^R(n|t) = p_F(t|t)p_F^R(n) + p_E(t|t)p_E^R(n) + p_S(t|t)p_S^R(n) + p_R(t|t)p_R^R(n),$$

and so on.

Our methodology for calculating $P^j(n)$ works up from the case of a time horizon of one period, $P^j(1)$, using an iterative approach. Trivially, we know that the probability of having visited a given state, from having started at that state, is one: $p_j^j(1) = 1$ for any state state

j. The probabilities for all of the remaining states are directly informed by the relevant columns of the transition matrix. So, for instance,

$$P^F(1) = \left[1, m_{E,F}, m_{S,F,} m_{R,F}\right]'$$

and analogously, for the other states,

$$P^E(1) = \left[m_{F,E}, 1, m_{S,E,} m_{R,E}\right]', \;\; P^S(1) = \left[m_{F,S}, m_{E,S,} 1, m_{R,S}\right]',$$

$$\text{and} \;\; P^R(1) = \left[m_{F,R}, m_{E,R,} m_{S,R,} 1\right]',$$

For time horizons of more than one period, we form the probability of visiting a given state using iterative equations that are informed by the transition matrix M. Specifically, we assert again, trivially, that $p_j^j(n) = 1$ for any state j and horizon n – because we know that the economy has visited state j if it began the time interval in that state. For the other states, probabilities can be formed using equations of the form

$$p_i^j(n) = \textstyle\sum_{i \neq j} m_{i,j} p_i^j(n-1) + m_{j,j} p_j^j(n-1) \;\; ,$$

where $p_j^j(n-1) = 1$. To provide a concrete example of how these iterative equations are formed in practice, consider the probabilities of transitioning to recession within n periods. Naturally, we start by noting that $p_R^R(n) = 1$. Then, we need to formulas to determine the probability of transitioning into recession from each of the other states. To do this, we use the transition matrix to form a weighted expectation of the probabilities of transitioning to recession in the following period, across each of the possible states that can be reached in the following period. Following our example for the probability of visiting the "recession" state, we calculate the iterative equation for the "fast expansion" state as:

$$p_F^R(n) = m_{F,F} p_F^R(n-1) + m_{F,E} p_E^R(n-1) + m_{F,S} p_S^R(n-1) + m_{F,R} p_R^R(n-1),$$

which is simply a weighted average of the transitioning to recession in the following period from each state, using the probabilities of transitioning to each of these phases from the relevant row of the matrix M as weights. Using similar logic, we can calculate iterative formulas for the "expansion" and "stall" states:

$$p_E^R(n) = m_{E,F} p_F^R(n-1) + m_{E,E} p_E^R(n-1) + m_{E,S} p_S^R(n-1) + m_{E,R} p_R^R(n-1)$$

$$p_S^R(n) = m_{S,F} p_F^R(n-1) + m_{S,E} p_E^R(n-1) + m_{S,S} p_S^R(n-1) + m_{S,R} p_R^R(n-1),$$

This provides iterative formulas that can then be applied to determine the set of probabilities for each horizon, given probabilities for the previous horizon.

We can greatly simplify the task of performing these iterative calculations by noting that the system of equations above for a given horizon can be neatly summarized in matrix form as:

$$P^R(n) = \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} + \begin{bmatrix} m_{F,F} & m_{F,E} & m_{F,S} & m_{F,R} \\ m_{E,F} & m_{E,E} & m_{E,S} & m_{E,R} \\ m_{S,F} & m_{S,E} & m_{S,S} & m_{S,R} \\ 0 & 0 & 0 & 0 \end{bmatrix} \cdot P^R(n-1),$$

where the matrix that pre-multiplies $P^R(n-1)$ is the transition matrix with the "recession" row replaced with zeros. Using analogous logic, we can form the following matrix systems to calculate the probabilities of transitioning to the other three states:

$$P^F(n) = \begin{bmatrix} 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 \\ m_{E,F} & m_{E,E} & m_{E,S} & m_{E,R} \\ m_{S,F} & m_{S,E} & m_{S,S} & m_{S,R} \\ m_{R,F} & m_{R,E} & m_{R,S} & m_{R,R} \end{bmatrix} \cdot P^F(n-1),$$

$$P^E(n) = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} m_{F,F} & m_{F,E} & m_{F,S} & m_{F,R} \\ 0 & 0 & 0 & 0 \\ m_{S,F} & m_{S,E} & m_{S,S} & m_{S,R} \\ m_{R,F} & m_{R,E} & m_{R,S} & m_{R,R} \end{bmatrix} \cdot P^E(n-1),$$

and $$P^S(n) = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} + \begin{bmatrix} m_{F,F} & m_{F,E} & m_{F,S} & m_{F,R} \\ m_{E,F} & m_{E,E} & m_{E,S} & m_{E,R} \\ 0 & 0 & 0 & 0 \\ m_{R,F} & m_{R,E} & m_{R,S} & m_{R,R} \end{bmatrix} \cdot P^S(n-1).$$

Given the estimated transition matrix M, calculations of the probabilities of visiting each state can then proceed fairly easily using any computer application that performs matrix calculations, such as a spreadsheet.

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