PREDICTING MEDIUM-TERM TFP GROWTH IN THE UNITED STATES: ECONOMETRICS VS 'TECHNO-OPTIMISM'

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We analyse TFP growth in the US business sector using a basic unobserved component model where trend growth follows a random walk and the noise is a first order autoregression. This is fitted using a Kalman-filter methodology. We find that trend TFP growth has declined steadily from 1.5 to 1.0 per cent per year over the past 50 years. Nevertheless, recent trends are not a good guide to actual medium-term TFP growth. This exhibits substantial variations and is quite unpredictable. Techno-optimists should not give best to productivity pessimists simply because recent TFP growth has been weak.

Keywords: productivity slowdown, secular stagnation, TFP growth

JEL codes: E32, N12, O47

1. Introduction

Technological change is the ultimate source of sustained growth of labour productivity and thus of long-run increases in living standards. In a conventional neoclassical growth model, it will be represented by the growth of total factor productivity (TFP). Growth accounting provides a methodology for estimating TFP growth and its contribution to labour productivity growth. Viewed from the perspective of this growth model, the growth accounting measure of the importance of TFP is an underestimate since the rate of growth of the capital stock is endogenous and, in the steady state, is equal to the exogenous natural rate of growth. Thus, a rise in the TFP growth rate induces capital accumulation and the steady-state rate of labour productivity growth is proportional to TFP growth. So, the TFP growth rate is a fundamental building block for projections of the rate of growth of potential output. In a world-leading economy (United States) this will be largely based on domestic innovative activity but in follower economies (Western Europe) there will be a significant contribution from technology transfer which exploits opportunities arising from TFP growth at the frontier.

The mainstream method of making such projections is by a more or less sophisticated extrapolation of recent performance. In other words, such methods embody a backward-looking perspective. As the heat of the ICT revolution has cooled and then been superseded by the financial crisis and its aftermath, these projections of future TFP growth have been revised downwards. An alternative, essentially forward-looking, approach is to try to evaluate the likely course of technological progress and its economic impact. At present, this gives a relatively wide range of future scenarios. On the upside, some commentators see a strong upturn in TFP growth based on the transformative scope of new technologies, such as artificial intelligence and robotics; on the downside, other voices say that the low-hanging fruit has all been picked or that the great inventions have already been made. Such punditry is, of course, notoriously difficult, as is epitomised by Robert Solow's 1987 remark that "you can see the computer age everywhere but in the productivity statistics".

The past few decades have seen big swings in expectations about future productivity growth, as the special century gave way to the productivity slowdown, which was followed by the new economy and then fears of secular stagnation. Revised beliefs about long-term future growth prospects have the potential to generate shocks to aggregate demand in the short term if they are reflected in changes in planned investment or

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consumption expenditure because, in classic Keynesian fashion, they impact upon the desired capital stock or permanent income.

In the light of this discussion, several questions arise which this paper addresses on the basis of time-series analysis. First, what has happened to trend TFP growth in the United States over time? Second, in past years, what would an econometric forecasting approach have predicted about future trend TFP growth? Third, how would these *ex-ante* forecasts have compared with estimates of trend TFP growth produced using data from the whole of the postwar period and with actual medium-term TFP growth performance in subsequent years? The results are used to provide a perspective on current debates about future productivity growth.

Given the time series properties of US TFP growth (high variability and modest autocorrelation), a basic unobserved component model, in which trend growth follows a random walk and the noise is a first-order autoregression, is fitted using Kalman filter methodology. Four information sets, the complete sample from 1947 to 2016 of TFP growth, a recursive sample, and two (rolling) fixed windows of length 20 and 25 years respectively, are investigated to provide a variety of forecasts of trend TFP growth.

Our main findings are as follows. First, over fifty years American trend TFP growth in the private non-farm economy has declined slowly but steadily over time from about 1.5 per cent per year in 1967 to about 1.0 per cent per year by 2016. Second, forecast trend TFP growth based on estimated trends over the previous 20- or 25-year window exhibits considerable variation and does not show monotonic decreases. From a level around 2 per cent at the start of the 1970s, these forecasts are generally falling until they reach lows of about 0.5 per cent at times in the 1990s before rising to about 1.2 per cent in the mid-2000s, and then falling back to 1990s levels more recently. Third, average realised TFP growth (adjusted for capacity utilisation) over 10-year intervals – the horizon for which the Congressional Budget Office makes projections – has also varied substantially over time. The outturn fell from 2.0 per cent per year or a little less for intervals starting in the 1960s to 0.5 per cent per year or a little more for intervals from the early 1970s to the late 1980s. It then rose to a peak of 2.0 per cent in the mid-1990s for the years encompassing the height of the 'new economy' before falling back to below 0.5 per cent per year for the period of the financial crisis and its aftermath. Fourth, these 10-year-ahead outturns are not predicted well by forecast trend TFP growth. In particular, sharp reversals of medium-term TFP growth performance are not identified in advance.

These results provide a perspective on today's discussions of the prospects for future American productivity growth. Three points stand out. First, medium-term TFP growth is very unpredictable. Recent performance is not a reliable guide, implying that the disappointing outcomes of the past fifteen years or so will not necessarily continue. Second, a smoothed estimate of trend TFP growth has changed only slowly over time and is well above recent actual TFP growth. This suggests that pessimism about long-term prospects can easily be overdone. Third, given the substantial fluctuations in medium-term TFP growth and the likelihood that forecasts are confounded, it would not be surprising if revisions to expectations about future productivity growth are a source of significant aggregate-demand shocks.

2. Literature review

It has been widely noticed that the productivity slowdown in the United States started before the financial crisis and has very largely been the result of a significant fall in TFP growth. It is also generally agreed in the specialist literature that the slowdown is not an artefact of the data. A recent careful review of the evidence (Byrne *et al*., 2016) demonstrated these points and its summary of the history of TFP growth is reported in table 1.[1] The mainstream view which is represented by these authors is that slower TFP growth in the recent past reflects a weaker impact from technological progress. It should, however, be noted that an alternative school of thought stresses the role of "declining business dynamism" (Decker *et al*., 2017) which entails reduced rates of business start-ups and job reallocation, possible explanations for which might include more onerous regulation or weaker competition.

Econometric investigations have concluded that slower TFP growth reflects a considerable reduction in trend TFP growth, although the extent of this fall varies somewhat depending on the data and techniques that are used. Thus, using an amalgam of a regression approach

Table 1. TFP growth in the US business sector, 1947–2015 (average rate, % per annum)

1947Q2 – 1973Q1	2.10
1973Q1 – 1995Q1	0.52
1995Q1 – 2004Q1	1.99
2004Q1 – 2015Q1	0.48

Source: Byrne *et al.* (2016).

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and Hodrick-Prescott filter methodology, Ollivaud *et al*. (2016) estimated that trend TFP growth for GDP was 1.1 per cent per year in 2000, falling to 0.9 per cent by 2007 and 0.7 per cent in 2015. Havik *et al*. (2014) employed an approach based on an unobserved components model incorporating a contemporaneous relationship between TFP and capacity utilisation and estimated using Bayesian techniques and the Kalman filter, finding that trend TFP growth for GDP fell from 1.6 per cent at the turn of the century to 0.9 per cent by 2008, at which level it remained through 2014. Antolin-Diaz *et al*. (2017) derived their estimates of trend labour productivity growth using a dynamic factor model. They concluded that this had fallen from well above 2 per cent per year in 2000 to about 1.5 per cent by the start of the crisis and to only about 1 per cent in recent years. Their estimate of trend TFP growth in the business sector (plotted in Figure K.1(b) of their Online Appendix) declines from around 1.8 per cent in 1970 to about 0.7 per cent in the early 1990s before rising to about 1.6 per cent in the late 1990s and then falling to about 0.4 per cent by 2015. They present their findings for the recent past as confirming claims that long-run growth in the United States has declined – in other words it might be expected that the slowdown will persist.

Estimates of this kind inform projections of future TFP growth over 10-year horizons, which are used as a guide by policymakers interested in fiscal sustainability or the output gap. The Congressional Budget Office has published such projections for the business sector regularly since 2002. Their projection of TFP growth is produced by extrapolating the growth rate of the recent past, sometimes with *ad hoc* adjustments (CBO, 2001, p.56). The CBO projection rose from 1.2 per cent per year in August 2002 to a peak of 1.5 per cent in August 2006, after which it fell back to 1.2 per cent by January 2011 and stood at 1.1 per cent as of January 2017. The CBO has clearly been more conservative in revising its projections than the revisions to estimates of trend TFP growth discussed above would indicate.[2]

All of these approaches to projecting future TFP growth rely on 'backward-looking' econometrics. They exhibit low variance compared with the (implicit) forecasts of commentators trying to predict the economic impact of future technological progress on a 'forward-looking' basis. Both 'techno-optimism' and 'techno-pessimism' feature prominently in contemporary discourse. Among the optimists, Brynjolfsson and McAfee (2014) stand out for their projections of the implications of what they call the "second machine age" based on artificial intelligence, robotics and the digital revolution. They suggested that this will be more important than anything since the industrial revolution and will deliver an unprecedented rate of technological advance. This would imply TFP growth of over 2 per cent per year to outstrip the best decades of the 20th century.[3] Their vision is supported by Frey and Osborne (2017), who undertook a detailed analysis of what jobs entail and estimated that 47 per cent of 2010 employment in the United States has at least a 70 per cent chance of being computerised by 2035.

Among the pessimists, the best-known is Gordon (2016). Without much supporting evidence, he argues that, although there will be vigorous innovative activity, its economic impact will be modest. Robots and driverless cars will have relatively little impact on productivity performance. The 'great inventions' are in the past and TFP growth over the next 25 years will be similar to the average of 2004–15. This would imply TFP growth in the business sector of around 0.4 per cent per year. These sentiments are echoed by Cowen (2011), who claimed that Americans have lived off 'low-hanging fruit' in the past but that this is mostly gone.

While Gordon (2016) sees the new technologies that comprise the 'digital revolution' as never having much effect on productivity growth, others, appealing to the experience of past general purpose technologies, see a gestation period before their full effect materialises, as happened, for example, when the ICT-related 'Solow productivity paradox' evaporated in the 1990s. Van Ark (2016) provides a good statement of this position.

Excessive optimism or pessimism by economists about future TFP growth is, of course, by no means unprecedented. Alan Greenspan (2000) said in a speech that, "When we look back at the 1990s from the perspective of, say, 2010. . . we may conceivably conclude. . . that, at the turn of the millennium, the American economy was experiencing a once-in-a-century acceleration of innovation which propelled forward productivity. . . at a pace not seen in generations, if ever."[4] Within a few years, this was revealed to be (widely shared) wishful thinking. In contrast, Alvin Hansen (1939), in the presidential address that made famous the idea of 'secular stagnation', offered a gloomy view of the possibilities for technological progress, stating that, "a full-fledged recovery. . . awaits the development of great new industries and new techniques. But such developments are not currently available. . .". Yet the period from the 1930s through the 1960s saw the fastest TFP growth in American economic history which underpinned the postwar investment boom.

Hansen's real concern was that, in the absence of good news about technology and in the face of declining population growth, investment expenditure would be weak and the economy would suffer from inadequate aggregate demand. Recent research has returned to this theme. Using simulations of the FRB/US macro model, Blanchard *et al*. (2017) find that news of a decline of 0.1 percentage points in the CBO-projected long-term potential output growth rate leads to a shock to aggregate demand of 0.39 percent of GDP under 'model-consistent (MC)' (forward looking) expectations in normal circumstances or 0.67 per cent when nominal interest rates are at the lower bound (LB). The effect of a 0.1 percentage point decline in projected TFP growth would be larger. In a Solow growth model setting, long-term potential output growth would fall by about 0.14 percentage points and the demand shock would be 0.55 (MC) or 0.96 (LB) per cent of GDP.[5]

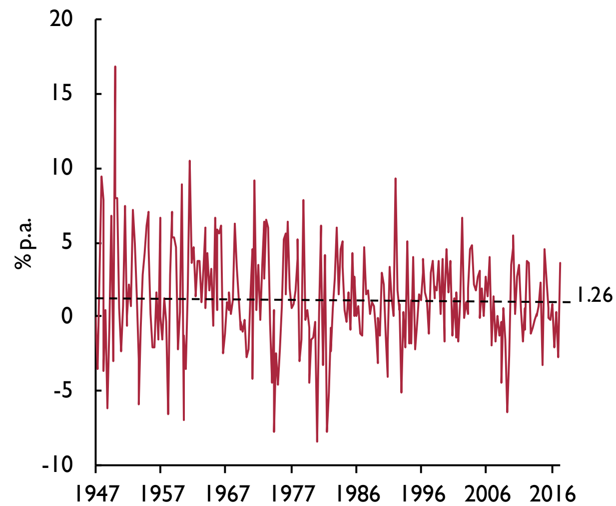
In sum, there is general agreement in papers based on econometric analysis of the recent past that trend TFP growth in the United States has fallen since the start of the 21st century. In contrast, well-informed commentators basing their claims on speculations about future technological progress and its economic impact offer a wide range of projections ranging from quite pessimistic to very optimistic.

3. Data and econometric modelling

We analyse quarterly TFP growth for the US business sector. The full sample covers 1947Q2 to 2016Q4. We make use of two series, one of which is a standard growth accounting estimate and the other incorporates an adjustment for variations in factor utilisation. The data are available at http://www.frbsf.org/economics/economists/jfernald/quarterly_tfp.xls. A full description of sources and methods is provided by the author in Fernald (2014). The data are recorded as 400 x log change. Our main econometric analysis estimates trend TFP growth using the standard growth accounting estimate but in figure 4 we also consider comparisons with actual average capacity-utilisation-adjusted TFP growth rates.

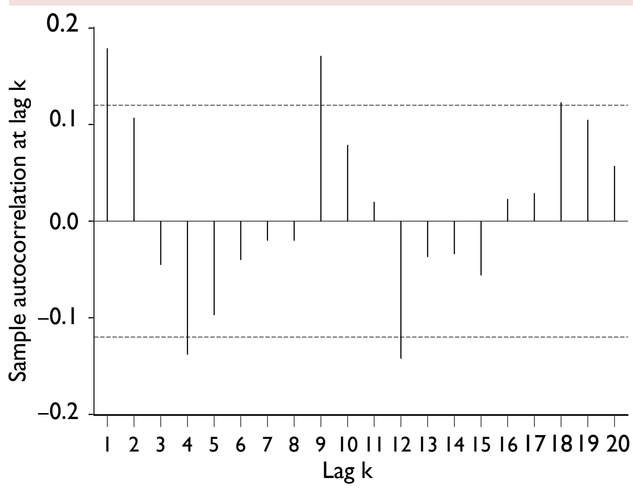
Figure 1 shows the growth accounting estimate of TFP growth for the full sample, while figure 2 shows its accompanying sample autocorrelation function. The series fluctuates widely around the sample mean of 1.26 per cent per annum, the standard deviation being 3.46 with a maximum value of 16.9 in 1950Q1 and a minimum of –8.4 in 1980Q2. The series is also modestly autocorrelated, with a significant lag-1 autocorrelation of 0.18, but no evidence of pronounced seasonality or cyclicality.

Figure 1. US TFP growth: per cent per annum, 1947Q1–2016Q4



Source: Fernald (2014).

Figure 2. Sample autocorrelations of US TFP growth with two standard error bounds (±0.12)



Consequently, given the relatively high level of noise and the limited extent of autocorrelation, the following basic unobserved component model for quarterly TFP growth, y_t, was chosen to analyse trend growth rates

$$y_t = \alpha_t + z_t \qquad t = 1, \ldots, T$$

α_t is the level component and may be regarded as 'trend TFP growth', while z_t is the noise component. The two components are specified as

$$\alpha_t = \alpha_{t-1} + a_t \qquad a_t \sim WN(0, \sigma_a^2)$$
$$z_t = \rho z_{t-1} + b_t \qquad b_t \sim WN(0, \sigma_b^2)$$

i.e., trend growth evolves as a random walk with the noise being generated as a first-order autoregression: the notation $x_t \sim WN(0, \sigma^2)$ is to be read as x_t is zero mean white noise with variance σ^2. This specification of the noise is consistent with the autocorrelation behaviour shown in figure 2. This is a state space model and thus can be estimated as such using Kalman filter technology (all computations were performed using the State Space (SSpace) object in *Econometric Views*: see *Econometric Views 8*, *Users Guide II*, chapter 19, for full details).

Estimates of the variances σ_a^2 and σ_b^2 and the autoregressive coefficient ρ, and hence the estimate of trend growth α_t, were computed using four different information sets: (i) the full sample $\{T\} = (1,...T)$; a recursive sample $\{t\} = (1,...,t)$ for $t = 100,...,T$; (iii) a 20-year fixed rolling window $\{t,80\} = (t-79,...,t)$ for $t = 80,...,T$; and a 25-year fixed rolling window $\{t,100\} = (t-99,...,t)$. Here $t = 1$ corresponds to 1947Q2 and $t = T$ corresponds to 2016Q4. The estimate $\hat{\alpha}_{t|\{T\}}$ is known as the 'smoothed' trend growth estimate, and utilises the full sample of observations to achieve an 'optimal' estimate of the trend growth component. Because future observations $t + 1,...,T$ are used in computing the estimate at t this smoothed estimate is inappropriate for forecasting purposes and should thus be regarded as a 'baseline' estimate with which other forecasts may be compared. The recursive estimate $\hat{\alpha}_{t+1|\{T\}}$ utilises only known observations to make a one-step ahead forecast of trend growth at t (the initial recursion uses 100 observations in order to provide a sufficiently precise first estimate $\hat{\alpha}_{101|\{100\}}$).

The two fixed window estimates, $\hat{\alpha}_{t+1|\{t,80\}}$ and $\hat{\alpha}_{t+1|\{t,100\}}$, attempt to incorporate the possibility that forecasters use only a limited history of past observations, rather than the entire available history as in the recursive estimate. Twenty and 25-year windows were chosen as a trade-off between using only recent history and the necessity of having a large enough sample to produce estimates of sufficient precision.

Figure 3 shows the smoothed, $\hat{\alpha}_{t|\{T\}}$, and recursive, $\hat{\alpha}_{t+1|\{T\}}$ estimates of trend TFP growth, while figure 4 shows the two fixed-rolling window estimates (forecasts), $\hat{\alpha}_{t+1|\{t,80\}}$ and $\hat{\alpha}_{t+1|\{t,100\}}$. Also shown in this figure is the 10-year-ahead outturn of average TFP growth (adjusted for capacity utilisation), computed as the sample mean of that series calculated using the previous ten years of quarterly observations.

Figure 3. Trend TFP growth estimates $\hat{\alpha}_{t|\{T\}}$ (smoothed) and $\hat{\alpha}_{t|\{t\}}$ (rolling): 1967–2016)

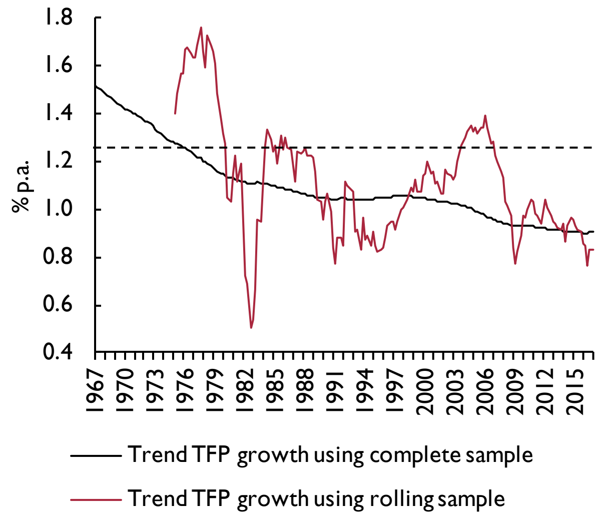
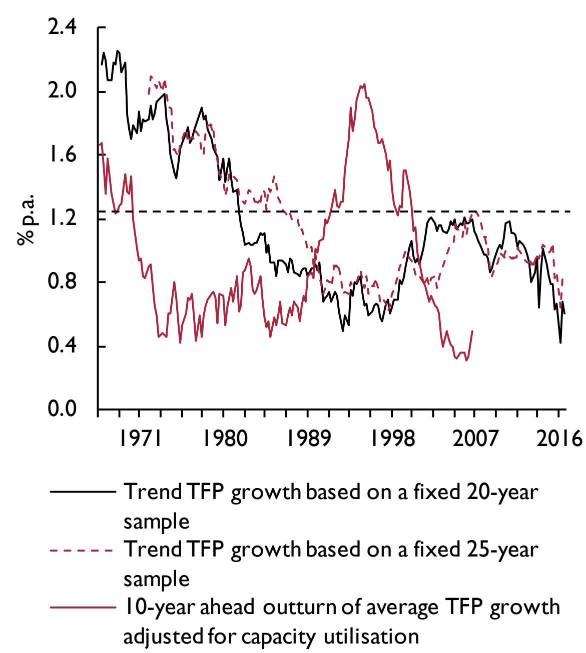


Figure 4. Trend TFP growth estimates $\hat{\alpha}_{t|\{t,80\}}$ (fixed 20-year window) and $\hat{\alpha}_{t|\{t,100\}}$ (fixed 25-year window) plus 10-year ahead outturn of average TFP growth adjusted for capacity utilisation: 1975–2016)



From figure 3, the smoothed estimate of trend TFP growth is seen to have declined slowly but steadily over time, from about 1.5 per cent per year in 1967 to about

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1.0 per cent per year by 2016. The standard errors attached to these estimates range from 0.33 in the middle of the full sample to 0.47 at the beginning and end of the sample, reflecting the well-known property of smoothed estimates that they become less precise at the two ends of the sample because of truncation effects. The recursive estimate displays a similar long-run movement but, naturally, is more variable, displaying irregular swings around the long-run declining trend. Trend TFP growth based on 20- and 25-year windows exhibits considerable variation and does not show monotonic decreases. From a level of around 2 per cent at the start of the 1970s, these forecasts are generally falling until they reach lows of about 0.5 per cent at times in the 1990s before rising to about 1.2 per cent in the mid-2000s, and then falling back to 1990s levels more recently. The recursive and fixed window forecasts have standard errors that range from 0.43 to 0.63, although the size of the standard error does not have a simple relationship with *t*.

The component model may be interpreted as implying that trend growth shifts permanently every quarter as new information becomes available. An alternative formulation that was also considered is that trend growth generally remains constant, shifting only occasionally in response to discrete exogenous shocks. These discrete breaks in the process may then be estimated using the Bai and Perron (1998, 2003) procedure or its subsequent variants (see *Econometric Views 8*, *Users Guide II*, chapter 12, for details). These tests all select 1973Q2 as a single break date, using which trend growth of 2.09 per cent per annum pre-break and 0.76 post-break was estimated. These values effectively average out the smoothed growth estimates across the pre- and post-break samples respectively. Such a 'breaking level' model is, of course, unsuited for forecasting as the (potential) break-dates are unknown before they occur.

The assumption inherent in our model that the level component follows a random walk rather than exhibiting 'mean reversion' was examined by allowing the level to be alternatively modelled as a stationary first-order autoregression, $\alpha_t = \rho\alpha_{t-1}+a_t$. The mean reversion parameter ρ was estimated to be in excess of 0.99, thus confirming the validity of our random walk assumption.

Average realised TFP growth (adjusted for capacity utilisation) over 10-year intervals – the horizon for which the Congressional Budget Office makes projections – has also varied substantially over time. The outturn fell from 2.0 per cent per year or a little less for intervals starting in the 1960s to just 0.5 per cent per year or a little more for intervals from the early-1970s to the late 1980s. It then rose to a peak of 2.0 per cent in the mid-1990s for the years encompassing the height of the 'new economy' before falling back to below 0.5 per cent per year for the period of the financial crisis and its aftermath. These 10-year-ahead outturns are not predicted well by using estimated trend TFP growth to forecast, as is apparent in figure 4.[6] Indeed, forecasting on this basis would have missed the productivity slowdown of the 1970s, the acceleration of the mid-1990s, and the slowdown of recent years – in other words, all the major episodes during the period!

4. Implications for US growth prospects

Our estimates of trend TFP growth in the business sector based on the complete sample of observations suggest that it was about 1.0 per cent per year in 2016. This certainly represents a significant decline compared with 50 years ago, but at the same time it is hardly the end of technological progress. If this estimate is used as a basis for a medium-term projection of future TFP growth, it would be quite similar to the analysis of the CBO (2017). If, however, trend TFP growth is inferred from a sample based on the past 20 or 25 years and this estimate is used as a basis for medium-term projection, then future TFP growth would be around 0.5 to 0.7 per cent per year, well below the turn-of-the-century level and quite close to what 'techno-pessimism' might imply, while the change since 2000 would be similar to that found by Ollivaud *et al.* (2016).

In fact, past experience suggests that neither of these approaches is a reliable way to forecast actual average TFP growth over the next ten years even when taking the capacity-utilisation-adjusted measure. This has exhibited a high variance, some sharp reversals and is not predictable. A notable example of this was the surge of the mid-1990s, which reminds us that the surprises can be on the upside. A repeat of this would quickly undermine belief in slow long-run growth. The 1990s' episode clearly owed a good deal to the end of the 'Solow productivity paradox' with the flowering of the ICT revolution after a long gestation period. Growth accounting estimates show an increase of 0.36 percentage points per year in the contribution of IT sectors in 1995–2004 compared with 1974–95; this was followed by a fall of 0.44 percentage points between 1995–2004 and 2004–12 (Byrne *et al.*, 2013).

There are good reasons to believe that this phased impact on productivity growth is typical of general purpose technologies (Lipsey *et al.*, 2005). Awareness of and excitement about the new technology comes well before it has matured to the point where it makes a big

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difference. A true believer in the 'second machine age' could take heart from this and at the same time offer a further justification for ignoring forecasts similar to those based on 20-year or 25-year windows in figure 4. Possibly, 'techno-optimists' could know better than econometricians.

This discussion suggests that as in the past there is scope for revisions to conventional wisdom about medium-term productivity growth prospects to affect aggregate demand and growth over the short term. Bad news about future growth prospects has a negative impact on today's consumption and investment expenditure. Our results suggest that shocks of this kind may have been important at times over the past 50 years, including in the aftermath of the recent financial crisis. For example, using the 20-year window to estimate trend TFP growth, there was an increase of about 0.5 percentage points in three years in the late 1990s and similar decreases in the early 1980s and around 2010. These moves are larger than those embodied in the projections made by the Congressional Budget Office, which almost never change by more than 0.2 percentage points over three years.[7]

Given that steady-state growth in potential output is a multiple of about 1.4 times the TFP growth rate, these shocks are non-trivial according to the estimates of Blanchard *et al.* (2017) reported above. A change in projected TFP growth of 0.5 percentage points over three years represents a demand shock of about 2.75 per cent of GDP (0.9 per cent per year) in normal circumstances but around 4.8 per cent at the lower bound. This suggests that reduced expectations of future growth may have played an important part in the resort to unconventional monetary policy during recovery from the financial crisis. By the same token, the ICT-based upturn in TFP growth during the 1990s implied a strong positive demand shock as would a general switch to 'techno-optimism' in future.

What, if any, are the implications of this discussion for the interpretation of recent productivity performance and future growth prospects in European countries (many of which, including France, Germany and the UK, have experienced serious slowdowns in TFP growth recently)? This is not altogether clear. If US TFP growth is dominated by changes in the rate of technological progress and new technologies are quickly and effectively adopted by European countries, then European prospects also depend on whether the techno-optimists or techno-pessimists are vindicated. Notably, employment structures are such that OECD countries have quite similar proportions of tasks that might be replaced by robots (Arntz *et al.*, 2016). If, however, American TFP growth is undermined by declining business dynamism and/or Europe engages vigorously in structural reform then future TFP performance may well diverge. Similarly, the financial crisis has significantly impaired TFP growth in some countries and may continue to do so for a while yet and this also complicates matters since a simple technological interpretation of recent trends is incomplete.[8]

5. Conclusions

Our smoothed estimate of the trend rate of TFP growth has declined persistently but slowly over the past 50 years and is now about 1 per cent per year. This is similar to projections of the average rate of TFP growth over the next 10 years made by the Congressional Budget Office (2017). The estimate of trend TFP growth is, however, sensitive to the econometric methodology employed, since trends inferred from 20- or 25-year windows are appreciably lower and have fallen considerably since 2007 to around 0.5–0.7 per cent per year.

Average annual TFP growth over 10-year periods, however, varies a lot – the range is from 0.4 to 2.0 per cent per year in the past 50 years – and exhibits sharp fluctuations. Not surprisingly, estimates of trend TFP growth based on *ex-ante* information are not good predictors of medium-term future TFP growth. Moreover, they have the inherent weakness of being unable to take account of information on technology futures. This suggests that the productivity slowdown may not be as firmly entrenched as is sometimes believed and expectations about future growth prospects could change significantly in a short space of time. Techno-optimism should not be dismissed simply on the basis of econometrics; past performance is not a good guide to future medium-term TFP growth. Our analysis suggests that the case for assuming that slow TFP growth is the 'new normal' is 'not proven'. More generally, it seems likely that revisions to beliefs about future TFP growth have been and will continue to be important sources of shocks to aggregate demand.

NOTES

1 Other papers concluding that mis-measurement is a minor issue and that the slowdown is real include Ahmad *et al.* (2017) and Syverson (2017).
2 The CBO does not reveal precise details of its methodology.
3 An important caveat is the emphasis placed by these authors on the likelihood that a significant fraction of the gains will not be reflected in GDP. There may also be time lags before the full impact comes through.

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4 It is fair to point out that Greenspan noted that it was not possible to rule out the alternative that there was a massive speculative bubble, but the speech makes clear that he was a true believer that it was a productivity miracle.

5 This assumes that steady-state growth is given by TFP Growth/$(1-\alpha)$, where α is the share of capital, assumed to be 0.3.

6 This remark is not specific to our approach but applies quite generally. For example, trend TFP growth as estimated by Antolin-Diaz *et al*. (2017) follows a rather similar path to that obtained using our 20-year window and therefore misses the key changes in realised medium-term outcomes in similar fashion.

7 The only exception to this is a reduction of 0.3 percentage points between August 2015 and August 2016 (CBO, 2017).

8 There are important papers which find evidence of significant adverse effects of the crisis, for example, Duval *et al*. (2017) and Gamberoni *et al*. (2016), but there is not yet a comprehensive account of its implications for comparative productivity performance.

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