US Viewpoint

Structurally higher US interest rates? Think again.

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BofA Data Analytics

Michael Gapen
US Economist
BofAS
+1 646 855 3270
michael.gapen@bofa.com

US Economics
BofAS

See Team Page for List of Analysts

A new higher interest rate regime?

In our year ahead global outlook (see Year Ahead 2024: Growing apart, cutting together, 19 November 2023), we asked an important question for the US and global economy over the next three to five years: are we going back to the low interest rate environment that prevailed prior to the pandemic or are we in a new regime of higher interest rates?

The neutral rate of interest has risen

In this report we estimate potential growth and the neutral rate of interest in the US. The neutral rate of interest is defined as the policy rate that would prevail when the economy is at full employment and GDP is in line with the productive capacity of the economy. The neutral rate is neither expansionary nor contractionary. We estimate that the real neutral policy rate is around 40bp. During the decade following the financial crisis, our estimate of the real neutral rate was negative or close to zero.

Hours worked boosting potential growth

Our framework relates changes in the neutral rate to changes in potential growth. We find that potential growth in the US has risen to 2.2% currently, up from 1.7% prior to the pandemic. That said, the entirety of the improvement comes from hours worked while productivity (output per hour) has remained unchanged. Demographics will likely reassert itself in coming years, returning participation rates toward their longer run trend, though how quickly this happens remains an open question. We think participation can remain elevated in 2024, but the state of the business cycle will be an important driver of labor market outcomes.

Higher neutral rates may be temporary

If the post-pandemic surge in participation proves relatively short lived and productivity does not accelerate, then growth in total hours and, in turn, potential growth could slow back to our pre-pandemic estimate of 1.7% in coming years. Based on the data in hand, our analysis strongly suggests that any rise in the neutral rate of interest in the US economy is likely to prove temporary.

The terminal rate could be lower than expected

Our estimates also have important implications for monetary policy. First, our estimates suggest any structural increase in neutral rates is likely to be modest and the zero lower bound is likely to remain a constraint on Fed policy options when managing the business cycle. Second, if the rise in the neutral policy rate is temporary and potential output decelerates over time, then the terminal policy rate at the end of any upcoming easing cycle could very well be lower than the Fed is currently projecting (2.9% as of December 2023). That said, this story is likely to play out slowly. Therefore, any additional Fed cuts versus market expectations may come later in the normalization process than earlier.

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Introduction: A higher US interest rate regime?

In our recently released year ahead global outlook (see Year Ahead 2024: Growing apart, cutting together, 19 November 2023), we highlighted one of the more important questions for US and global economy over the next three to five years is whether we are going back to the low interest rate environment that prevailed prior to the pandemic or are we in a new regime of higher interest rates. We seek an answer in this report.

A number of reasons have been cited to justify structurally higher US real interest rates following the pandemic. One is the nature of the pandemic itself, where reopening forces have been strong, insulating the economy from tighter Fed policy and leading to a temporary increase in real neutral rates of interest. Large and persistent fiscal deficits could also produce a similar result, with interest rate-insensitive federal spending helping to offset higher policy rates from the Fed.

Another is re-shoring, which has been credited for supporting higher capital expenditures, particularly in manufacturing-related industries, which could modernize capital stocks and lead to increased labor productivity. The artificial intelligence boom has been cited as doing the same with potential benefits for both goods-producing and services-providing sectors.

> A number of factors could be pushing neutral rates of interest higher in the US, including COVID re-opening forces, faster potential growth, reshoring, artificial intelligence, and fiscal deficits. The question is whether it will be sustained.

To address the question of whether the US is transitioning to a structurally higher neutral rate of interest, we use a multivariate approach to estimate potential growth, its component parts, and the neutral rate of interest using quarterly data from 1967 to the present. The neutral rate policy rate is defined as the federal funds rate that would prevail when the economy is at full employment and is neutral with respect to economic activity. When the federal funds rate is at neutral, it would neither support nor restrain growth in economic activity.

Our key findings? We find evidence in support of a higher neutral rate of interest relative to the post-financial crisis period, with our estimate of the neutral real policy rate hovering around 40bp. During the decade following the global financial crisis, our estimate of the real neutral rate was negative or close to zero.

We also find evidence in support of faster potential growth, with our estimate for trend growth at 2.2% currently, up from 1.7% prior to the pandemic. That said, we find that all the improvement in potential growth comes from hours worked while output per hour has remained unchanged. We suspect that demographics and an ageing population will reassert itself in coming years, returning participation rates toward their longer run trend. Absent any pickup in productivity growth, this would mean the increase in neutral rates of interest and potential growth could be temporary, setting the stage for a lower terminal rate in any Fed easing cycle than markets currently expect.

Separating cycle from trend

Potential output, the output gap, the natural rate of unemployment (also referred to as the non-accelerating inflation rate of unemployment, or NAIRU), and the natural rate of interest are important variables to anyone trying to understand where the economy is at any given point in time in relation to its sustainable trend. An economy growing too quickly with a positive output gap and unemployment below the natural rate is likely to force the Fed to put its policy rate into restrictive territory, particularly if inflation is overshooting target. The problem is that the variables of interest to understand the cyclical position of the economy and the outlook for monetary policy – potential growth, NAIRU, and the neutral policy rate – are unobservable. Hence, they must be estimated.

In this section, we briefly describe our approach to estimating the neutral policy rate and potential output. We follow the methodology in Fleischman and Roberts (2011) and Roberts (2014), modified to include estimates of the real policy rate, similar in spirit to Laubach and Williams (2001).[1] Those interested in the details of this approach can proceed to the appendix, which extensively describes the multivariate state-space model used to generate our estimates. Those readers interested mainly in the results of the estimation can skip forward to the next section on the neutral policy rate. In what follows, we try to provide a succinct conceptual explanation of our approach.

We make the standard assumption that each variable is a combination of trend and cycle and we apply widely accepted statistical methods to decompose movements in these observable variables into trend and cycle estimates. This transformation – the separation of the cycle from the trend – becomes a key factor in our assessment of where the US economy is at any given point in time relative to long-run "sustainable" levels. The transformation is done using inputs on population, working hours, gross domestic product, gross domestic income, nonfarm business product, nonfarm business income, employment, unemployment, the labor force, interest rates, and inflation, along with other control variables.

We assume the variables are comprised of the sum of a trend (X^*_i), a cycle component (cyc_t) that represents the output gap, and an idiosyncratic residual (u_{it}) according to

$$X_{it} = X^*_{it} + \lambda_{i0} cyc_t + \varphi_i (X_{it-1} - X^*_{it-1}) + u_{it}$$

where ($X_{it-1} - X^*_{it-1}$) is a partial adjustment mechanism that smooths the transition process from one quarter to the next.[2]

Inflation

We include an expectations-augmented Phillips curve. Our inflation specification is

$$DPCXFE_t = \alpha_1 DPCXFE_{t-1} + (1 - \alpha_1)PTR_t + \beta_{11}(L)drpe_{t-1} + \beta_{12}(L)d85_t drpe_{t-1}$$

$$+\beta_2(L)drpi_{t-1} + \theta(\Upsilon_{20} cyc_t + \varphi_4(ER_{t-1} - ER^*_{t-1})) + u_{9t}$$

where *DPCXFE* is the annualized quarterly change in core PCE inflation, *PTR* is a measure of long-run inflation expectations, *drpe* is a control for the relative change in consumer energy prices, *drpi* is a control for the change in the relative price of imports, *d85* is a dummy from 1985 to the present to account for rising share of the import ratio in consumer spending, and (*L*) represents lagged values. Inflation is also dependent on prior inflation, the output gap, and the employment rate (*ER*) gap.

[1] See Fleischman, Charles and John Roberts, 2011, "From many series. one cycle: Improved estimates of the business cycle from a multivariate unobserved components model," *Finance and Economics Discussion Series* 2011-46; Roberts, John, 2014, "Estimation of latent variables for the FRB/US model," Federal Reserve; Laubach, Thomas and John C. Williams, 2001, "Measuring the natural rate of interest." Also see: Jun Ma and Mark Wohar, 2012, "An unobserved components model that yields business and medium run cycles." August; and Arabinda, Basistha, and Richard Stactz, 2008. "Measuring the NAIRU with reduced uncertainty: A multiple-indicator common-cycle approach," *Review of Economics and Statistics*, 90. 805-11. Also see James H. Stock and Mark W. Watson, 1989. "New indices of coincident and leading economic indicators," *NBER Macroeconomics Annual 1989*, Oliver Blanchard and Stanley Fischer, eds., 351-394.

[2] Roberts (2014) provides some of the detail of the transformation of the Fleischman and Roberts (2011) framework into a FRBUS-compatible framework. The main transformation includes the partial adjustment framework over the lagged cycle specification and the use of PCE inflation over CPI. FRBUS has a partial adjustment mechanism built into many equations to smooth and extend the transition process and evolution of economic variables. As a result, the trend variables that are estimated in the state space framework can be used as inputs to the FRBUS model with greater confidence. We are generally agnostic about the partial adjustment formulation versus a lagged cycle specification so long as the framework allows the data to determine the lag structure.

Natural rate of interest

Identification of the real neutral policy rate of interest (R^*) is accomplished by relating the output gap to two lags of the real interest rate gap according to

$$cyc_t = \rho_1 cyc_{t-1} + \rho_2 cyc_{t-2} + \varphi_6(R_{t-1} - R^*_{t-1}) + \varphi_6(R_{t-2} - R^*_{t-2}) + \eta_t$$

with the imposed restriction that the coefficients on the two lags of the real interest rate gap are the same. We use two lags of the real interest rate gap to conform to the empirical conclusion that the output gap can be summarized as an AR(2) process.

The advantage of this specification is that provides a useful metric to understand the long-run stance of monetary policy from a business cycle setting, while its chief weakness is that it assumes the output gap accurately captures the many factors that are thought to drive the natural rate of interest, including, but not limited to, demographics, the "global saving glut", the safe asset shortage (or surplus), changes in the regulatory environment, inflation risk and the term premium, deleveraging, secular stagnation, and tail risks and fundamental uncertainty.[3]

We also believe that the system may be misidentified, since we are attempting to estimate the level of interest rates that is neither expansionary nor contractionary. We believe this rate is more closely associated with the cost of capital than the federal funds rate. The former is what equates saving and investment, while the latter is the interest rate that equates the supply and demand for federal funds. Nevertheless, there should be a strong link between actual and expected changes in the federal funds rate and the cost of capital and we simply note our concerns about the validity of model estimates here.

A multivariate approach improves trend and cycle estimates

We see several advantages to our approach. Research supports the conclusion that the economic data favor a common trend and use of a multivariate framework improves the accuracy of cycle estimates. These findings indicate that it is reasonable from a statistical perspective to assume that the US business cycle generates common cyclical behavior across sectors, industries, and variables. The "one cycle-one gap" interpretation improves the accuracy of model estimates.

Using a single system with many inputs has the disadvantage of increasing computational difficulty, but it has the advantage of uniformly accounting for trade-offs between alternative signals. By forcing the framework to estimate the neutral rate of interest, potential growth, the output gap, and NAIRU simultaneously, the model must trade off signals from different data, as opposed to estimating each variable individually in a partial equilibrium setting. While the latter approach is easier to implement, it risks generating trend and cycle estimates that may be inconsistent across variables and sacrifices statistical accuracy.

Data abundancy in the US, where gross domestic product and gross domestic income are estimates of the same measure – gross domestic output – means we can use both inputs to inform our trend and cycle estimates. Together with GDP adding up constraints, the process generates a decomposition of potential output and its components.

We note again that those readers interested in the estimation process can proceed to the appendix to this report for further details and, indeed, the academic research cited. We only provide the main highlight of our approach in the body of this report.

[3] "Long-term interest rates: A survey," 2005, Council of Economic Advisors, July. Also see Bernanke, Ben, 2013, "Long-term interest rates," Annual Monetary/Macroeconomics Conference: The Past and Future of Monetary Policy, San Francisco, March.

The neutral rate of interest has risen

We estimate the model using quarterly data from 1967 1Q to 2023 3Q and plot the results for the neutral rate of interest in Exhibit 1 and Exhibit 2. Exhibit 1 plots the two-sided estimate of the neutral real federal funds rate with one-standard deviation error bands, while Exhibit 2 includes the one-sided estimate. The two-sided estimate uses past and future data to estimate *R** at any given moment in time, while the one-sided estimate only uses prior data. We generally prefer the two-sided estimate but show both for completeness.

Several stylized facts emerge from the estimates:

- **The neutral rate has declined over time.** The first is the well-documented decline in the neutral rate of interest over time, which has been linked to the slowdown in potential growth over the same time period.

- **The neutral rate turned negative in the financial crisis.** The second stylized fact is the sharp decline in the neutral rate of interest following the 2008-09 financial crisis, when the two-sided estimate fell to around -1.0% and the one-sided estimate closer to -1.5%. Negative neutral rates of interest and the effective lower bound complicated the Fed's ability to fully support the US economy after the global financial crisis with interest rate policy alone, leading it to employ asset purchases in hopes of reducing term premia on longer-dated Treasury and mortgage-backed securities. The Fed also used more aggressive forward guidance about how long its policy rate would remain near zero.

- **The neutral rate rose as the economy healed after the financial crisis.** The third stylized fact that emerges is that the neutral rate has indeed risen. As the US economy healed following the global financial crisis, both one- and two-sided estimates of the neutral rate of interest gradually rose, though neutral rates remained in negative territory for quite some time.

- **The COVID pandemic also boosted the natural rate of interest.** The one-sided estimate, in particular, shows behavior consistent with short-term re-opening effects, with the estimate of the neutral rate of interest rising to 1.0% in 2021 4Q before falling back to about 40bp currently. The two-sided estimate displays less volatility since it can "see" into the future when estimating where the neutral rate of interest is today. Nonetheless, both estimates put the real federal funds rate at about 40bp currently. If the US is in a structurally higher interest rate environment it is likely due to two sources: the eventual healing of the economy following the global financial crisis and the effects of the global pandemic.

- **Take any point estimate of R* with a grain of salt.** The f stylized fact is extremely wide confidence intervals around any estimate of the neutral rate of interest. As we show in Exhibit 1, the one-standard deviation confidence interval ranges from about -1.5% to 2.5%. The two-standard deviation band is even wider. Hence, while we report the point estimate of the model output at 40bp, we also note the wide confidence interval around this point estimate suggests the output should be interpreted with caution.

Statistically speaking, the most we can say is that we are about 68% confident that the neutral policy rate is somewhere between -1.5% to 2.5%. This reinforces our view that the model may be misidentified. At a minimum we may be “asking too much” from the output gap in identifying where the neutral rate of interest lies at any point in time. We suggest readers take more confidence from the direction of travel – is the neutral rate of interest rising or falling – as opposed to any point estimate.

Altogether, our estimates suggest the neutral rate of interest has risen, and the US economy is as far away from the effective lower bound as it has been since the onset of the global financial crisis. Our results lend credence to the idea that the US has entered a new interest rate environment following the global pandemic. That said, our estimates suggest the neutral rate of interest has risen only modestly and remains well below that observed in prior decades. In other words, the new normal for interest rates may be higher, but not so high as to rule out effective lower bound episodes during future economic downturns.

Hours worked drive improvement in potential growth

As noted in the introduction, a number of forces could be behind structurally higher neutral rates of interest in the US economy. One, which our framework is well suited to assess, is growth in potential output, which could be driven by improvements in labor productivity, total hours worked, or both. Our framework imposes the structural relationship that

*Potential output = Trend total hours worked * Trend productivity per hour*

where the trend in total hours worked is made up of trend employment and the work week, or

*Trend total hours worked = Trend employment * Trend work week.*

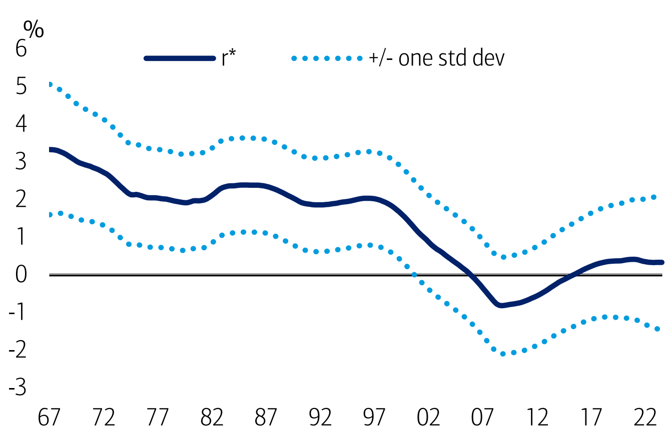
We then use the fact that trend employment equals

*Trend employment = Trend employment rate * Trend labor force participation rate*

where the unemployment rate is 100*[1 - exp(employment rate)].

Exhibit 3 presents potential growth in the US and its component parts by decade from 1970 to the present. We also report the results as of the third quarter in 2023 in the final column, which is the latest quarter through which data is available.

Exhibit 1: Two-sided estimate of the neutral real federal funds rate (%)
The neutral rate of interest has risen back into positive territory, but remains below levels observed in prior decades



Source: BofA Global Research

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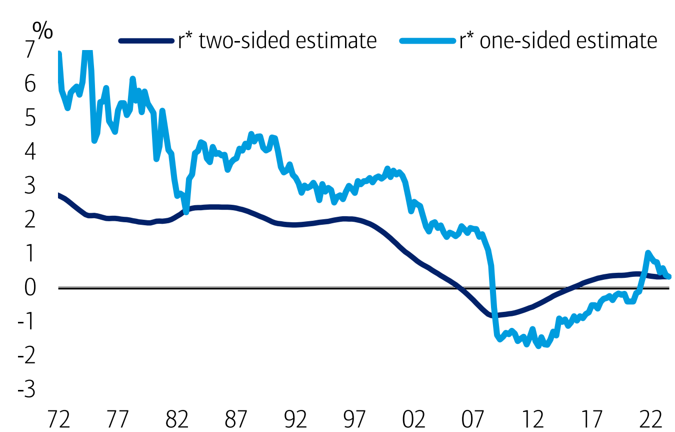
Exhibit 2: One- and two-sided estimates of the neutral real federal funds rate (%)
Both estimates of the neutral rate of interest rate have risen



Source: BofA Global Research

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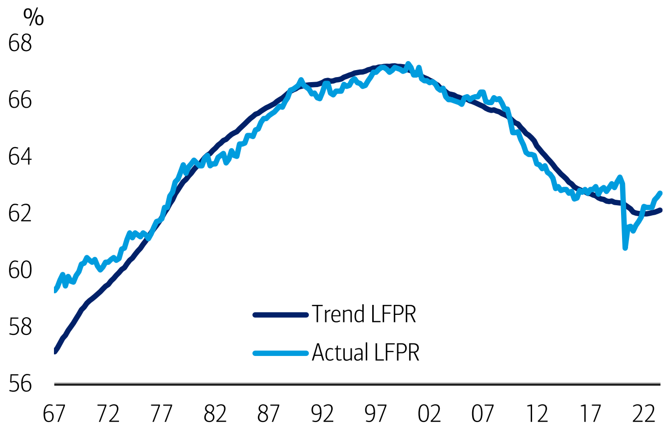
Exhibit 4: Trend LFPR versus actual (%)
Actual LFPR has overshot its longer-run demographic trend



Source: BEA, Haver Analytics, BofA Global Research

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Exhibit 5: Output per hour (%, annual rate)
Productivity growth has remained stable since the financial crisis

Source: BofA Global Research

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In the three decades leading up to the millennium, potential growth was estimated between 3.0-3.6%. The growth rate in trend hours worked was strong in the 1970s and 1980s at 2.6% and 1.6%, respectively, while trend growth in non-farm productivity accelerated from 1.4% in the 1970s to 2.1% in the 1990s. The slowdown in hours worked that began in the 1990s was initially offset by faster productivity growth, which we attribute to the technology revolution that began in the US in the mid-1990s.

An ageing workforce and a productivity slowdown

We estimate that trend growth in the US began to slow markedly beginning in 2001, falling from 3.5% to 1.8% by 2007 on the eve of the global financial crisis, and subsequently to 1.1% in 2009, as the benefits of technological progress began to fade, the workforce continued to age, and the after-effects of the economic downturn took effect. The decline in labor force participation since its peak in the early 2000s mainly reflects the ageing of the baby boomers. While labor force participation among the 55+ age cohort had risen during this time period on account of Americans living longer and delaying retirement, participation rates for the 55+ cohort were about half that for the prime working age population (those aged 25-54), resulting in structurally lower rates of labor force participation.

Exhibit 3: US potential growth and its component parts
Potential growth in the US has slowed due to population ageing and the fading of the 1990s tech boom. More recently, potential growth has picked up again.

%, annualized rate	1970-79	1980-89	1990-99	2000-09	2010-19	2020-3Q 23	3Q 24
Potential output	3.6	3.3	3.0	2.6	1.6	1.7	2.2
Total hours	2.6	1.6	1.0	0.8	0.4	0.4	0.8
Population	2.0	1.2	1.1	1.2	0.9	0.7	0.7
LFPR	0.8	0.5	0.1	-0.3	-0.4	-0.1	0.1
Employment rate	0.0	0.2	0.1	0.0	0.0	-0.1	0.1
Non-farm work week	-0.3	-0.2	-0.2	-0.1	-0.1	-0.1	-0.1
Non-farm productivity	1.4	1.7	2.1	2.0	1.3	1.3	1.3
GDO to NFBO	-0.5	-0.2	-0.4	-0.3	-0.2	-0.2	-0.1
NFB employment to total employment	0.2	0.2	0.3	0.0	0.1	0.1	0.2

Source: BofA Global Research

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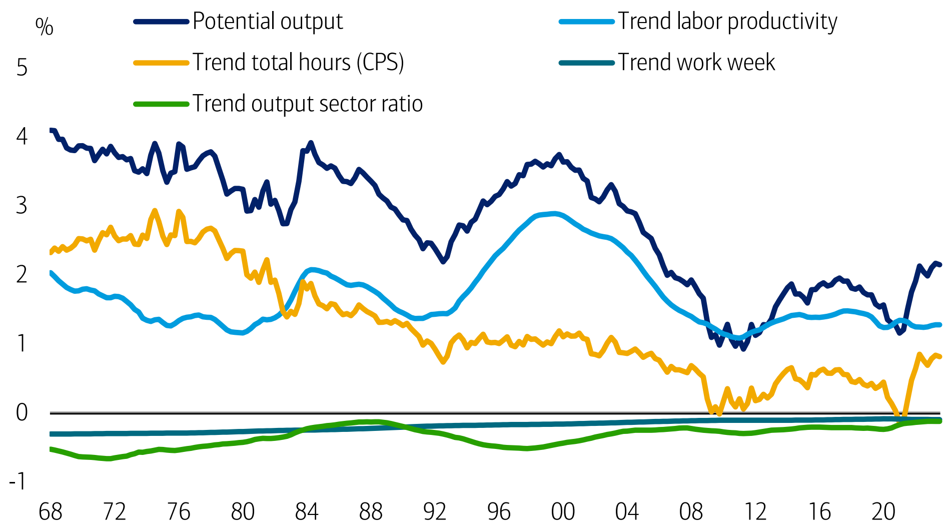
The model estimates that the trend participation rate dropped 3.3pp from 2007 to 2019, prior to the onset of the COVID-19 pandemic, accounting for more than the 2.6pp decline in the actual participation rate during the same period (Exhibit 4). By 2019, the long expansion that had taken place over the prior decade had induced many workers to

Exhibit 6: Potential growth and its component parts (%, annual rate)
The recent pickup in potential growth has been driven solely by an improvement in hours worked



Source: BofA Global Research

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return to the workforce and the model estimated that actual labor force participation was overshooting its longer run trend, which was weighed down by population ageing. This is consistent with the view that most of the decline in the participation rate relative to prior decades is structural and unlikely to be reversed.

In addition to the demographics, we note that the US has been in a gradual transition from a goods-producing economy to a services-providing economy over many decades. With services-providing sectors associated with more part-time employment, a shorter average work week, and lower productivity, this would tend to reduce potential output. Altogether, we estimate that these factors caused US potential CDP growth to slow from 2.6% in the ten years ending 2009 to 1.6% 2010 through 2019.

A post-pandemic rebound in total hours…

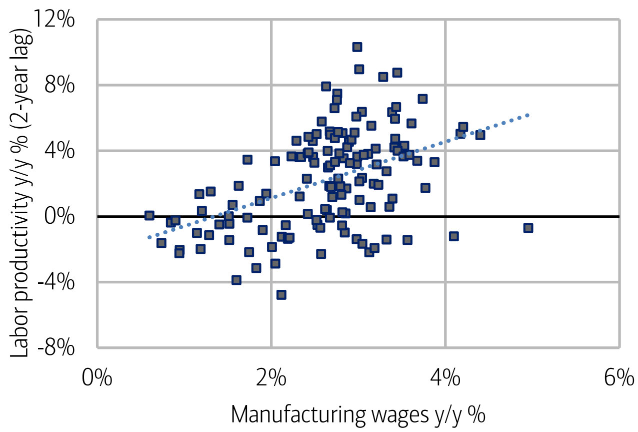
While the longer-term view in the US is one of potential growth weighed down by population ageing and a fading technology boom, the post-COVID period has seen a reversal of this trend. After bottoming at 1.2% in mid-2021, the model estimates that potential growth has risen to 2.2% presently, about 50bp above its pre-pandemic average. We see this as only likely driver of higher structural real rates of interest in the US economy.

That said, the source of the improvement in potential growth leaves us concerned about the sustainability of the acceleration in trend growth. As shown in Exhibit 3 and Exhibit 6, the improvement in potential can be accounted for solely through a pickup in trend hours worked, while model estimates of trend productivity growth have remained unchanged (also see Exhibit 5).

At 0.8% as of 3Q 23, the growth rate of total hours is running at twice its average pace from 2010-19. Much of this comes from an estimated improvement in the trend participation rate, which subtracted 0.3pp and 0.4pp, respectively, from potential growth between 2000 and 2019. Participation is now estimated to add 0.1pp presently, a 0.5pp improvement.

The rebound in participation rates among prime aged workers (25-54y olds) – and participation among women in particular – is the main feature of this story. In addition, though somewhat masked through the presentation of multi-year averages to smooth through deviations in the quarterly data, population growth has accelerated recently, which we see as related to the rebound in immigration flows following the pandemic.

Exhibit 9: Wage inflation has historically driven labor productivity growth on a lagged basis
US Manufacturing wage inflation and labor productivity (y/y % changes)



Source: Bureau of Labor Statistics, BofA Global Research

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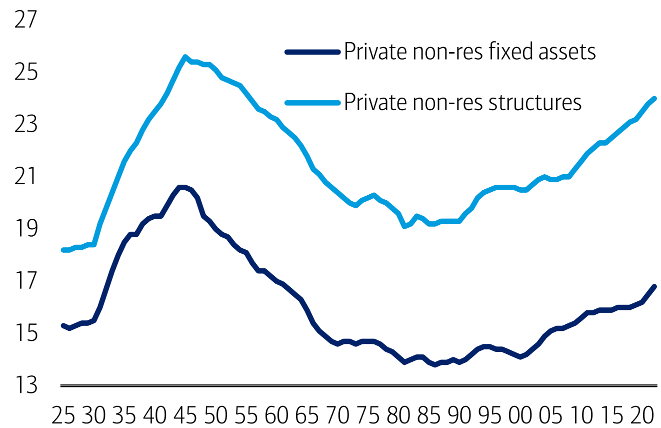
Exhibit 10: Stuff is old. Productivity should improve as equipment gets upgraded
Average age of fixed assets and structures (years; 1925-2021)



Source: BEA, BofA Global Research

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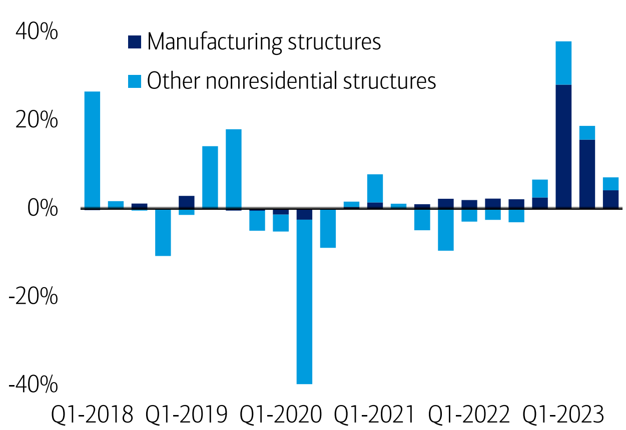
…against stable productivity growth

There is a strong case to be made that that output per hour in the US is on the verge of improvement. As noted by Savita Subramanian, our Head of US Equity and Quantitative Strategy, reshoring, fiscal policy initiatives, and AI advancements have supported capital investment by US firms (see Five reasons for S&P500 @ 5000, 21 November 2023).

These are topics we have taken up in our writing on the US economy, including our recently released year ahead outlook (see Year Ahead 2024: Growing apart, cutting together, 21 November 2023), where policies enacted by the Biden administration crowded in private investment in the manufacturing sector and boosted infrastructure spending (Exhibit 7). Though we believe the fiscal impulse and its effects on rates of growth in capital spending are set to fade over our forecast horizon, it does not negate the potential for past investments to bear fruit on future productivity growth.

Savita and her team argue that US firms have more incentive than ever to increase efficiency and productivity, which, if successful, could enable wider margins even in an environment of slower growth. She cites stagnant revenue per worker since 2008 as incentivizing firms to improve efficiency that can no longer be had from outsourcing production to lower cost destination (Exhibit 8), as well as rising wage costs (Exhibit 9),

Exhibit 7: Contribution to growth in structures investment (% q/q saar)
Investment in manufacturing buoyed nonresidential structures investment



Source: BEA, Haver Analytics, BofA Global Research

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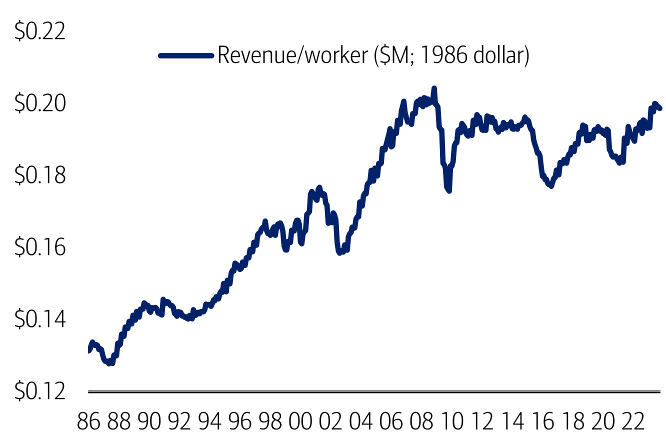
Exhibit 8: Labor efficiency has been stuck since the financial crisis
S&P500 companies revenue per worker ($M; 1986 dollar)



Source: FactSet, Bloomberg, BofA Global Research

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an ageing capital stock (Exhibit 10), and lack of opportunities to improve earnings per share through buybacks in support of this view.

> Firms have more incentive than ever to become more efficient. Yet productivity has not accelerated, calling into question just how long any rise in potential growth – and neutral policy rates – may last.

That said, our model estimates of trend productivity have remained unchanged. Trend growth in output per hour has held steady at 1.3% per year, equal to its 2010-19 average. The model suggests that the tech-driven productivity boom lasted about fifteen years between 1992 and 2007, though rates of growth in output per hour peaked in 2000. To date, our model does not detect any measurable improvement in productivity from reshoring effects or the adoption of artificial intelligence. This is not to say that it could not happen in the future; we simply note the model has not "seen" enough evidence to suggest that it is happening now.

…but for how long?

In terms of assessing the sustainability of any pickup in potential growth and, in turn, the durability of any rise in the neutral real policy rate, we find the source of the rise in potential growth troubling. While the rebound in labor force participation is unquestionably good news on a number of fronts, we suspect any improvement is likely to be short-lived. Given the outlook for US demographics and dim prospects for comprehensive immigration reform, we view the rebound in participation as likely temporary in nature.

COVID-19 re-opening effects, including the rotation of activity from goods to services, have been strong, generating forceful snapbacks in consumer spending, production, and employment. We think the rebound in participation and immigration can be closely tied to these effects. If so, and considering the continued ageing of the population and the fact that actual participation is running 0.7pp above its longer run trend, we doubt the participation rate will be higher than it is today at the end of our forecast horizon (4Q 2025). We are somewhat agnostic on the timing – perhaps the rebound in participation could go on for longer than we expect – but we have more confidence in our belief that the observed rise in participation above its longer run trend will be temporary.

Higher neutral rates of interest may only be temporary

If the post-pandemic surge in participation proves relatively short lived and, in the absence of any future rise in trend growth in output per hour, then growth in total hours and, in turn, potential growth could slow back to our pre-pandemic estimate of 1.7% in coming years, roughly equal to the Federal Reserve's longer run estimate of 1.8%. Our framework, based on the data in hand, strongly suggests that any rise in the neutral rate of interest in the US economy is likely to prove temporary.

Looking ahead, we think there still is more job normalization to be done in the service sector, though to a far lesser degree than was the case in previous years. These lingering rotational effects and demand for labor should keep employment growth, growth in disposable income, and GDP growth (gross domestic product) positive over our forecast horizon, consistent with our outlook for a soft landing in the US economy.

When these forces fade – and after whatever labor force participation strength is left due to increased incidence of work from home – then we think participation will return toward its underlying (lower) trend. We remain fully open to the prospect of faster growth in productivity in coming years, but, for now, the behavior of total hours points more to temporary changes in potential output and neutral policy rates as opposed to permanent ones.

We also remain open to the prospect that fiscal profligacy, sizable US fiscal deficits, and the Fed's balance sheet runoff policies could support a higher interest rate environment, independent of any sloughing off in total hours. As we noted earlier, our framework may ask a lot of the output gap to synthesize all the various factors that may alter the structure of real interest rates. We think a full investigation of the relationship between fiscal deficits, sustainability concerns, and interest rates lies beyond the scope of this report and we leave the question for further research at this time.

Warning: the terminal rate at the end of any easing cycle could be lower than expected

Our conclusions have important implications for monetary policy. Among these are:

- **A lower terminal rate in any easing cycle.** As of December, the Fed's estimate of the longer run neutral policy rate remained unchanged at 2.5%, while the median estimate of the 4Q 2026 policy rate was 2.9%. This suggests most policymakers think the real neutral policy rate will need to remain higher for longer to achieve the dual mandate. In other words, the Fed appears to be building in a prolonged period of higher neutral rates of interest that may be warranted.

- **A return of the zero lower bound.** The modest rise in the neutral rate of interest likely has not ruled out zero lower bound episodes going forward. If the neutral rate is drifting lower in coming years, then the probability of hitting the zero lower bound in any easing cycle will only increase.

- **The market may get the cuts its wants, but some of them may come later.** At times, financial markets have been pricing in about twice as much easing in 2024 as the median FOMC member is indicating. If the terminal rate is declining over time, some of the cuts the market has frontloaded could ultimately be delivered later in 2025 or early 2026. It will likely take time for the Fed to internalize what is happening to the neutral rate of interest and they will be reluctant to prejudge any outcome. Hence, the market may get what it wants, but later than it expects.

Appendix: Multivariate state-space framework

This appendix describes the state-space framework used to generate the estimates in this report for potential output, the output gap, the long-run employment rate (used to generate estimates of NAIRU, the long-run unemployment rate), and the equilibrium real policy rate, or r*. The framework follows that outlined in Fleischman and Roberts (2011) and Fleischman and Roberts (2014), modified to include estimates of the real policy rate, similar in spirit to Laubach and Williams (2003).[4]

The variables mentioned above – all largely unobservable in isolation – are key variables of interest in the setting of monetary policy and serve as anchors to many econometric models. However, since they are unobservable, we need to apply statistical methods to decompose movements in observable variables into trend and cycle estimates. This transformation – the separation of the cycle from the trend – becomes a key factor in our assessment of where the US economy is at any given point in time relative to long-run "sustainable" levels. The transformation is done using inputs on population, working hours, gross domestic output, nonfarm business output, income, employment, unemployment, the labor force, interest rates, and inflation.[5] Together with GDP (gross domestic product) adding up constraints, the process generates a decomposition of potential output and its components.

We see several advantages to applying a multivariate approach. Academic research has demonstrated empirical evidence that the data favor a common trend and use of a multivariate framework improves the accuracy of cycle estimates. In other words, the data lend itself naturally to estimating a cycle common amongst all input variables. These findings indicate that it is reasonable (from a statistical perspective) to assume that the US business cycle generates a common cyclical behavior across sectors, industries, and variables. The "one cycle-one gap" interpretation improves accuracy of the estimates.

Using a single system also has the advantage of uniformly accounting for trade-offs between alternative signals. Since the estimation procedure relies on the Kalman filter, we can identify those variables that have the highest information content when it comes to the identification of cycle and trend components. Hence, not only are cycle estimates improved, but we can identify those variables that send the most consistent signal about expansions and contractions, as well as the evolution of trend growth. An alternative approach would be to estimate each trend variable separately in a partial equilibrium setting. While this may be easier to implement, it risks generating trend and cycle estimates that may be inconsistent across variables and sacrifices statistical accuracy.

By assuming a common cycle, we make the general assumption that each input variable is represented as the sum of a cyclical and trend component, with an idiosyncratic residual. The cyclical component (cyc) measures the output gap is assumed to be common across all variables, while each variable is permitted to have a unique trend.

Trend and cycle specification

The framework includes ten input variables: real gross domestic product, real gross domestic income, real nonfarm business output, real nonfarm business income, nonfarm business employment, the work week, the labor force participation rate, the real rate of

[4] See "From many series. one cycle: Improved estimates of the business cycle from a multivariate unobserved components model," *Finance and Economics Discussion Series* 2011-46; and Jun Ma and Mark Wohar, 2012, "An unobserved components model that yields business and medium run cycles." August; and Arabinda, Basistha, and Richard Stactz, 2008. "Measuring the NAIRU with reduced uncertainty: A multiple-indicator common-cycle approach," *Review of Economics and Statistics*, 90. 805-11. Also see James H. Stock and Mark W. Watson, 1989. "New indices of coincident and leading economic indicators," *NBER Macroeconomics Annual 1989*, Oliver Blanchard and Stanley Fischer, eds., 351-394.

[5] The employment rate (ER) can be transformed into the unemployment rate (UR) according to ER = log[1-(UR/100)].

interest, the employment rate, and core PCE inflation. The Fleischman and Roberts (2011) specification uses CPI instead of PCE inflation, but Roberts (2014) substitutes PCE inflation and we do the same, given its importance in the Fed's dual mandate.[6] Data availability in the US allows for both product- and income-side measures that improve the accuracy of our trend and cycle estimates.[7]

The observable variables in our list can be constructed as the sum of a trend (X_i), cycle component (cyc_t), and an idiosyncratic residual (u_{it}) according to

$$X_{it} = X^*_{it} + \lambda_i(L)cyc_t + u_{it}$$

where the cyclical component is common across each variable. Basistha, and Startz (2008) allow for the possibility of separate cycles in unemployment and output and find the data strongly supports one common cycle.[8][9] The lag polynomial $\lambda_i(L)$ could be used to allow for the possibility for contemporaneous as well as lagged effects that can differ across the cycle. For example, labor market data could be assumed to have contemporaneous and lagged effects, while other variables would only have contemporaneous effects.

Instead of allowing for lagged cycle effects, we use a simple partial-adjustment specification for some labor market variables as detailed in Roberts (2014) - a short note that, in our view, provides some of the detail of the transformation of the Fleischman and Roberts (2011) framework into a FRBUS-compatible framework. The main transformation includes the partial adjustment framework over the lagged cycle specification and the use of PCE inflation over CPI. FRBUS has a partial adjustment mechanism built into many equations to smooth and extend the transition process and evolution of economic variables. As a result, the trend variables that are estimated in the state space framework can be used as inputs to the FRBUS model with greater confidence. We are generally agnostic about the partial adjustment formulation versus a lagged cycle specification so long as the framework allows the data to determine the lag structure.

The partial-adjustment structure we use for the labor force participation rate (*LFPR*), the employment rate (*ER*), and nonfarm business employment (*ENFB*), is

$$X_{it} = X^*_{it} + \lambda_{i0}cyc_t + \varphi_i(X_{it-1} - X^*_{it-1}) + u_{it}$$

For the work week, we follow Roberts (2014) and assume

$$X_{it} = \theta_{i0}cyc_t + \theta_{i1}(cyc_t - cyc_{t-1}) + \varphi_i(X_{it-1} - X^*_{it-1}) + X^*_{it} + u_{it}$$

For the cycle, like Fleischman and Roberts (2011), we assume and *AR(2)* specification

$$cyc_t = \rho_1 cyc_{t-1} + \rho_2 cyc_{t-1} + \eta_t$$

[6] Using PCE instead of CPI may affect the estimate of NAIRU, given the historical gap between the two measures. Model estimates of NAIRU may be higher with CPI than PCE.

[7] All variables are in log terms and we subtract the working age population from real GDP, real GDI, real nonfarm business output, real nonfarm business income, and nonfarm business employment since population is a readily identifiable trend.

[8] Fleischman and Roberts (2011) explicitly allow for tags between movements in labor market variables and the cycle. Equations for employment, the work week, the employment rate, and participation are modeled as a function of the current cycle estimate and two lags of the cycle. Roberts (2014), which reconfigures the framework of Fleischman and Roberts (2011) to be more consistent with the structure of the FRBUS model, drops the lagged cycle terms in favor of a partial-adjustment specification. This allows for cycle lags to affect current labor market variables through lagged labor market variables. As a result, it has the potential to capture some of these lagged cycle effects. That said, we view the partial adjustment setting in Roberts (2014) as more restrictive than that in Fleischman and Roberts (2011).

[9] Basistha and Startz (2008) use a multi-variate framework to estimate NAURU. The authors find that such an approach to extract a common unobserved factor reduces uncertainty as measured by variance in half and the confidence band by 33%. They conclude that the existence of a common cycle that drives all the macro variables accounts for the improved estimation. In particular, they find that the GDP deflator and real GDP are valuable indicators of the gap in the business cycle and account for the narrower confidence band.

The standard restrictions are to assume ρ_1>1 and ρ_2<1 to create a hump-shaped response to a shock in η_t. The sum of ρ_1 and ρ_2 should be less than one to create a persistent, yet stationary, business cycle.[10]

Output variables

The equations for real gross domestic product (GDP), real gross domestic income (GDI), nonfarm business product (NFBP) and nonfarm business income (NFBI) are given by

$GDP_t = GDO^*_t + cyc_t + u_{it}$

$GDI_t = GDO^*_t + cyc_t + u_{it}$

$NFBP_t = NFBO^*_t + \Upsilon_{10}cyc_t + u_{it}$

$NFBI_t = NFBO^*_t + \Upsilon_{10}cyc_t + u_{it}$

where GDO* represents the common trend component of GDP and GDI (eg, potential gross domestic output) and NFBO* represents the common trend for nonfarm business output from NFBP and NFBI. Here we take advantage of property that product and income side variables are alternative measures of the same output concept. Both estimates, in theory, should yield the same output.[11]

Labor market variables

The observed data on employment, the work week, the employment rate, and participation are decomposed into the sum of a trend and cyclical components

$ENFB_t = ENFB^* + \Upsilon_{20}cyc_t + \varphi_2(ENFB_{t-1} - ENFB^*_{t-1}) + u_{5t}$

$WW_t = WW^*_t + \Upsilon_{20}cyc_t + \Upsilon_{31}(cyc_t - cyc_{t-1}) + \varphi_5(WW_{t-1} - WW^*_{t-1}) + u_{6t}$

$ER_t = ER^*_t + \Upsilon_{40}cyc_t + \varphi_4(ER_{t-1} - ER^*_{t-1}) + u_{7t}$

$LFPR_t = LFPR^*_t + \Upsilon_{50}cyc_t + \varphi_5(LFPR_{t-1} - LFPR^*_{t-1}) + u_{8t}$

where ENFB is employment in the nonfarm business sector, WW is the work week, ER is the employment rate, LFPR is the labor force participation rate, and * indicates the trend for each variable. The framework includes a partial adjustment mechanism. The idea behind the partial adjustment formulation is that the observed variable may be related to its trend, but there may also be inertia in the system such that the observed value is a

[10] For example, Fleischman and Roberts (2011) report estimates for ρ_1 and ρ_2 of 1.62 and -0.66, respectively. The sum is narrowly less than one, suggesting a high degree of persistence to business cycle shocks, but still consistent with stationarity. In a version of the model with PCE inflation instead of CPI, we estimated the variables at 1.41 and -0.45, respectively, which suggest similar dynamics.

[11] We also include nonfarm business sector output to aid our identification of trend and cycle estimates. Its inclusion could improve estimates of trend productivity since the BLS/BEA prefers to exclude the gross product of the general government and private households and not-for-profit institutions when calculating productivity (In 2012, the business sector accounted for approximately 75 percent of the value of GDP. This measure and the measure of nonfarm business sector output, which also excludes farm output, are the real output series used to calculate BLS measures of labor productivity - defined as real output per hour worked - in the US business and nonfarm business sectors. See “Overview of output measures used by BLS to construct productivity statistics for major sectors of the US economy,” Bureau of Labor Statistics, Division of Major Sector Productivity, September 29, 2014). The public sector and household non-profit sectors may have different cycles and excluding them may improve information content and reduce noise. Since NFBO is not the same as GDO (since it excludes the farm sector, public sectors, and households/nonprofits), we specify that it has its own trend and Υ =I cannot be assumed for a contemporaneous, normalized cycle. We also estimate Υ and assume it is the same across NFBP and NFBI, under the prior that nonfarm business output likely has a larger amplitude than CDP since the latter includes the public sector, which is not very cyclical. If true, then the coefficient on the cycle, Υ_{10}, will be greater than one. Overall, this specification still imposes the same cycle across the four variables, but allows for the amplitude of NFBO to differ from GDO, given its construction. We find that Υ_{10} = 1.448 in our specification, which includes partial adjustment and PCE inflation, but excludes any estimate of r*. In the framework including r*, we found that Υ_{10} = 1.398. Fleischman and Roberts (2011) find 1.41. Hence, the amplitude of the nonfarm business sector cycie is about 40% larger than that of GDP. The excess volatility of the nonfarm business sector cycle is likely accounted for on the expenditure side by chances in private inventories.

compromise between its value in the previous period and that justified by the current trend. The coefficient o describes the speed of adjustment between periods, where a value of 0 indicates no adjustment and a value of 1 indicates full adjustment from the current period.[12] The rationale for this specification is like that we used to justify including lags of the cycle; adjustment costs may mean firms find it costly to adjust the factors of production so that changes in labor market activity may lag changes in output. If present, these adjustment costs could preclude full adjustment from one period to the next.

During the 2008-09 financial crisis and COVID-19 pandemic, US policymakers made greater use of federal and state emergency and extended benefits (EEB) problems. Like Fleischman and Roberts (2011), we account for the influence of these programs on the unemployment rate and labor force participation by including a measure of the size of the EEB programs in the employment and participation rate equations above. The availability of emergency benefits increases the unemployment rate (decreases the employment rate) unrelated to cycle estimates. This would be the case if emergency benefits programs are enacted on an ad hoc basis and independent of the relationship to the business cycle versus regular state-level unemployment insurance programs (initial and continuing jobless claims). Second, because eligibility for emergency benefits is contingent on continued job search, among other items, their availability could induce some individuals who otherwise would have ended their job search and left the labor force to report active job search. This would have the effect of temporarily boosting participation and increasing unemployment. Finally, these benefits may induce some workers to become more selective in their job search, thus extending their period of unemployment.

On the other hand, Fleischman and Roberts (2011) hypothesize that EEB programs typically are available only during periods of unusual weakness in labor demand. If so, they would be less likely to significantly curtail employment. To balance these competing effects, we impose the restriction that EEB programs do not affect employment by including the variable in the employment and participation rate equations with coefficients that are equal but of opposite sign.

$$ER_t = ER^*_t + \Upsilon_{40} cyc_t + \varphi_4(ER_{t-1} - ER^*_{t-1}) + \delta EEB_t + u_{7t}$$

$$LFPR_t = LFPR^*_t + \Upsilon_{50} cyc_t + \varphi_5(LFPR_{t-1} - LFPR^*_{t-1}) - \delta EEB_t + u_{8t}$$

Inflation

We include a model of inflation, similar to that used in other studies including Laubach and Williams (2003), Basistha and Startz (2008), Fleischman and Roberts (2011), and Roberts (2014). It is an expectations-augmented Phillips curve, replacing CPI with PCE, and is similar to dynamics within the FRBUS framework. This inflation model was highlighted by Federal Reserve Chair Janet Yellen (2015). Our inflation specification is

$$DPCXFE_t = \alpha_1 DPCXFE_{t-1} + (1 - \alpha_1)PTR_t + \beta_{11}(L)drpe_{t-1} + \beta_{12}(L)d85_t drpe_{t-1}$$

$$+\beta_2(L)drpi_{t-1} + \theta(\Upsilon_{20} cyc_t + \varphi_4(ER_{t-1} - ER^*_{t-1})) + u_{9t}$$

where DPCXFE is the annualized quarterly change in core PCE inflation, PTR is a measure of long-run inflation expectations, drpe is the relative change in consumer energy prices, drpi is the change in the relative price of imports, d85 is a dummy from 1985 to the present to account for rising share of the import ratio in consumer spending, and (L) represents lagged values. To reduce the number of estimated coefficients, we use a six quarter moving average representation for the lag structure in drpe. This reduces the need to estimate 12 coefficients to two, which should improve convergence. For drpi we

[12] We find empirical support for the partial-adjustment specification: employment and the employment rate adjust fairly rapidly. but not fully, while the work week adjusts slower. The estimation procedure chooses to put the statistical significance on the lagged cycle term, not the partial-adjustment term in the work week specification.

use six lagged terms. Like Roberts (2014), we constrain the sum of the coefficients on lagged inflation and PTR to be equal to one. The inflation equation also assumes cyclical deviations in output from its trend and transition effects in labor markets effect inflation.

Natural rate of interest

The specification for the natural rate of interest is similar to that in Laubach, and Williams (2001).[13] Since the Federal Reserve uses a short-term interest rate (the federal funds rate) as the primary tool of policy, it is useful to estimate the natural rate of interest simultaneously with estimates of potential output, the trend employment rate, and inflation. The advantage of this specification is that provides a useful metric to understand the long-run stance of monetary policy, while its chief weakness is that it abstracts from many other factors that are thought to cause variations in the natural rate of interest, including, but not limited to, demographics, the "global saving glut", the safe asset shortage, changes in the regulatory environment, inflation risk and the term premium, deleveraging, secular stagnation, and tail risks and fundamental uncertainty.[14] We also believe that the system may be misidentified, since we are attempting to estimate the level of interest rates that is neither expansionary nor contractionary. We believe this rate is more closely associated with the cost of capital than the federal funds rate. The former is what equates saving and investment, while the latter is the interest rate that equates the supply and demand for federal funds. These are interchangeable in the framework only if changes in the federal funds rate are translated on a 1:1 basis into the cost of capital. Nevertheless, we proceed with the assumption that R* is the overnight policy rate controlled by the Federal Reserve and simply note our concerns about the validity of model estimates here.

Identification of the real neutral policy rate of interest is accomplished by relating the output gap to two lags of the real interest rate gap according to

$$cyc_t = \rho_1 cyc_{t-1} + \rho_2 cyc_{t-2} + \varphi_6(R_{t-1} - R^*_{t-1}) + \varphi_6(R_{t-2} - R^*_{t-2}) + \eta_t$$

with the imposed restriction that the coefficients on the two lags of the real interest rate gap are the same (Laubach and Williams (2001) make a similar assumption). We use two lags of the real interest rate gap to conform to the empirical conclusion that the output gap can be summarized as an AR(2) process. An alternative would be to specify the real equilibrium interest rate as its own separate equation, similar to other variables. However, when we estimated this specification, it led to what we felt was excessive variability in real interest rate estimates that seemed inconsistent with recent experience. In other words, the estimate of the trend likely takes on too much of the current federal funds rate, imparting excessive cyclicality in trend estimates. This adds to our concern that the real interest rate is likely poorly specified as an adjustment variable and ties it to cycle assumptions.

Structural relationships and potential output

The ten equations above make up our system. Before proceeding to the structural relationships that define potential output, we note that we subtract the natural log of the civilian working-age population from CDP, GDI, NFBP, NFBI, and ENFB since it is a readily identifiable common trend to each. Consequently, the estimation of the system is done on a per capita basis and only later, in the summing up process for potential output, will population growth re-enter the discussion.

We use the structural relationships among the trend components in the equations above to decompose nonfarm business potential output, NFBO*, into trends in nonfarm business hours and productivity according to

[13] Laubach, Thomas and John C. Williams, 2001, “Measuring the natural rate of interest.”
[14] “Long-term interest rates: A survey,” 2005, Council of Economic Advisors, July. Also see Bernanke, Ben, 2013, “Long-term interest rates,” Annual Monetary/Macroeconomics Conference: The Past and Future of Monetary Policy, San Francisco, March.

$NFBO^*_t = HNFB^*_t + OPH^*_t$

where HNFB* and OPH* are nonfarm business hours and nonfarm business sector productivity (real output per hour all persons). Hours can then be broken apart into the sum of trend employment, ENFB*, and the trend workweek, WW*

$HNFB^*_t = ENFB^*_t + WW^*_t$

This means that nonfarm business output is now

$NFBO^*_t = ENFB^*_t + WW^*_t + OPH^*_t$

We also need to reconcile the differences between employment from the establishment survey, which is used to estimate nonfarm business sector employment, ENFB, and the variables that come out of the Current Population Survey (CPS), such as the employment rate, ER, and the labor force participation rate, LFPR.

The Current Population Survey contains a wider set of workers, including those who are self-employed, work in agriculture, unpaid family workers, and private household workers, among others. In contrast, the establishment survey that yields ENFB includes only those on actual payrolls. CPS employment is usually about 10mn higher than ENFB employment, but the trends in the two series are very similar. The BLS also produces a population adjusted series that turns CPS household employment into a payroll-equivalent measure.

In the Current Population Survey, per capita aggregate employment, ECPS, is defined as

$ECPS_t = ER_t + LFPR_t$

and, since CPS employment and payroll employment generally move together over time, we can specify the following

$ENFB^*_t = ECPS^*_t + ESR^*_t$

where ESR is the employment sector ratio. In practice, ENFB = ECPS*ESR, and since ECPS>ENB, the value of ESR would be below unity. Once logs are applied, the equation turns into the additive equation above. Now, using the definition of ECPS, we have

$ENFB^*_t = ER^*_t + LFPR^*_t + ESR^*_t$

Therefore, we now have trend nonfarm business employment comprising the trend employment rate, trend participation, and the employment sector ratio. This establishes the equivalence between the two concepts of employment and allows us to examine important labor market inputs in potential GDP.

Next, note that the trend employment rate is a transformation of NAIRU

$NAIRU^*_t = 100[1 - \exp(ER^*_t)]$

Then, we define potential output in the economy as potential gross domestic output, GDO*,

$GDO^*_t = NFBO^*_t + OSR^*_t$

where OSR is the output sector ratio and has a equivalent relationship to ESR. Gross domestic output includes government and agriculture output, while nonfarm business output does not. As discussed above, the ability to use multiple variables should enhance the accuracy of our estimates, but we must be careful in constructing the structural relationships that define potential growth by taking into account any discrepancies between the underlying series. ESR and OSR are intended to bridge these gaps and ensure equivalence.

This now creates a system of trends that are the building blocks on which the other trends can be constructed

$NFBO^*_t = HNFB^*_t + OPH^*_t$

$HINFB^*_t = ENFB^*_t + WW^*_t$

$ENFB^*_t = ECPS^*_t + ESR^*_t$

$ECPS^*_t = ER^*_t + LFPR^*_t$

$GDO^*_t = NFBO^*_t + OSR^*_t$

Once LFPR* and ER* are known, this gives ECS*. ECPS* plus ESR* gives ENFB*. ENFB* and WW* give HINFB*, which yields NFBO* along with OPH*. NFBO* and OSR" then give GDO*. Not surprisingly. these six trends (and population growth) are the building blocks of potential growth from the supply side of the economy.

Specifying the trend and idiosyncratic errors

We now need to make assumptions about how the trend evolves and the error specification. We have stated that the observed variables are a function of the trend and cycle (and we have defined the properties of the cycle to be AR(2)), but we have yet to define the properties of the trend itself and the errors. Each trend is assumed to follow a random walk with drift

$Z_t = Z_{t-1} + \Upsilon^*_{zt} + \varepsilon_{zt}$

The Υ variable is the rate of drift over time. If it is greater than zero, the trend will exhibit a random walk around an upward trend. If it is less than zero, the drift will be downward. In the unlikely case that Υ equals zero, the trend would be better modelled as a random walk without drift (note also that we are explicitly defining the coefficient on Z(t-1) to be equal to 1. Otherwise, we would be positing an AR(.) process like we do for the cycle).

We assume the drift term evolves as a random walk without drift

$\Upsilon_{zt} = \Upsilon_{zt-1} + v_{zt}$

This is necessary so that the trend in z could be positive or negative over time. LFPR, for example, trended higher before turning negative in the early part of the previous decade.

The exception is the employment rate, ER, which we assume follows a random walk without drift. This makes intuitive sense since ER and, hence, the unemployment rate, are stationary over time and no drift term is needed. Therefore,

$ER^*_t = ER^*_{t-1} + \varepsilon_{ERt}$

with $\Upsilon_{ERt} = 0$.

The errors for the labor market variables and inflation are assumed to be IID. As noted in Fleischman and Roberts (2011), the assumption that errors are IID is equivalent to saying there could be measurement errors or reflect the presence of ID structural shocks. An alternative specification could be an MA(.) process where the current shock and persistence of the previous shock both matter for the current observation.

For the output measures, the interrelationship between the errors is more complex. The idiosyncratic errors for the nonfarm business sector are modelled as composed of two components, one that is common to the two and another that is measure specific. For the nonfarm business income and output equations, we have

$NFBP_t = NFBO^*_t + \Upsilon_{10}cyc, + u_{3t}$

$NFBI_t = NFBO^*_t + \Upsilon_{10}cyc, + u_{3t}$

where

$u_{3t} = v_{3t} + \varepsilon_{3t}$

$u_{4t} = v_{4t} + \varepsilon_{3t}$

The v_{3t} and v_{4t} terms reflect the shock unique to each variable and ε_{3t} represents the common shock. One interpretation is that v_{3t} and v_{4t} can be seen as measurement error, while ε_{3t} captures the structural component. After all, NFBP and NFBI are product and income measures of the same output, and structural shocks should affect both the same way.

Finally, we assume a similar relationship for GDP and GDI

$GDP_t = GDO^*_t + cyc_t + u_{3t}$

$GDI_t = GDO^*_t + cyc_t + u_{2t}$

where

$u_{1t} = \sigma u_{3t} + \xi_{1t}$

$u_{2t} = \sigma u_{4t} + \xi_{1t}$

where

$\sigma = 1/\lambda_{10}$. The equations reflect the accounting identity that GDP is the sum of NFBP plus the output sector ratio, OSR, while GDI is the sum of NFBI and the income sector ratio. Thus, there is room in the system for a shock to affect NFBI, NFBO, GDP. and GDI in a similar way that also respects the accounting identities. imposing $\sigma = 1/\lambda_{10}$ reflects this. There is only one idiosyncratic factor for both GDP and GDI because any discrepancy between NFBO and GDO Is measured only on the Income side. As a result, GDP - NFBP = GDP - NFBI.

in sum, the idiosyncratic errors can be rearranged as

$u_{1t} = \sigma(v_{3t} + \varepsilon_{3t}) + \xi_{1t}$

$u_{2t} = \sigma(v_{4t} + \varepsilon_{3t}) + \xi_{2t}$

which can be simplified to

GDO: $u_{1t} = \sigma(v_{3t} + \varepsilon_{3t}) + \xi_{1t}$

GDO: $u_{2t} = \sigma(v_{4t} + \varepsilon_{3t}) + \xi_{2t}$

NFBO: $u_{3t} = v_{3t} + \varepsilon_{3t}$

NFBO: $u_{4t} = v_{4t} + \varepsilon_{3t}$

Here it is straightforward to see the common error in GDO and NFBO. NFBO has its own separate IID errors in v_{3t} and v_{4t} which are transmitted to GDO via $\sigma = 1/\lambda_{10}$. This structure mimics the fact that nonfarm business output is a subset of total output with its own common shock and separate IID errors. GDO must receive these, scaled by the output sector ratio, but since GDO > NFBO, then GDO needs its own unique shock. Then, given how NIPA accounting works (with discrepancy between NFBO and GDO measured only on the income side), we only need one IID error term in GDO instead of two.

Model summary

Based on the relationships above, we can now characterize the data and define GDP, NFBP, and NFBI. For GDP:

$GDP_t = GDO^*_t + cyc_t + u_{1t}$

$GDP_t = NFBO^*_t + OSR^*_t + cyc_t + u_{1t}$

$GDP_t = HNFB^*_t + OPH^*_t + OSR^*_t + cyc_t + u_{1t}$

$GDP_t = ENFB^*_t + WW^*_t + OPH^*_t + OSR^*_t + cyc_t + u_{1t}$

$GDP_t = ECPS^*_t + ESR^*_t + WW^*_t + OPH^*_t + OSR^*_t + cyc_t + u_{1t}$

$GDP_t = ER^*_t + LFPR^*_t + ESR^*_t + WW^*_t + OPH^*_t + OSR^*_t + cyc_t + u_{1t}$

$GDP_t = ER^*_t + LFPR^*_t + ESR^*_t + WW^*_t + OPH^*_t + OSR^*_t + cyc_t + \sigma(v_{3t} + \varepsilon_{3t}) + \xi_{1t}$

As constructed, GDP comprises trends in the employment rate, labor force participation, the employment sector ratio, the work week, output per hour in the nonfarm business sector, the output sector ration, an estimate of the cycle, a common error associated with NFBO, and an IID error specific to GDP.

Similar substitutions can be done to arrive at:

$NFBP_i = ER^*_t + LFPR^*_t + ESR^*_t + WW^*_t + OPH^*_t + \lambda_{10}\, cyc_t + v_{3t} + \varepsilon_{3t}$

$NFBI_i = ER^*_t + LFPR^*_t + ESR^*_t + WW^*_t + OPH^*_t + \lambda_{10}\, cyc_t + v_{4t} + \varepsilon_{3t}$

From here, we refer readers to Fleischman and Roberts (2011) to see how the system of equations can be represented in matrix form. In forming the system of equations, it turns out that a subset of the output variables contains the same information as the full set of variables. We follow the decision of Fleischman and Roberts (2011) to take advantage of the situation and exclude GDI from the model.

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Research Analysts

US Economics

Michael Gapen
US Economist
BofAS
+1 646 855 3270
michael.gapen@bofa.com

Aditya Bhave
US Economist
BofAS
+1 646 855 9929
aditya.bhave@bofa.com

Stephen Juneau
US Economist
BofAS
+1 202 442 7429
stephen.juneau@bofa.com

Shruti Mishra
US and Global Economist
BofAS
+1 646 855 1040
smishra44@bofa.com

Jeseo Park
US Economist
BofAS
+1 646 855 8688
jeseo.park@bofa.com