Europe Economics

Additional Evidence on Some Points Relating to Frontier Shift

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Contents

Executive Summary

This report presents further evidence in relation to some of the issues covered in the CMA's provisional findings on the scale of frontier shift that water companies can be expected to achieve over AMP7. In particular, it provides further evidence in relation to the following:

- The explanations put forward in the academic literature for the economy-wide productivity slowdown observed in advanced economies since the mid-2000s and why they do not imply lower frontier shift in the water sector.
- The application of gross value-added TFP estimates.
- Further academic evidence on the size of uplift needed to account for embodied technical change.
- Additional productivity gains from totex and outcomes regime.

We summarise the additional evidence in each of these areas below.

Economy-wide slowdown in productivity

The academic literature has put forward a range of possible explanations for the economy-wide slowdown in productivity observed in advanced economies, including in the UK, since the mid-2000s.

In the context of assessing the scale of frontier shift water companies can be expected to achieve over AMP7, this has two implications.

First, we cannot be sure whether the slowdown will continue throughout AMP7. This is because we cannot be sure what has caused the historical slowdown given the number of competing explanations put forward by the literature with no consensus about which explanation is the correct one. Further, a significant minority of the explanations that have been put forward suggest a much more optimistic picture about future productivity growth, including a reversion of the slowdown.

Second, the factors that may have contributed to the economy-wide slowdown in productivity do not imply lower frontier shift for the water sector. The reasons for this are summarised in the table below.

Table 1: Summary of factors contributing to the slowdown in productivity

Factor driving slowdown in productivity	Why this factor does not imply lower frontier shift in the water sector
Underestimation of productivity growth in ICT and digital services	Factor has small effect and is not relevant to water sector; in any case, it would mean that true productivity growth was higher than reported figures.
End of temporary period of faster productivity growth driven by ICT and associated business reorganization	No reason why new technologies (e.g. smart water networks) will not materialise in the water sector over AMP7.
Slowdown is confined to specific sectors, including manufacturing and financial services	Productivity slowdowns in finance and manufacturing were driven by idiosyncratic factors not relevant to water sector (measurement issue in finance sector, reduced capital deepening in manufacturing) .
Labour hoarding following 2008-09 crisis	Even for the economy as a whole, unlikely still to apply this many years after the 2008-09 crisis; in any case, water sector not affected in the same way due to stable demand and revenues.
Lax monetary policy and low interest rates led to higher survival of less efficient ('zombie') firms	Capital misallocation less likely in the UK due to a more efficient financial system; none of the regulated water companies bear any resemblance to 'zombie' firms (where current profits do not cover debt interest costs over extended period); regulated framework requires laggard firms to catch up, regardless of monetary environment.
Credit constraints prevented firms investing to increase productivity	Ofwat is allowing substantial capex within allowed revenues at PR19, and has a financeability duty which means efficient water companies should not face credit constraints.
Weak anticipated consumption growth weakens investment incentives	Demand faced by water companies is less affected in periods of downturn and revenues are protected through revenue cap; further, firms have ability and incentive to invest due to funding for allowed capex programme within allowed revenue and the RCV mechanism which guarantees cost recovery and a return on investment.
Increase in industry concentration reduces aggregate productivity and causes TFP measurement problems	No significant changes in industry concentration or market power in water sector; in any case, regulation seeks to set frontier shift on basis of what would be achieved in competitive market.
While frontier firms have continued to increase productivity, laggard firms have fallen further behind	Frontier shift ideally measured on basis of performance of frontier firms in comparator sectors; hence, this explanation implies that our frontier shift estimate (based on sectoral averages) is an underestimate of true frontier shift.
Regional differences in productivity growth between London / the South East and the rest of the country	Water companies identified as efficient by Ofwat's assessment of efficient costs cover a range of geographical areas across England and Wales.

Application of gross value-added TFP estimates

In a recent report for the Energy Networks Association, First Economics (John Earwaker's company) argued that a frontier shift figure based on value added productivity growth can only be applied to costs excluding intermediate inputs, in order to be consistent with the way in which the TFP figure has been estimated.[1]

[1] First Economics, "Frontier Productivity Growth; A report prepared for the Energy Networks Association", August 2020, p.15-16, available at: https://www.northerngasnetworks.co.uk/wp-content/uploads/2020/09/RIIO-2-frontier-productivity-growth-First-Economics.pdf

Therefore, First Economics argues that there is an internal inconsistency in using value-added TFP to set a frontier shift challenge for the whole of totex. At first glance, this would appear to remove the rationale for using value-added TFP to aim up when selecting a point estimate for totex frontier shift at PR19.

Our assessment highlights three points in relation to First Economics' argument.

First, First Economics has itself applied value-added TFP to all components of totex in a report for South East Water at PR14.[2]

Second, only some purchases of inputs from other sectors are relevant to the point that First Economics makes. For example, First Economics' point does not apply to purchases of goods and services from other sectors that are part of capex, since capital inputs are conceptually distinct from intermediates in the growth accounting framework that is used to calculate TFP. Similarly, in our view it would be inappropriate to apply First Economics' point to outsourced water sector activities since this would – illogically – lead to a lower frontier shift challenge for a firm which has outsourced more of its operational activities.

Finally, and crucially, a more detailed analysis of how TFP is calculated continues to show that value-added TFP estimates imply higher frontier shift than gross output TFP measures, even after accounting for the point made by First Economics. In particular, in the area of capital, the relevant input into TFP calculations is the total capital stock and not just capex (which is the addition to the capital stock over a given time period). A given percentage TFP growth rate therefore implies a much larger reduction in capex in order to achieve the required reduction to the firm's total capital stock. For example, if capex is 10 per cent of the projected Regulatory Capital Value (RCV), a 10 per cent reduction in capex would be required to achieve a 1 per cent reduction in the RCV. This effect will be much greater in the case of value-added TFP growth rates given that mathematically they will always be greater than gross output TFP growth rates, meaning the value-added TFP estimates will imply higher frontier shift even after accounting for the point made by First Economics.

Further evidence on size of uplift for embodied technical change

Our previous report – informed by the works of Uri (1983) and Hulten (1992) – suggested a traditional TFP estimate would need to be uplifted by a further 60 per cent to account for embodied technical change. In particular, Uri (1983) suggested that embodied and disembodied technical change are of the same order of magnitude.

Further evidence by Sakellaris and Wilson (2004) suggest that embodied technical shift may account for around two-thirds of total technological change, a much larger share than previously assumed. This implies that embodied technical shift is twice as high as disembodied technical shift, and that our previously suggested uplift of 60 per cent should be taken as a lower bound for the size of uplift needed to account for embodied technical change. Combined with our previous assumption from Hulten (1992) that 20 per cent of TFP represents embodied technical shift that has "leaked" into TFP due to measurement error, this new academic evidence could justify an uplift as high as 140 per cent to a TFP estimate to account for embodied technical change.

Additional productivity gains from totex and outcomes regime

There are theoretical reasons for thinking that the additional "industry catch-up" productivity gains that the water sector can achieve due to the totex and outcome framework are likely to last into AMP7 (and beyond).

[2] First Economics, "Water Industry Input Price Inflation and Frontier Productivity Growth A report prepared for South East Water", August 2013, p.22-24, 31-32 available at: https://corporate.southeastwater.co.uk/media/1494/app18tps_firsteconomics.pdf

First, the residual lifetime of assets in the sector is a crucial driver of the time period over which gains can continue to be made, given that firms may only replace existing capex solutions with superior solutions when the existing assets reach the end of their life. Given the typical lifetime of assets in the water sector spans decades, there are strong reasons to expect water sector to continue to make "industry catch-up" productivity gains throughout AMP7 as they continue to re-optimise between capex and opex and between different approaches to achieving outcomes as existing assets reach the end of their life.

Further, current major events such as the COVID-19 crisis and the end of the Brexit transition period may suggest higher potential gains from the totex and outcomes framework over AMP7 due to potential shifts in the relative price of different inputs. For example, the COVID-19 crisis may place downward pressure on wages and could thus increase the cost savings that water companies can achieve from solutions which use more labour and less capital compared with traditional approaches.

Conclusions

In summary, our overall conclusions are:

- The academic literature puts forward a range of competing explanations for the economy-wide productivity slowdown which for various reasons do not imply lower frontier shift in the water sector.
- Even when we take into account First Economics' argument that value added productivity growth can only be applied to costs excluding intermediate inputs, gross value-added TPF growth continues to imply a higher frontier shift assumption than gross output TFP growth.
- Further academic evidence regarding the size of uplift needed to account for embodied technical change suggests that our previous estimate of a 60 per cent uplift should be taken as a lower bound, since the new evidence could justify an uplift as high as 140 per cent.
- There are theoretical reasons for thinking that the additional productivity gains that water companies can achieve due to the totex and outcome framework are likely to last into AMP7 (and beyond).

Taken together, these qualitative and quantitative arguments regarding the scale of frontier shift water companies can be expected to achieve over AMP7 justify an overall frontier shift figure higher than the 1 per cent figure stated in the CMA's provisional findings.

1 Introduction

Aims of the report

Under the PR19 Delivery Partner contract, Europe Economics provided Ofwat with a report on real price effects (RPEs) and frontier shift.[3]

Following the publication of the PR19 final determinations, Ofwat made four references from water companies (Anglian Water, Bristol Water, Northumbrian Water and Yorkshire Water) to the Competition and Markets Authority (CMA) for a redetermination. The CMA published its provisional findings for the water redeterminations on 29 September 2020.[4]

This report presents further evidence in relation to some of the issues covered in the CMA's provisional findings. These include:

- Economy-wide slowdown in productivity: the report presents a range of factors put forward by the academic literature as potential contributors to the productivity slowdown observed in advanced economies since the mid-2000s. We then set out various reasons why none of these factors imply lower frontier shift in the water sector. Our work also considers a number of reasons why the slowdown may not continue in the future.
- Application of gross value-added TFP estimates: in this section of the report, we provide further evidence on why value-added TFP measures justify aiming up when selecting a point figure for frontier shift. This responds to a recent report for the Energy Networks Association by John Earwaker, in which he argued that a frontier shift figure based on value added productivity growth can only be applied to costs excluding intermediate inputs to be consistent with the way in which the TFP figure has been estimated.[5]
- Size of uplift for embodied technical change: our previous report presented some illustrative evidence to suggest that TFP growth estimates might need to be uplifted by as much as 60 per cent to account for embodied technical change, which is excluded from TFP estimates using EU KLEMS data. We present some additional quantitative evidence on the potential size of this uplift, showing that 60 per cent is a lower bound and that the actual uplift that is required may be much larger.
- Additional productivity gains from totex and outcomes regime: in this report, we explain the theoretical reasons for why additional efficiency gains from the totex and outcomes framework are likely to continue in the future, and explain why such efficiency gains may be greater in light of the ongoing COVID-19 economic crisis and the end of the Brexit transition period.

Structure of the report

Our report is structured as follows:

- Section 2 explores the potential factors contributing to the economy-wide slowdown in productivity and explains why they do not apply to the water sector;
- Section 3 provides further detail on why value-added TFP estimates justify aiming up, in response to a point made recently by First Economics (John Earwaker's company);
- Section 4 presents additional academic evidence on the potential size of embodied technical shift; and

[3] Europe Economics, "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", 7 December 2019

[4] CMA, "Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations; Provisional findings", 29 September 2020, [online].

[5] First Economics (2020): Frontier Productivity Growth – A report prepared for the Energy Network Association, p.14-15 [online].

- Section 5 discusses the additional productivity gains that water companies can be expected to achieve from the totex and outcomes regime over AMP7.

2 Economy-wide Slowdown in Productivity

In this chapter we explore the slowdown in productivity that has been observed in advanced economies, including in the UK, since the mid-2000s. First, we explain why this slowdown may not continue in the future. Second, we investigate the reasons contributing to this slowdown that have been put forward by the academic literature and why these do not imply lower frontier shift in the water sector.

2.1 It is not clear that the slowdown will continue

Despite the significant slowdown in productivity shown in the data, it is not at all clear at this point in time that the slowdown will continue in the future, for at least for two main reasons.

First, as presented in the section below, many possible explanations for the productivity slowdown have been put forward, and there is no consensus about which explanation is the correct one. Given the number of competing explanations, we cannot be sure what has caused the historical slowdown and therefore whether it will continue.

Second, a significant minority of the academic literature has put forward explanations that suggest a much more optimistic picture about future productivity growth, including a reversion of the slowdown. This includes:

- Brynjolfsson et al (2018)[6] argue that productivity growth as currently measured may not include the full benefits associated with technologies such as artificial intelligence, which when coupled with complementary innovations can lead to productivity growth that is higher by various orders of magnitude than suggested by current measures.
- Syverson (2013)[7] argue that similar patterns in labour productivity growth during the electrification era in the early 1900s and the IT era starting around 1970 suggest that productivity growth associated with general purpose technologies comes in multiple waves. In particular, he notes that in both cases the initial period of relatively low productivity growth was followed by a decade-long acceleration (1915-24 for electrification and 1995-2004 for IT) followed by a period of slowdown in labour productivity growth. In the case of electrification, this further period of slowdown between 1924 and 1932 then led to a period between 1932 and 1940 in which labour productivity growth started to increase again by an average 2.7 per cent annually. In turn, he argues that these historical patterns may point to accelerating productivity growth in the future.
- Baily et al (2013)[8] offer an optimistic view regarding future productivity growth based on potential future innovation similar to that experienced in the 1990s in various sectors. For example, strong technological opportunities in advanced manufacturing (e.g. industrial robotics and automation or big data) may increase productivity growth in manufacturing. Developments in the energy sector (e.g. increase in natural gas

[6] Brynjolfsson et al (2017): "Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics" No. w24001. National Bureau of Economic Research.

[7] Syverson (2013): "Will history repeat itself? comments on "Is the information technology revolution over?" *International Productivity Monitor*, (25), 37.

[8] Baily et al (2013): "US productivity growth: An optimistic perspective" International Productivity Monitor 25 (2013): 3.

resources in the US due to shale gas extraction) are likely to increase investment and output both in energy and in transport and energy-intensive manufacturing (e.g. chemicals, metals, paper and pulp, and food manufacturing), thus increasing the scope for productivity improvements in a range of sectors.

- Tenreyro (2018) also offers a more optimistic view regarding future UK productivity. For example, she explained that as deleveraging in the financial sector is likely to end, the sector will start to contribute more to productivity growth again. In addition, she argues that once uncertainties regarding future EU trading relations are resolved business investment may also start to increase again.

Finally, the ongoing COVID-19 pandemic could affect productivity growth in either direction. Potential negative effects include reduced trade and supply chain impacts, reduced research and development (R&D) activities, lower mobility or reduced scope for resource reallocation. Nonetheless, the pandemic may also bring about increases in productivity growth. For example, the broad adoption of new technologies due to the crisis may lead to increased innovation and investment in intangible inputs (e.g. organisational effectiveness) as well as firms becoming 'smarter', which in turn could increase productivity growth. In addition, reallocations across sectors (e.g. from transport to healthcare or IT) could also increase aggregate productivity growth.[9] We note, however, that the CMA's provisional determinations stated that given the significant uncertainties associated with the COVID-19 pandemic at this stage, the best mechanism for taking account of these impacts would be for Ofwat to consider them through an industry-wide approach.[10]

2.2 The factors driving the slowdown do not apply to the water sector

In this section we investigate the factors that have been put forward by the literature as driving the productivity slowdown observed in advanced economies, including in the UK since the mid-2000s. These factors include:

- productivity mismeasurement;
- technological progress;
- a slowdown in specific sectors;
- labour market factors;
- monetary policy and interest rates;
- credit constraints and financially fragile firms;
- low demand and investment;
- differences in productivity between frontier and laggard firms; and
- regional differences within the UK.

For each factor, we first summarise the mechanism of effect through which it affects productivity growth and present the empirical evidence associated with the hypothesis. Finally, we set out various reasons why the factors that may have driven the slowdown in economy-wide productivity growth do not apply to the water sector.

2.2.1 Productivity mismeasurement

Mismeasurement of productivity, and in particular the underestimation of productivity growth related to ICT goods and services and the digital economy has been widely discussed as a factor contributing to the

[9] di Mauro and Syverson (2020): "The COVID crisis and productivity growth" [online].
[10] CMA (2020): "Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations – Provisional findings", p.13 [online].

slowdown in productivity.[11] The academic literature discusses various channels through which productivity growth measured in official statistics may be lower than actual productivity growth. For example, quality improvements associated with ICT goods and services may not be fully reflected in prices given the difficulties associated with accurately measuring price changes for ICT production and investment. In turn, this would imply that the price indices and deflators for these products may be overestimated while productivity growth is underestimated. Further, free digital services (through online information such as Wikipedia, entertainment or social connections) may not be reflected in GDP as these are typically available to consumers free of charge, despite generating significant consumer surplus. Consequently, official statistics could suggest slowing output growth even though consumer surplus is increasing.[12]

The mismeasurement hypothesis has been investigated by a range of studies, and the balance of the literature appears to suggest that while mismeasurement may explain part of the slowdown in productivity growth, this is unlikely to be the primary reason explaining the slowdown.

For example, a study by the OECD[13] estimated that correcting for the potential mismeasurement of price indices associated with ICT services may translate into a 0.2 per cent revision to recorded GDP growth as an upper bound across advanced economies. For the US, the estimated effect of mismeasurement associated with ICT services and software again was between 0.1 and 0.2 per cent for the last decade. Moreover, the study found that while official statistics may not capture the digital economy and digitally-enabled services, their impact on GDP and broad productivity measures is likely to be small or negligible in cases.

Similarly, Byrne et al (2016)[14] also explored the mismeasurement hypothesis in the context of US productivity growth focusing on IT-related hardware and software, while also proposing a new method to account for free digital services. The authors found that while productivity in these sectors was indeed subject to measurement errors, these concerns are not new and that adjustments (e.g. quality-adjusted prices and adding a broad measure of intangible investment) played an even more important role prior to the start of the productivity slowdown, and therefore are unable to explain the slowdown in productivity growth.

Further, Syverson (2016)[15] presented four different patterns in the data that pose challenges for the mismeasurement hypothesis. First, he noted that over a dozen countries experienced a slowdown in productivity growth yet the size of the slowdown appears unrelated to factors such as consumption or production intensity of ICT. Second, even if the quality improvements associated with ICT products are reflected in the price deflators, this would only be able to account for part of the "missing output" due to the productivity slowdown. Third, the estimated value associated with free, digitally-enabled services again is unable to account for more than third of the missing output. Fourth, gross domestic income (GDI) has exceeded GDP since 2004, suggesting that workers are compensated to produce goods that are then sold at discounted prices or are given away for free. While at first sight this appears to be consistent with the mismeasurement hypothesis, Syverson showed that GDI had exceeded GDP as early as 1998, many years before the onset of the slowdown in productivity growth.

[11] For example, the mismeasurement hypothesis has been discussed by: Feldstein (2015): "Underestimating the Real Growth of GDP, Personal Income, and Productivity" and Hatzius et al. (2016): "Productivity paradox v2. 0 revisited" US Economics Analyst.

[12] Byrne et al (2017): "The productivity slowdown is even more puzzling than you think" [online] and Byrne et al (2016): "Does the United States have a productivity slowdown or a measurement problem?" *Brookings Papers on Economic Activity* 2016.1: 109-182.

[13] Ahmad et al (2017): "Can potential mismeasurement of the digital economy explain the post-crisis slowdown in GDP and productivity growth?" OECD.

[14] Byrne et al (2016): "Does the United States have a productivity slowdown or a measurement problem?" *Brookings Papers on Economic Activity* 2016.1: 109-182.

[15] Syverson (2016): "Challenges to Mismeasurement Explanations for the US Productivity Slowdown" NBER Working Paper Series No. w21974.

Why this factor does not imply lower frontier shift in the water sector

Productivity mismeasurement is thought to account for only a relatively small part of the slowdown in productivity growth, and is believed to be particular pronounced in sectors other than water such as ICT services.

To the extent that mismeasurement leads to consistently lower measured productivity growth, this would suggest that the figures reported for the post-2005 period (and certainly for the post-crisis period) would underestimate the 'true' growth in productivity.

2.2.2 Technological progress

Another widely examined potential factor behind the rise in productivity growth in the late 1990s and early 2000s and the subsequent slowdown relates to technological progress and the use of information and communications technology (ICT).

Cette et al (2016)[16] explored the role of technological progress, focusing on ICT investment and the associated business re-organisation (e.g. whereby firms re-organise the way in which the manage sales, inventories or supply chains as a result of new technologies) as factors explaining the rise and fall in productivity growth since the mid-1990s. The authors looked at the experience of various countries, and for the US found some empirical support for the hypothesis that ICT improvements, when coupled with significant investments in re-organisation, can raise productivity, albeit with a lag. This is because the contribution of ICT producing industries to productivity growth was highest during the late 1990s, corresponding to gains in hardware production, followed by an increase in the contribution of market services (e.g. business services or wholesale retail and trade) in the early 2000s once sufficient business re-organisation had taken place to allow these industries to garner the benefits from ICT improvements. Turning to the experience of continental Europe, Cette et al did not find the same increase in the contributions of ICT producing industries and market services to productivity growth over the same time period in the case of Germany, France, Italy and Spain. The authors considered lower levels of ICT investment, labour and product market rigidities and increasing capital misallocation in certain parts of Europe (including Italy and Spain) as potential explanations. These factors are explored in more detail in the sections below.

Gordon and Sayed (2020) [17] also examined the role of ICT in productivity growth in the US and ten Western European countries since the mid-1990s and concluded that both regions suffered a slowdown in productivity growth after 2005, suggesting that any benefits from ICT improvements experienced in the US (but not in Europe) earlier were temporary rather than part of permanent productivity growth through ongoing innovation.

Brynjolfsson et al (2018)[18] explored four potential channels behind the paradox that despite new, potentially transformative technologies (such as artificial intelligence), measured productivity growth across OECD countries and other developed economies has slowed significantly. The authors conclude that the existence of an implementation and restructuring lag[19] may help explain the paradox. In fact, the authors argue that the two phenomena could simultaneously exist, suggesting a more optimistic view regarding future productivity growth. This is because sufficient time needs to pass before the productivity growth associated with new technologies may be harnessed, in particular in the case of major new technologies that have a significant impact on aggregate growth and welfare. These general purpose technologies (GPTs) first have no immediate

[16] Cette et al (2016): "The pre-Great Recession slowdown in productivity" *European Economic Review* 88 (2016): 3-20.
[17] Gordon and Sayed (2020): "Transatlantic Technologies: The Role of ICT in the Evolution of US and European Productivity Growth" No. w27425. National Bureau of Economic Research.
[18] Brynjolfsson et al (2017): "Artificial intelligence and the modern productivity paradox: A clash of expectations and statistics" No. w24001. National Bureau of Economic Research.
[19] Other mechanisms explored by the authors include false hopes, mismeasurement and redistribution.

impact on productivity statistics; however, as sufficient stock of the new technology is built and complementary processes and assets become available, the impact of the new technology starts to feed through to aggregate productivity statistics.

Why this factor does not imply lower frontier shift in the water sector

There is no reason to think that a new technology (e.g. artificial intelligence) leading to a temporary or permanent increase in productivity will not become available over the next price control period.

By way of example, the sector expects substantial benefits from technologies such as smart networks and smart metering. The Smart Water Networks Forum has recently announced a strategic collaboration to further increase the use of smart, data-driven solutions in utilities and in water metering in particular. Through Internet of Things (IoT) adoption and water metering applications such as real-time data allowing for leak identification or monitoring of water quality, these technologies have the potential to bring about significant benefits to the water market. This, in turn, suggests that new technologies can be a relevant driver of productivity growth for the water sector over the next price control period and beyond.[20]

As an illustration of the possibilities that exist for the sector, Yorkshire Water has adopted a data-led IoT approach that allows the company to gather real-time information about water and sewerage trends and operations. Further, through the use of technology such as 'acoustic ear' devices and data intelligence, the company will also be able to intervene as early as possible to minimise disruption. As an example, this could mean that bursts and leaks could be repaired within three hours compared to the three days it typically takes the company to resolve such issues.[21] This data-led approach is part of the company's wider commitment to encourage innovation throughout the sector, as well as to increase transparency and improve operational performance through becoming 'open by default'.[22]

2.2.3 A slowdown in specific sectors

The literature has also explored the hypothesis that the slowdown may be confined to (a few) specific sectors of the economy, suggesting more idiosyncratic rather than economy-wide causes for the slowdown.

For example, Tenreyro (2018)[23] looked at the sectoral breakdown of productivity growth, noting that the slowdown is concentrated in a few industries, thus suggesting idiosyncratic causes. The paper found that the UK's productivity slowdown is confined to four sectors,[24] with finance and manufacturing accounting for as much as three quarters of the slowdown.

The finance sector was found to be the biggest contributor to the productivity slowdown, experiencing a growth rate of 5 per cent before the crisis which then turned into a productivity reduction of 2.1 per cent a year after 2009. TFP accounts for the majority of this decrease in slowdown (over 80 per cent), and potential explanations for this fall relate to the growth of leverage and the under-pricing of systemic risk before the onset of the crisis. While productivity mismeasurement on its own in unlikely to account for all of the slowdown, increased profits, earnings and output within the financial sector before the crisis hit (e.g. through factors such as increased leverage and risk illusion) could also have contributed to positive spillovers in the rest of the economy. Tenreyro then argued that such (unsustainable) increases in leverage are unlikely to occur after the financial crisis, partly reflecting financial stability reforms. At the same time, she noted that a

[20] Smart Water Magazine (2020): "SWAN Forum and LoRa Alliance® enter liaison to drive expanded network coverage and IoT adoption" [online].
[21] Yorkshire Water: "Open data" [online].
[22] Yorkshire Water (2018): "Yorkshire Water to publish majority of operational and service data by 2020" [online].
[23] Tenreyro (2018): "The fall in productivity growth: causes and implications" Speech given by Silvana Tenreyro, External MPC Member, Bank of England Peston Lecture Theatre, Queen Mary University of London.
[24] These are: manufacturing; finance; information and communication technologies; and professional, scientific and technical services.

neutral projection regarding the future productivity growth of the sector may be appropriate, which would then boost productivity growth in other industries such as professional services as well.

At the same time, the manufacturing sector has been growing at 0.8 per cent since 2009, compared to a growth rate of 4.3 per cent between 2000 and 2007. Capital deepening[25] can account for a third of this slowdown (around 1.1 percentage point) while the rest is included in residual TFP which experienced the highest growth rate among all industries before the crisis.

Why this factor does not imply lower frontier shift in the water sector

The academic literature argues that the slowdown may be limited to a few, specific sectors of the economy which clearly exclude the water sector.

Turning to the potential explanations put forward for the productivity slowdown in the affected sectors, within financial services increased leverage directly increased measured output (and hence productivity) due to the way in which financial intermediation services are measured, whereas deleveraging since the financial crisis had the opposite effect on measured output and productivity growth. In particular, output is measured in the sector through the FISIM (or 'financial intermediation services indirectly measured') concept, which has the implication that the intermediation services provided by banks increase one-for-one with the size of their balance sheets.[26] In contrast, leverage does not affect measured output and productivity growth in the same way in the water sector.

Similarly, the possible explanations put forward for the slowdown observed in the manufacturing sector do not apply to the water sector.

2.2.4 Labour market factors

Cyclical explanations such as spare capacity within firms have also been put forward as possible factors contributing to the productivity slowdown. The Bank of England (2014)[27] considered whether spare capacity within firms, whereby the initial drop in output is not immediately followed by a drop in employment due to firms retaining workers, thus leading to reduced labour productivity, may account for part of the productivity slowdown. The paper discussed a range of explanations as to why firms may be unable or may not wish to shed workers despite lower demand, such as minimum staffing requirements to keep a business going (i.e. overhead labour), avoidance of the costs associated with firing and re-hiring, or ensuring that skilled workers are available when the economy recovers. While the paper found some evidence supporting the hypothesis that firms held onto workers during the global financial crisis, it noted that decisions by firms to operate with underutilised resources are unlikely to be sustainable in the longer term. At the same time, the paper highlighted that hiring was also high (at or above pre-crisis levels), consistent with slightly higher output growth in 2013, but productivity growth still remained low. A possible explanation put forward by the Bank relates to more people seeking to participate in the labour market as a result of reduced incomes or changes to the retirement age and rules for benefit provision. Moreover, analysis conducted by the Bank of England[28]

[25] Tenreyro also explored potential links between the lower capital investment and intensity observed during and since the financial crisis and labour market flexibility. In particular, she examined whether the flexibility of the UK labour market could account for trends in capital accumulation and the slowdown in productivity (e.g. through firms substituting away from capital to labour due to lower real wages). She suggested that while such factors may help explain the relative slowdown in UK productivity (e.g. compared to the euro area characterised by less flexible labour markets), other explanations such as uncertainty regarding the future trading relationship between the UK and the UK are also likely to have contributed to the slowdown.

[26] Tenreyro (2018): "The fall in productivity growth: causes and implications" Speech given by Silvana Tenreyro, External MPC Member, Bank of England Peston Lecture Theatre, Queen Mary University of London, p.16.

[27] Barnett et al (2014a): "The UK productivity puzzle." *Bank of England Quarterly Bulletin* (2014): Q2.

[28] Barnett et al (2014b) "The productivity puzzle: a firm-level investigation into employment behaviour and resource allocation over the crisis.".

looking into employment behaviour and resource allocation during the crisis found some evidence of 'labour-hoarding' as well.

Cette et al (2016)[29] examined the role that structural rigidities in labour and product markets played in the slowdown and found that in continental Europe tighter regulations made the re-allocations associated with the diffusion on ICT investments more challenging to achieve. In addition, aspects such as education and in particular post-secondary education may also matter, as ICT generally requires more skilled labour than other technologies. Research looking at the low productivity growth experienced in the euro area[30] highlighted that increasing the flexibility of permanent employment contracts and reducing the average degree of job protection in the euro area to the level in the UK could increase new employment contracts, both job-to-job and jobless-to-job. In turn, the reallocation of factors (including labour) to more productive uses could increase TFP growth.

Fernald and Inklaar (2020)[31] discussed demographics and in particular the potential for an aging population to have a small, negative impact of TFP growth. Potential channels include skills depreciation, reduced managerial talent over time, reduced mobility or greater resistance of the workforce to innovation.

Why this factor does not imply lower frontier shift in the water sector

Overall, labour hoarding may be less important in a UK context – compared to, for example, other European countries – as labour markets tend to be more flexible in terms of hiring and firing workers.

As noted by the Bank of England as well, labour hoarding will reduce measured productivity during recessions.[32] However, as the economy recovers from the recession and demand rises, this means that measured productivity will increase due to labour utilisation increasing again. While it may have been possible to argue in 2014 that demand had not yet recovered from the 2008-09 crisis and firms were still hoarding labour, it seems hard to imagine that the same argument still applies by 2020 (setting aside the ongoing COVID-19 pandemic and economic crisis).

Moreover, demand for water is relatively stable over time, and therefore the water sector would have been much less affected by the 2008-09 crisis than demand in many other sectors. In addition, the revenue cap set by Ofwat for regulated companies protects the sector from business cycles, meaning that water companies' revenues are unaffected by changes in the volume of demand. Therefore, the labour hoarding mechanism is unlikely to be relevant in the water sector.

2.2.5 Monetary policy and interest rates

Lax monetary policy and low interest rates are also believed to have contributed to the productivity slowdown through resource misallocation and higher survival of less efficient firms (also called 'zombie firms'), which reduces aggregate productivity.[33]

For example, research by the European Central Bank (ECB)[34] suggested the survival of these zombie firms is closely linked with weak banks and bank forbearance, which then restricts the potential growth of more productive firms, eventually leading to lower levels of aggregate productivity. Further, the ECB found that weak banks can account for as much as a third of the impact of these inefficient firms on capital misallocation, partly reflecting worsening credit constraints for more efficient firms.

[29] Cette et al (2016): "The pre-Great Recession slowdown in productivity" *European Economic Review* 88 (2016): 3-20.
[30] Caixa Bank Research (2016): "The role of labour rigidity in the euro area's low productivity", [online].
[31] Fernald and Inklaar (2020): "Does Disappointing European Productivity Growth Reflect a Slowing Trend? Weighing the Evidence and Assessing the Future" Federal Reserve Bank of San Francisco.
[32] Barnett et al (2014a): "The UK productivity puzzle." *Bank of England Quarterly Bulletin* (2014): Q2.
[33] For example. see: Barnett et al (2014a): "The UK productivity puzzle." *Bank of England Quarterly Bulletin* (2014): Q2.
[34] Andrews and Petroulakis (2019): "Breaking the shackles: zombie firms, weak banks and depressed restructuring in Europe" European Central Bank Working Paper Series.

Cette et al (2016) examined the hypothesis that reductions in nominal and real interest rates in "peripheral economies" in Europe (including Italy and Spain) associated with the introduction of the euro in 1999 can help explain weaker productivity growth in these countries. The authors noted that between the early-and mid-1990s and early-and mid-2000s (i.e. before and after the introduction of the euro) Italian and Spanish 10-year government rates fell significantly in Italy and Spain while they did so less in Germany, France and the UK. This drop in real interest rates led to debt accumulation in the private sector in Italy and Spain. Cette et al discussed whether these events led to increased misallocation of capital through three different channels, based on the literature: (i) these capital inflows increased non-tradable output characterised by lower productivity growth than tradables or manufacturing;[35] (ii) high productivity firms did not force less efficient firms to exit the market;[36] and (iii) less stringent financial conditions may have led to "soft budget constraints" which then translated into weaker institutions and rule of law.[37] The authors find empirical support for the hypothesis that (real) interest rates can in fact affect productivity growth.

Moreover, other streams of the literature focused on how credit booms associated with exceptionally large capital inflows and lax credit conditions affect the misallocation of resources and productivity. For example, Benigno et al (2015)[38] looked at how episodes of large capital inflows can reallocate resources towards less productive sectors (e.g. through shifting capital and labour out of manufacturing). The authors found that the larger the shift of labour out of manufacturing, the greater the contraction in output afterwards.

Why this factor does not imply lower frontier shift in the water sector

Theories citing capital misallocation as a contributor to the productivity slowdown are less likely to be applicable in a UK context, where the financial system is believed to be more efficient than, for example in southern European economies. This is consistent with the literature finding evidence of increasing misallocation of capital in southern Europe.[39]

Further, arguments based around lax monetary policy allowing the survival of 'zombie firms' are not relevant to the water sector. Zombie firms are defined as firms which do not generate sufficient current profits to cover debt service costs over an extended period. Given that price controls in the water sector are set to allow efficient firms to maintain adequate financial ratios, no regulated water company is likely to end up as a 'zombie firm'.

Further, the regulatory framework in the water sector requires the least productive firms to catch up with the frontier over time. Hence, the regulatory framework does not facilitate continued low productivity by less efficient firms, regardless of the wider monetary environment in the UK.

For all these reasons, considerations relating to monetary policy and low interest rates are unlikely to be relevant for setting a forward-looking frontier shift figure for the water sector.

[35] For further information on this channel, please see for example: Kalantzis (2016): "Financial fragility in small open economies: firm balance sheets and the sectoral structure. Working papers 505, Banque de France or Benigno, et al (2015): "Large capital inflows, sectoral allocation, and economic performance" J. Int. Money Financ. 55, 60–87.

[36] For further information on this channel, please see for example: Reis (2013): "The Portuguese Slump and Crash and the Euro Crisis" Brookings Papers on Economic Activity, 46. Spring 143–193 or Gopinath et al (2015): "Capital Allocation and Productivity in South Europe" NBER Working paper no.21453.

[37] For further information on this channel, please see for example: Challe et al (2015): "The South of Europe's Institutional Decline" mimeo, Ecole Polytechnique.

[38] Benigno et al (2015): "Large capital inflows, sectoral allocation, and economic performance." *Journal of International Money and Finance* 55 (2015): 60-87.

[39] For example, see: Gopinath et al (2015): "Capital Allocation and Productivity in South Europe" NBER Working paper no.21453.

2.2.6 Credit constraints and financially fragile firms

Financial frictions may also have contributed to the reduction in productivity by leading to reductions in innovation and R&D expenditure during periods when, for example, available credit is constrained,[40] followed by a rebound once financial conditions improve.

Duval et al (2020)[41] explored the impact of financial frictions on productivity through reduced R&D and innovation spending using the sharp and unforeseen tightening of credit that followed the collapse of Lehman Brother in 2008 as a natural experiment. The authors argued that a combination of tightening credit conditions and firms' weak corporate balance sheets led to a decrease in productivity which can account for up to a third of the within-firm productivity slowdown shown in the data in the six years before and after the crisis. This impact was also found to be higher for firms with weaker pre-crisis balance sheets, i.e. those that are more financially vulnerable[42] and experienced more severe credit constraints. The authors then investigated the reasons why such frictions matter for productivity post-crisis. The channels explored include lower weaker intangible investment (e.g. R&D) due to the riskier and more uncertain return associated with these intangible assets (e.g. compared with physical capital), which could have contributed to lower TFP growth post-crisis. This conjecture is supported by empirical evidence from eleven advanced economies including the UK. Further, the paper also investigated the impact of financial fragility on innovation, finding that more vulnerable firms indeed submitted fewer patent applications than their financially less vulnerable counterparts.

Why this factor does not imply lower frontier shift in the water sector

Ofwat calculates price limits taking account of firms' allowed capex programmes, and has a financeability duty to ensure that efficient companies are able to finance their operations. This means that water companies should not face credit constraints that prevent them carrying out investment to improve their productivity.

An additional reason why credit constraints should not prevent firms from funding innovation is that Ofwat has recently announced that an additional £200 million that will be made available to companies as part of an innovation competition to foster collaboration between companies and across the supply chain. From 2021 Ofwat will run two competitions allowing water companies to enter with their innovations: (i) a £2 million 'Innovation in Water Challenge' which will be open from January 2021 and which will fund projects up to £250,000; and (ii) a £40 million main competition which will accept entries from April 2021.[43]

2.2.7 Low demand and investment

In previous sections, we have already discussed some of the channels through which weaker demand and investment may affect productivity growth. For example, firms retaining workers despite lower overall demand could lead to reductions in productivity and tightening credit conditions may (temporarily) reduce investment by firms in R&D and innovation.

In addition to these channels, other hypotheses relating to weak demand or a combination of weak demand and sluggish potential output growth have also been put forward. For example, weak aggregate demand stemming from weak consumption growth (e.g. through consumers repaying debt accumulated over previous periods) could discourage business investment.[44] In the context of interest rates approaching zero, this could

[40] For example, Barnett et al (2014a) stated that tight credit conditions could slow both investment and innovation.

[41] Duval et al (2020): "Financial frictions and the great productivity slowdown." *The Review of Financial Studies* 33.2 (2020): 475-503.

[42] In particular, the authors use "maturing debt (i.e. the amount of debt prior to the crisis scheduled to mature during the crisis) as their preferred measure of volatility since this is believed to be uncorrelated with the decline in TFP post-crisis given that the crisis was unforeseen.

[44] Walsh (2017): "The Productivity Slowdown- Exploring A Role For Demand" [online].

present challenges to policy-makers wishing to increase both consumer and business spending and may lead to secular stagnation.[45]

A survey of leading economists by the Centre for Macroeconomics[46] earlier this year also suggested low demand as one of the key contributors to the slowdown experienced in the UK. In terms of the causes of low demand and productivity growth, the explanations given included the financial crisis itself, austerity policies, Brexit, and low R&D and business investment driven by low expectations of future market growth.

Why this factor does not imply lower frontier shift in the water sector

As an essential service, the demand faced by water companies is less likely to be affected in periods of downturn. Further, in the water industry, Ofwat sets a revenue cap for regulated companies, meaning that water companies' revenues are unaffected by changes in the volume of demand.

Moreover, water companies' allowed investment programmes are factored into their allowed revenues, and the RCV mechanism guarantees cost-recovery and a return on investment. This in turn provides water companies with both the ability and the incentive to invest.

Therefore, factors centred around low demand and investment are unlikely to play a role in water sector productivity growth.

2.2.8 Increased market power

There are various studies which suggest that an increase in concentration and market power can be associated with lower productivity growth through different channels.

First, based on the dynamic strategic competition literature, low interest rates can lead to a stronger investment response from market leaders to preserve their profits. At the same time, market followers – anticipating market leaders will respond by increasing investment – make a less aggressive investment decision to avoid 'neck-to-neck' competition. This in turn will increase concentration and reduce aggregate productivity. Liu et al (2019)[47] investigated two effects through which market power may affect productivity growth. First, they focused on the channel typically described in the literature whereby lower interest rates can increase the present value of future cash flows linked with higher productivity, and therefore incentivise investment in productivity enhancement. Moreover, the authors highlighted a second strategic effect that prompts a strong investment response from market leaders as discussed above. The authors presented a theoretical model showing that this second strategic effect dominates when interest rates approach zero. In particular, this result crucially hinges on the assumption that market followers only gradually catch up with market leader firms (i.e. followers cannot 'leapfrog' leaders), incentivising market leaders to accumulate a strategic advantage through investment, consistent with firms carrying out defensive R&D or raising entry barriers.

Second, there is a reason to believe that growth accounting techniques do not work very well when there are high economic profits associated with high mark-ups,[48] leading to a TFP measure that is lower than the 'true' one. This channel was explored by Fernald and Inklaar (2020)[49] who argued that if the capital share of value added revenue were to decline and the labour share were to rise, this may increase aggregate productivity by up to 0.1 percentage point.

[45] The idea of secular (long-term) stagnation has been presented by, for example, Larry Summers [online].
[46] Ilzetzki (2020): "Explaining the UK's productivity slowdown: Views of leading economists" [online].
[47] Liu et al (2019): "Low interest rates, market power, and productivity growth" No. w25505, National Bureau of Economic Research.
[48] This is because they tend to give too much weight to capital compared to labour, as the revenue shares of capital are not a good approximation for capital elasticity.
[49] Fernald and Inklaar (2020): "Does Disappointing European Productivity Growth Reflect a Slowing Trend? Weighing the Evidence and Assessing the Future" Federal Reserve Bank of San Francisco.

Why this factor does not imply lower frontier shift in the water sector

The arguments related to changes in concentration and market power do not apply to the water sector, which did not see any significant changes in either industry concentration or the market power of individual firms.

Further, the regulatory framework in England and Wales is designed to mimic the features of competitive markets, including through the identification of an efficiency frontier based on what could be achieved in a competitive market. Hence, the scale of frontier shift the sector should be expected to achieve over the next price control period, as determined by the regulator at price reviews, should reflect this competitive environment and not any distortions to productivity growth that might be caused by market power.

2.2.9 Differences in productivity between frontier and laggard firms

Increasing differences between firms at the top and bottom of the productivity distribution have also been explored as a factor contributing to the productivity slowdown, through negative catch-up of laggard firms and higher growth in productivity of those firms at the frontier.

Research by the Centre for Economics Performance[50] analysed the productivity of firms at the top (i.e. the 'global productivity frontier'[51]) and the bottom (i.e. non-frontier firms[52]) of the productivity distribution. Importantly, it found that the productivity gap between frontier and laggard firms had increased during the 2000s, with the top 5 per cent of firms experiencing robust productivity growth while those below the frontier had sluggish productivity growth rates.

Turning to the potential drivers of this divergence in productivity, the authors considered a range of mechanisms, including:

- Market power dynamics: the paper found that the divergence between frontier and laggard firms were not due to market power dynamics whereby frontier firms increased their mark-up. In the case of firms in the services sector, the mark-up has increased, but this only accounted for a third of the divergence observed in the data.
- "Winner-takes-all" dynamics: the increasing gap in productivity between frontier and laggard firms has been accompanied by a divergence in revenues (or market share). These patterns appeared strongest in ICT services where factors such as cost advantages and network externalities can lead to a market with a few dominant players. Finally, within the global frontier group of firms, productivity of the top 2 per cent of firms has risen relative to the remaining top 5 or 10 per cent of firms. Once again, these patterns were found to be strongest in the case of ICT services.
- Rate of productivity catch-up: the pace of productivity convergence to the global productivity frontier has decreased over time, which can be indicative of weaker diffusion of knowledge from frontier firms to non-frontier ones.
- Business dynamism: data showed a decrease in the share of younger firms, coupled with higher productivity thresholds for entrants. At the same time, firms with weaker productivity also showed higher rates of survival.

Further, research by the OECD[53] focused on the characteristics and contribution to aggregate productivity growth of firms at the bottom of the productivity distribution. The study examined the case of "laggard

[50] Andrews et al (2019): "The Best versus the Rest: Divergence across Firms during the Global Productivity Slowdown", Centre for Economic Performance [online].

[51] The global productivity frontier is defined as "the top 5% of firms in terms of labor or multi-factor productivity (MFP) levels within two-digit industries". Andrew et al (2019), p.1.

[52] Non-frontier or 'laggard' firms are defined as those that are not at the frontier.

[53] Berlingieri et al (2020): "Laggard firms, technology diffusion and its structural and policy determinants." , OECD.

firms"[54] located at the 'left tail' (i.e. bottom 40 per cent) of the distribution and found evidence of a slowdown in this catch-up effect over time which appeared to be strongest in digital and knowledge intensive industries, suggesting a potential "breakdown of the diffusion machine".

Haldane (2018)[55] also found that the gap between the top- and bottom-performing companies has widened, and that this has happened by far more in the UK than in other countries. He presented data showing that the top 1 per cent of companies in the UK achieved annualised productivity growth of 8 per cent between 2004 and 2014, compared with 1 per cent annualised productivity growth by the remaining 99 per cent of firms. He argued that this was driven by problems with the dissemination and diffusion of innovation.

In contrast, Schneider (2018)[56] argued that the slowdown is driven by firms at the top of the productivity distribution,[57] although he did not explore the reasons for the slowdown in further depth.

Why this factor does not imply lower frontier shift in the water sector

Conceptually, frontier shift reflects the efficiency improvement achieved by firms at the frontier. Therefore, to establish the frontier shift water companies could achieve over the next price control period, the ideal approach would be to identify frontier firms in each of the comparator sectors and use these as a proxy for water sector frontier shift. Our approach uses average TFP in comparator sectors as a proxy for frontier shift and assumes zero catch up.[58] If the dispersion between frontier and laggard firms is increasing, as suggested by the OECD and Haldane (2018), then our approach will understate the true rate of frontier shift. In other words, this explanation for the economy-wide productivity slowdown means that our frontier shift estimate is actually conservative.

2.2.10 Regional differences within the UK

The geographic distribution of productivity growth within the UK displays significant regional differences, with London and its Greater South East hinterland economy representing the regions with the highest productivity growth.[59] The differences in productivity growth reported across UK regions are not only significant in absolute terms but also in comparison to other advanced economies. For example, using the NUTS2[60] regional classification only two out of 18 European countries (Poland and Romania) have larger gaps in productivity between the regions with the highest and lower productivity growth. Moreover, the underlying data suggest very few – if any – productivity puzzles in London and its hinterland area where productivity growth tends to outperform OECD and EU productivity indicators, with robust productivity growth even in the post-crisis period. By contrast, productivity growth in the rest of the UK remained well below OECD and EU levels, especially since the financial crisis.[61]

Within the economic geography literature, typically a combination of factors is considered to be the root cause of these spatial differences in productivity growth. These include:

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[54] Laggard firms are defined as "firms belonging to the bottom 40% of the productivity distribution in each country, industry and year". OECD (2020): "Laggard firms, technology diffusion and its structural policy determinants", p.3.

[55] Haldane (2018), "The UK's productivity problem: hub no spokes" Speech given by Andrew G Haldane, Chief Economist, Bank of England, Academy of Social Sciences Annual Lecture, 28 June 2018

[56] Schneider (2018): "The UK's productivity puzzle is in the top tail of the distribution" Bank Underground.

[57] Schneider's discussion focuses on firms in the top two deciles, however he does not offer a formal definition of the 'top tail' of the distribution.

[58] For further details on the effect of catch-up on TFP estimates, please see: Europe Economics, "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", 7 December 2019, p.64.

[59] McCann (2018): "Productivity Perspectives Synthesis." *ESRC Productivity Insights Network*.

[60] NUTS2 regions correspond to groups of counties, unitary authorities and council areas.

[61] Zymek and Jones (2020): "UK Regional Productivity Differences: An Evidence Review" *Report for the Industrial Strategy Council* [online].

- Place fundamentals capturing aspects such as geography, local culture, governance and infrastructure, which in turn influence the local workforce and investment within the region;
- Agglomeration relating to clusters of economic activity characterised by both:
  - 'localisation economies' capturing benefits enjoyed by firms, such as within-sector trade and interaction, and
  - 'urbanisation economies' capturing the resources offered by cities;
- Sorting whereby (skilled) workers with similar characteristics tend to select similar places to live and work, thus sorting themselves into the same neighbourhoods.

The literature offers at least some level of support for these mechanisms.[62] For example, Gibbons et al (2013)[63] found that sorting can account for a relatively large share of wage differences across UK regions.

Why this factor does not imply lower frontier shift in the water sector

In its PR19 final determinations Ofwat identified six companies (Severn Trent / Hafren Dyfrdwy, South West Water, Wessex Water, Portsmouth Water, South East Water and South Staffs Water) as more efficient than their baseline, meaning that their proposed base cost expenditure was lower than Ofwat's estimate of the efficient level of base costs. Ofwat also identified five companies (Severn Trent / Hafren Dyfrdwy, South West Water, Thames Water, Portsmouth Water and South Staffs Water) that proposed lower total base costs (for wholesale and retail) in their August 2019 business plans compared with Ofwat's efficient level of base costs.[64] While some of the companies identified as more efficient than Ofwat's baseline on a historical basis are located in the South East (e.g. South East Water), others (e.g. Severn Trent / Hafren Dyfrdwy, South West Water, South Staffs Water) are located in other areas of the UK. Hence, the most efficient water companies cover a range of geographical areas across England and Wales. Therefore, there is no reason to think that the geographical difference in productivity applies in the water sector.

2.2.11 Summary

The table below summarises these factors that may have contributed to the economy-wide slowdown in productivity growth and the reasons why they do not imply lower frontier shift in the water sector.

Table 2.1: Summary of factors contributing to the slowdown in productivity

Factor driving slowdown in productivity	Why this factor does not imply lower frontier shift in the water sector
Underestimation of productivity growth in ICT and digital services	Factor has small effect and is not relevant to water sector; in any case, it would mean that true productivity growth was higher than reported figures.
End of temporary period of faster productivity growth driven by ICT and associated business reorganization	No reason why new technologies (e.g. smart water networks) will not materialise in the water sector over AMP7.
Slowdown is confined to specific sectors, including manufacturing and financial services	Productivity slowdowns in finance and manufacturing were driven by idiosyncratic factors not relevant to water sector (measurement issue in finance sector, reduced capital deepening in manufacturing) .

[62] Zymek and Jones (2020): "UK Regional Productivity Differences: An Evidence Review" *Report for the Industrial Strategy Council* [online].

[63] Gibbons et al (2013): "Area disparities in Britain: understanding the contribution of people vs. place through variance decompositions" Oxford Bulletin of Economics and Statistics, online. pp. 1-19. ISSN 0305-9049.

[64] Ofwat (2020): "Reference of the PR19 final determinations: Cost efficiency – response to common issues in companies' statements of case", p.11-12 [online].

Labour hoarding following 2008-09 crisis	Even for the economy as a whole, unlikely still to apply this many years after the 2008-09 crisis; in any case, water sector not affected in the same way due to stable demand and revenues.
Lax monetary policy and low interest rates led to higher survival of less efficient ('zombie') firms	Capital misallocation less likely in the UK due to a more efficient financial system; none of the regulated water companies bear any resemblance to 'zombie' firms (where current profits do not cover debt interest costs over extended period); regulated framework requires laggard firms to catch up, regardless of monetary environment.
Credit constraints prevented firms investing to increase productivity	Ofwat is allowing substantial capex within allowed revenues at PR19, and has a financeability duty which means efficient water companies should not face credit constraints.
Weak anticipated consumption growth weakens investment incentives	Demand faced by water companies is less affected in periods of downturn and revenues are protected through revenue cap; further, firms have ability and incentive to invest due to funding for allowed capex programme within allowed revenue and the RCV mechanism which guarantees cost recovery and a return on investment.
Increase in industry concentration reduces aggregate productivity and causes TFP measurement problems	No significant changes in industry concentration or market power in water sector; in any case, regulation seeks to set frontier shift on basis of what would be achieved in competitive market.
While frontier firms have continued to increase productivity, laggard firms have fallen further behind	Frontier shift ideally measured on basis of performance of frontier firms in comparator sectors; hence, this explanation implies that our frontier shift estimate (based on sectoral averages) is an underestimate of true frontier shift.
Regional differences in productivity growth between London / the South East and the rest of the country	Water companies identified as efficient by Ofwat's assessment of efficient costs cover a range of geographical areas across England and Wales.

3 Application of Value-added TFP Estimates

In this section, we respond to a point relating to the application of value-added TFP estimates which has been raised by First Economics (John Earwaker's company) in the context of Ofgem's RIIO-2 draft determinations. We first explain the issue raised by First Economics, and we then provide our response.

3.1 Issue raised by First Economics in context of RIIO-2 draft determinations

In a report for the Energy Networks Association, First Economics argues that if a value-added measure of TFP is being used to set frontier shift, then it should only be applied to costs excluding intermediate inputs.[65] First Economics recognises that both gross output and value-added measures of TFP are valid measures of productivity growth. However, it argues that there is a difference in how they should be applied when setting frontier shift. In particular, it argues that:

- Gross output TFP growth can be used to set a frontier shift for the whole of totex, since it is based on analysis of the efficiency with which all inputs are used to produce output.
- On the other hand, value-added TFP growth can only be applied to value-added in the regulated industry (i.e. to costs excluding intermediates), because it is based on analysis of the efficiency with which firms have created value-added from labour and capital inputs.

Hence, First Economics argues that there is an internal inconsistency in using value-added TFP to set a frontier shift challenge for the whole of totex.

At first glance, this argument would appear to remove the rationale for using value-added TFP to aim up when selecting a point estimate for frontier shift. This is because Europe Economics has calculated gross output TFP growth by starting from EU KLEMS data on value added TFP growth and multiplying it by the ratio of value added to gross output.[66] Applying value-added TFP growth just to the value-added share of output would be equivalent to multiplying value-added TFP growth by the ratio of value added to gross output to calculate a frontier shift number for the cost base as a whole — which would give an identical result to applying a gross output TFP estimate across the entire cost base.

3.2 Response by Europe Economics

We would make three points in response to the point raised by First Economics (of which the third point is the most significant):

- First, First Economics has itself applied value-added TFP estimates to all components of totex in past work;
- Second, only some intermediates are relevant to the point that First Economics is making;

[65] First Economics, "Frontier Productivity Growth; A report prepared for the Energy Networks Association", August 2020, p.15-16, available at: https://www.northerngasnetworks.co.uk/wp-content/uploads/2020/09/RIIO-2-frontier-productivity-growth-First-Economics.pdf

[66] Europe Economics, "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", 7 December 2019, p.75-76

- Third, a more detailed analysis of how TFP is calculated continues to show that value-added TFP estimates imply higher frontier shift than gross output TFP measures, even after accounting for the point made by First Economics.

We elaborate on each of these points below.

3.2.1 First Economics has itself applied value-added TFP to all components of totex in past work

In a report for South East Water at PR14, First Economics used value-added estimates of TFP growth for comparator sectors. It applied a "nature of work" comparator approach to weight these value-added TFP data to derive productivity growth estimates for wholesale opex, wholesale capex and retail costs. It then recommended that these productivity growth estimates should be applied to these respective cost areas, without any attempt to exclude intermediates. In making this recommendation, it stated the following:[67]

> "we are content that our estimates of input price inflation and productivity growth combine to give a reasonable and robust estimate of the cost escalation that South East Water is likely to have to deal with during the next seven years"

Hence, First Economics has itself made clear that a "reasonable and robust estimate" of cost increases in the water sector can be obtained by applying value-added TFP estimates to all components of totex, without excluding intermediates.

3.2.2 Only some intermediates are relevant to the point made by First Economics

Only some purchases of inputs from other sectors are relevant to the point that First Economics makes in its report for the Energy Networks Association. In particular, we consider that it would be inappropriate to apply First Economics' point to the following inputs:

- Purchases of goods and services from other sectors that are part of capex. The entirely of capex represents additions to the capital stock, and capital inputs are conceptually distinct from intermediates in the growth accounting framework that is used to calculate TFP.
- Outsourced water sector activities. Taken at face value, the point made by First Economics would imply that any given figure for value-added TFP growth would lead to a lower frontier shift challenge for a firm which has outsourced more of its operational activities, as more of its cost base would be comprised of intermediates. However, this would clearly be illogical – there is no reason why two firms should have different frontier shift challenges simply because one of the firms has outsourced operational activities that the other firm still does in-house.

Hence, even if First Economics' point were taken at face value, it would not be appropriate to exclude all purchases from other sectors from a frontier shift challenge.

[67] First Economics, "Water Industry Input Price Inflation and Frontier Productivity Growth A report prepared for South East Water", August 2013, p.22-24, 31-32 available at: https://corporate.southeastwater.co.uk/media/1494/app18tps_firsteconomics.pdf

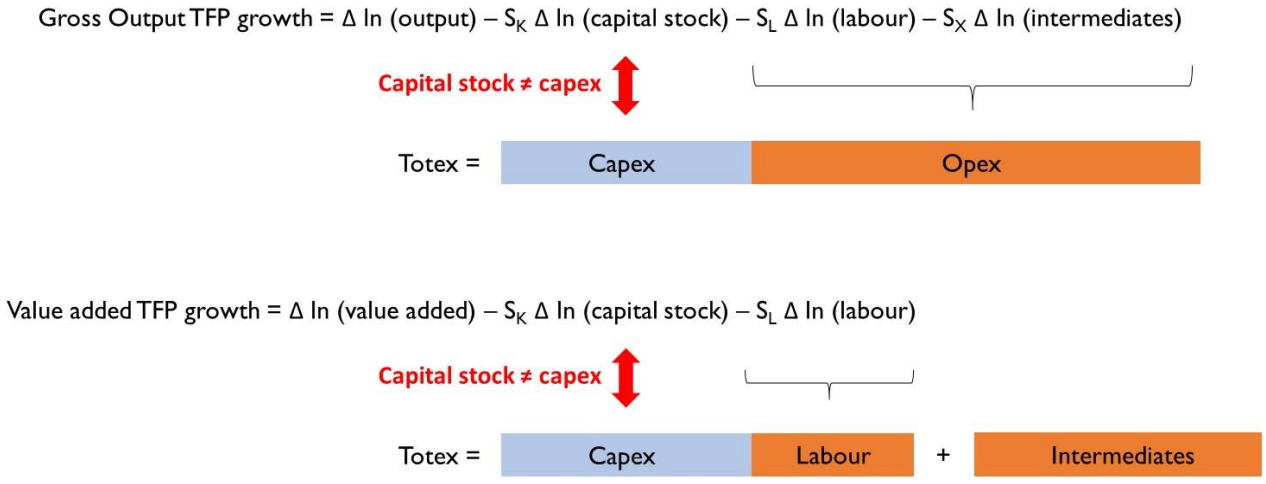
3.2.3 More detailed analysis of TFP inputs continues to suggest that value-added TFP estimates imply higher frontier shift

When the inputs into TFP calculations are examined in more detail, it becomes clear that value-added TFP estimates do imply a higher frontier challenge than gross output TFP estimates, even once the point made by First Economics is taken into account.

In making its new claim in its report for the Energy Networks Association, First Economics appears to want match more closely the inputs into a TFP calculation with the element of a firm's cost base to which the frontier shift assumption is applied. However, First Economics has only done this matching exercise in a partial way, and has ignored a much more significant issue that would need to be taken into account in such a matching exercise.

First Economics is not taking account of the fact that, in the area of capital, the relevant input into TFP calculations is the total capital stock and not just capex (which is just the addition to the capital stock over a specific time period). As shown in the figure below, gross output TFP growth is the residual growth in (quality-adjusted) output that is not explained by the weighted growth of (quality-adjusted) capital, labour and intermediates. Value added TFP growth is the residual growth in value-added that is not explained by the weighted growth of (quality-adjusted) capital and labour. While First Economics has focused on the fact that intermediates are not treated as an input when calculating gross value added TFP, it has ignored the fact that for both types of TFP there is a difference between the capital stock that is used to calculate TFP and the capex that is included within totex.

Figure 3.1: Comparison of inputs into TFP calculation with components of totex



Notes:
- Δ refers to the change
- ln is the natural logarithm
- In the first equation, S_K, S_L and S_X are the shares (respectively) of capital, labour and intermediates in gross output
- In the second equation, S_K and S_L are the shares (respectively) of capital and labour in value added

As explained below, once the distinction between capital stocks and capex is taken into account, it becomes clear that value-added TFP growth estimates still imply a higher frontier shift assumption than gross output TFP growth estimates, even after taking account of the point that First Economics is making.

Starting with a gross output measure of TFP growth, a TFP growth estimate of 1 per cent means that quality-adjusted output is growing 1 per cent faster than can be explained by the growth of quality-adjusted inputs, due to greater disembodied technical efficiency. Equivalently, this can be interpreted as meaning that the same level of quality-adjusted output could be produced using 1 per cent less quality-adjusted inputs — which is why TFP growth rates are used to reduce cost projections when applying frontier shift. However, if one is

being precise, a 1 per cent growth rate for gross output TFP growth would actually imply a 1 per cent reduction to the capital stock (not to capex), alongside a 1 per cent reduction to labour and intermediates. The capital stock of a regulated firm is measured for regulatory purposes by its Regulatory Capital Value (RCV).

As shown in the figure on the next page, a 1 per cent reduction in the capital stock equates to a much larger reduction in capex. The hypothetical example shown is based on a scenario in which capex is 10 per cent of the projected RCV. In this scenario, a 1 per cent gross output TFP growth estimate would imply a 10 per cent reduction in capex in order to achieve the required reduction in RCV.

The right-hand side of the figure shows the equivalent situation if we use value-added TFP instead of gross output TFP. For the sake of illustration, we have assumed that value-added TFP growth is 2 per cent i.e. twice as high as gross output TFP growth.[68] As shown in the figure, a 2 per cent reduction in the projected RCV would imply a 20 per cent reduction in capex. This is much greater than the 10 per cent reduction in capex implied by the use of a gross output TFP measure.

While the precise figures that we have used are hypothetical, they serve to illustrate a point that will hold true more generally: if TFP inputs are matched precisely onto a regulated firm's cost base, value-added TFP figures imply a very much greater reduction in the firm's capex than gross output TFP figures.

Hence, if we closely match TFP inputs to a regulated firm's cost base, then using value-added TFP growth rather than gross output TFP growth will have three effects:

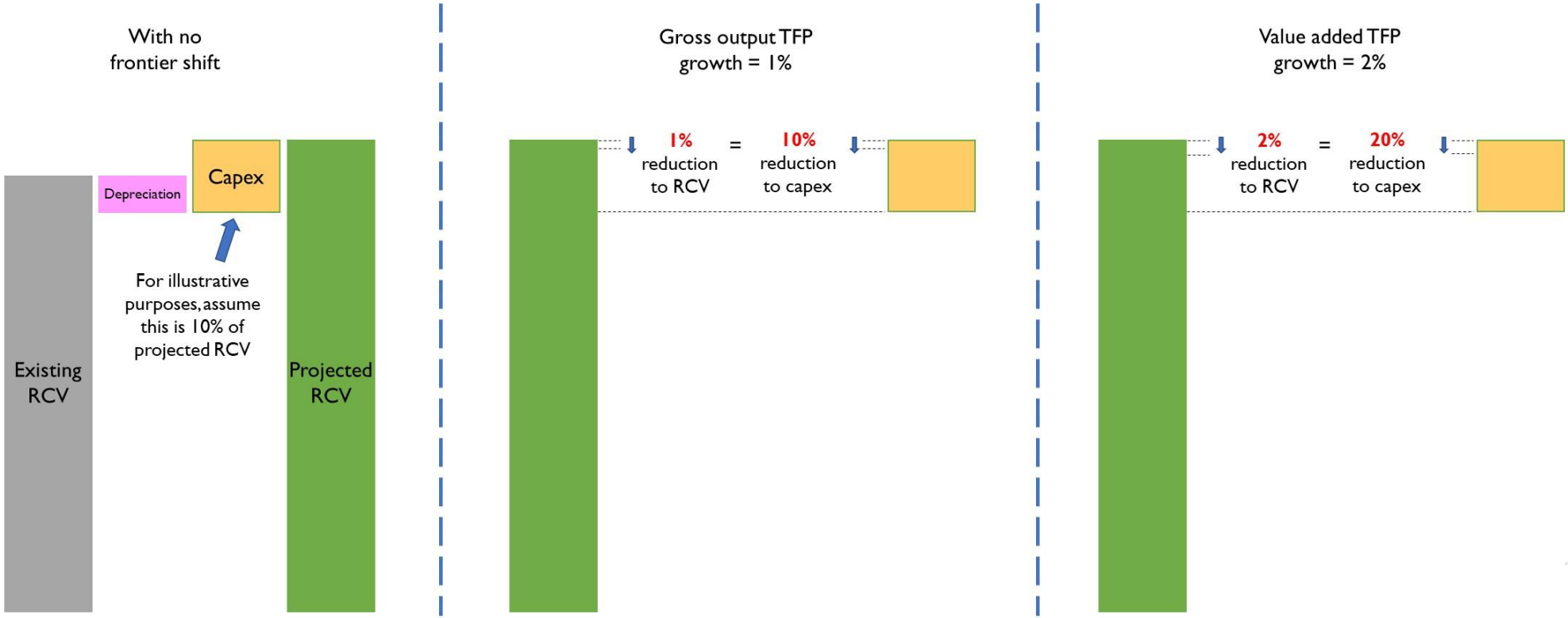
- The TPF growth rate itself will be higher (since value added TFP growth is always higher than gross output TFP growth, provided the sector uses some intermediates)
- A frontier challenge would not be applied to all intermediates (although some purchases from other sectors would still require a frontier shift challenge, as discussed in the previous sub-section);
- A much greater efficiency challenge would be applied to the firm's capex.

Given that the first two effects would be expected to offset each other (for the reasons set out at the end of Section 3.1), once the third effect is taken into account value-added TFP measures will imply a higher frontier shift challenge than gross output TFP measures. Indeed, the effect could be substantial, given that the use of value-added TFP estimates may require capex to be scaled back by a much larger amount to achieve the required reduction in capital stock.

Hence, once this capital-related effect is taken into account, value-added TPF growth continues to imply a higher frontier shift assumption than gross output TFP growth, even once the point being made by First Economics is taken into account.

[68] This assumption that value-added TFP growth is twice as high as gross output TFP growth is realistic. For example, our final PR19 report showed a gross output TFP growth rate for comparator sectors for the entire period covered by the NACE2 dataset of 0.6 per cent, and a value added TFP growth rate for the same sectors and time period of 1.3 per cent. See Europe Economics, "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", 7 December 2019, p.77-78

Figure 3.2: How an increased percentage reduction in the capital stock translates into a much larger reduction to capex



4 Further Evidence on Size of Uplift for Embodied Technical Change

In this chapter we first summarise the two broad approaches to estimating the size of embodied technical change discussed in the literature, and present further empirical evidence on the estimated size of embodied technical change. Second, we discuss the implications of this further evidence on the size of uplift that would be needed to a traditional TFP estimate to account for embodied technical change.

4.1 Further evidence on the size of embodied technical change

The academic literature has adopted two broad approaches to assessing the size of embodied technical change that is not captured by traditional TFP growth estimates.[69]

The first broad approach covers price-based estimates that identify the size of embodied technical change through correcting mismeasurement of prices using quality-adjusted price indices. An important contribution to this stream of literature includes Gordon (1990)[70] who estimated these quality-adjusted price indices for a range of producer and consumer durable goods. In turn, Hulten (1992) and Greenwood et al (1997) both used the price index data provided by Gordon to quantify embodied technical change.

The second approach involves production-based estimates of embodied technical change which use data on production and the age of capital stock to investigate the size of embodied technical change, following Nelson's (1964) seminal contribution.[71]

Below, we summarise two further pieces of academic literature estimating the size of embodied technical change through a production-based approach.

Sakellaris and Wilson (2004)[72] estimated the growth rate of embodied technological change from plant-level production, input, and investment decisions using US manufacturing plant data between 1972 and1996. Intuitively, the authors argued that if embodiment (vintage effects) was present, then newer plants with relatively newer equipment should be more productive once materials, labour input, and utilisation of capital and labour have been taken into account. They estimated the growth rate of embodied technological change to be between 8 and 17 per cent (with a preferred estimate of 12 per cent), which significantly exceeded previous estimates of around 4 per cent suggested by price-based methods. They also found that embodied technological change can account for up to two-thirds of the total technological change of manufacturing plants between 1972 and 1996.

The approach adopted by Hobijn (2000)[73] used a simple stochastic vintage capital growth model to investigate embodied and disembodied technical change using aggregate U.S. data covering the period between 1947 and 1999. He found that around two thirds of US GDP per capita growth during the post-war period that he

[69] The summary of these two approaches draws on Section 3 of Sakellaris and Wilson (2004): "Quantifying embodied technological change" *Review of Economic Dynamics*, 7(1), 1-26.

[70] Gordon (2007): "The measurement of durable goods prices" University of Chicago Press.

[71] As Sakellaris and Wilson (2004) states, Nelson's work implies that "a standard production function estimation (in logs) provides an estimate of embodied technological change by dividing the coefficient on average age by the coefficient on capital stock". Sakellaris and Wilson (2004): "Quantifying embodied technological change" *Review of Economic Dynamics*, 7(1), 1-26, p.11.

[72] Sakellaris and Wilson (2004): "Quantifying embodied technological change" *Review of Economic Dynamics*, 7(1), 1-26.

[73] Hobijn (2000): "Identifying Sources of Growth" mimeo, Federal Reserve Bank of New York.

examined can be attributed to embodied technological change (quality improvements of capital goods) while the rest is due to disembodied technological change. Moreover, subject to certain caveats,[74] he found a negative growth rate for disembodied technological change since 1973, suggesting embodied technological change as the primary driver of productivity growth between 1973 and 1999.

4.2 Implications for the size of uplift for embodied technical change

The evidence base previously covered in our report suggested that a traditional TFP estimate would need to be uplifted by 60 per cent to account for embodied technical change. This was primarily informed by:

- Uri (1983), whose results suggested that embodied and disembodied technical change are of the same order of magnitude; and by
- Hulten (1992), whose results suggested that 20 per cent of TFP growth (which should be capturing only disembodied technical shift) may actually represent embodied technical shift which has "leaked" into the TFP measure due to inadequate adjustment of inputs for quality changes.[75]

The additional empirical evidence discussed in the previous sub-section suggests that embodied technical shift may account for a larger share (around two-thirds) of total technological change than we previously assumed. This implies that our previously suggested uplift of 60 per cent should be taken as a lower bound rather than a central value for the size of uplift needed to a TFP estimate to account for embodied technical change.

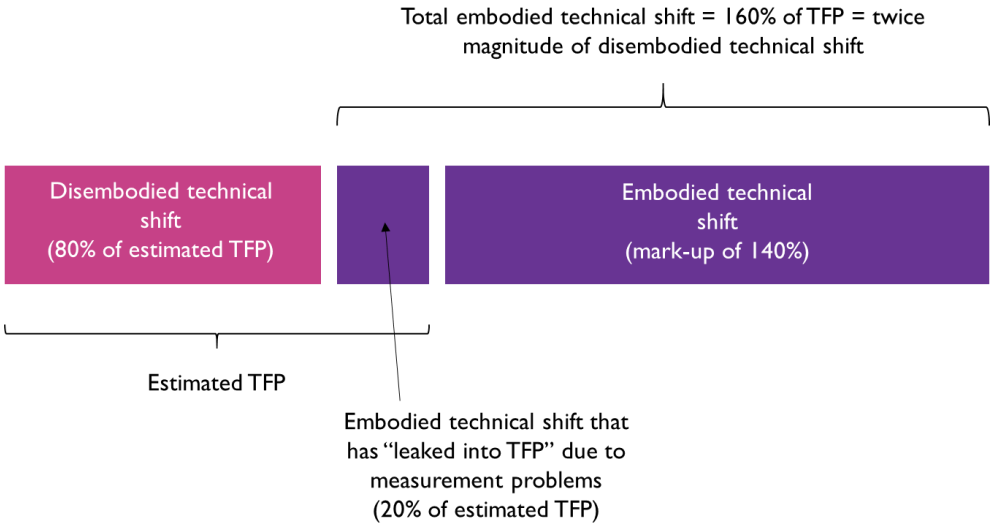
Figure 4.1 shows that the new academic evidence presented in this paper could justify an uplift as high as 140 per cent. First, Sakellaris and Wilson (2004) suggest that embodied technical change accounts for two-thirds of total technological change and disembodied technical shift (as measured by TFP) accounts for one third, implying that embodied technical shift is twice as high as disembodied technical shift.[76] Combined with our previous assumption from Hulten (1992) that 20 per cent of TFP represents embodied technical shift that has "leaked" into TFP due to measurement error, this implies that a TFP estimate needs to be uplifted by 140 per cent to account for embodied technical change. We consider that this provides an upper bound to the uplift that is appropriate.

[74] In particular, Hobijn considered two factors that may affect his results. First, measurement error in both output and CPI may mean that estimates of embodied technological shift are biased upwards while estimates of disembodied technological shift are biased downward. Second, his analysis did not take account of changes in the quality of labour.

[75] Europe Economics (2019): "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", p.66-68 [online].

[76] As mentioned earlier, our previous calculations used the assumption that embodied and disembodied technical change are of the same order of magnitude, as suggested by Uri (1983).

Figure 4.1: Estimation of embodied technical change excluded from TFP using further evidence



Source: Europe Economics' analysis using Hulten (1992) and Sakellaris and Wilson (2004).

The CMA's provisional findings report stated that based on TFP growth in gross output terms "companies in competitive sectors with similar activities to the water companies have achieved average TFP growth of 0.7% per year" and that "productivity gains driven by embodied technical change are not fully captured in the 0.7% figure".[77] Applying a 60 per cent uplift to this figure of 0.7 per cent as a lower bound to account for embodied technical change would imply a frontier shift of least 1.1 per cent per year. Applying our upper bound uplift of 140 per cent would imply a frontier shift number of 1.7 per cent per year.

[77] CMA (2020): "Anglian Water Services Limited, Bristol Water plc, Northumbrian Water Limited and Yorkshire Water Services Limited price determinations – Provisional findings", para 4.377 [online].

5 Additional Productivity Gains from Totex and Outcomes Framework

In this section, we present theoretical reasons for thinking that the additional productivity gains that water companies can achieve due to the totex and outcome framework are likely to last into AMP7 (and beyond). We make the following points:

- The totex and outcomes framework should allow the water sector to achieve additional productivity gains over and above "normal" frontier shift.
- The period over which these additional productivity gains can be achieved is likely to be decades, given the typical lifetime of assets in the water sector.
- The potential gains from the totex and outcomes framework may be higher over AMP7 due to current events.

We discuss these points in turn below, and then consider the implications for the CMA's final decision.

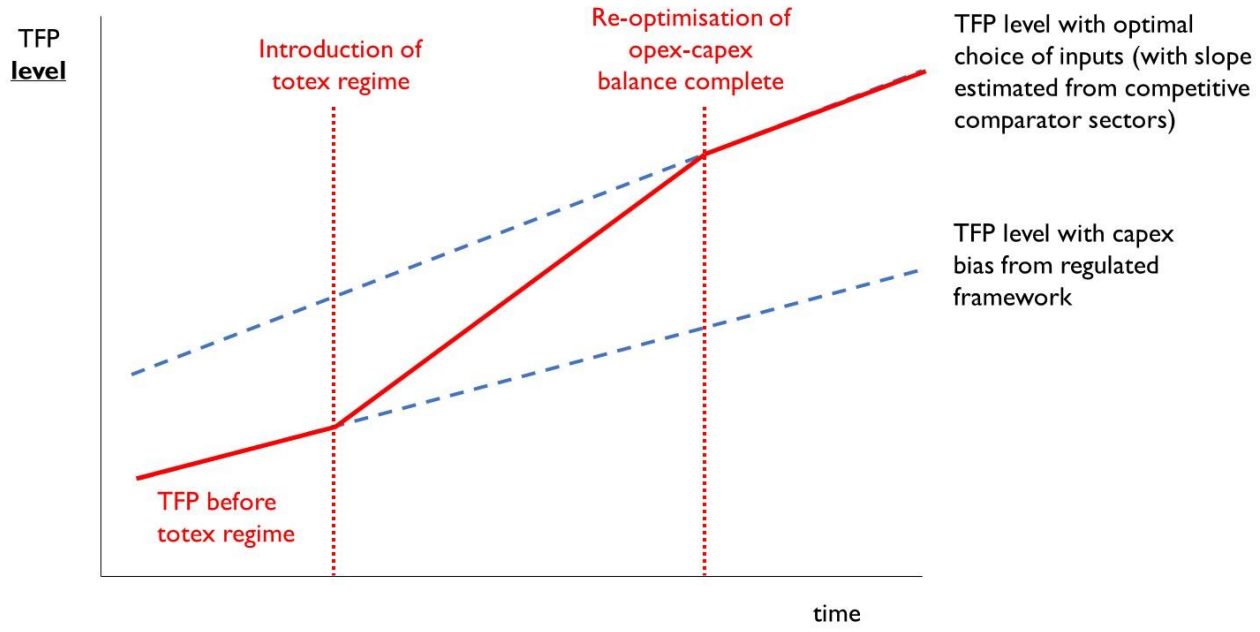
The totex and outcomes framework should allow the water sector to achieve additional productivity gains over and above "normal" frontier shift.

As explained in our final PR19 report, there are strong theoretical reasons for believing that the totex and outcomes framework introduced by Ofwat at PR14 will allow water companies to achieve additional efficiency gains.[78] These additional efficiencies arise because the water sector will be able to "catch up" with the productivity of comparator sectors by re-optimising between opex and capex and adopting more efficient solutions to achieve outcomes.

The diagram below illustrates why "industry catch up" efficiency gains from the totex and outcomes framework are additional to "normal" frontier shift. The diagram is presented in terms of the level of Total Factor Productivity (meaning that the slope of any line in the diagram represents the rate of growth of Total Factor Productivity). The lower blue dashed line shows the level of TFP achieved through time when firms' choices are constrained by the capex bias that existed in the previous regulatory framework. The higher blue dashed shows the level of TFP that can be achieved through time when firms adopt an optimal choice of inputs. The red line shows that after the introduction of the totex and outcomes regime, there will be a period of time (shown by the time period between the vertical red dotted lines) in which firms will make faster efficiency gains as they move from the lower blue dashed line to the upper blue dashed line. In other words, there will be a period of time in which firms will make additional efficiency gains from re-optimisation of their balance between capex and opex and their approach to outcomes, and these efficiency gains will be over and above trend efficiency gains which can be made from "normal" frontier shift.

[78] Europe Economics, "Real Price Effects and Frontier Shift – Final Assessment and Response to Company Representations", 7 December 2019, p.123-4

Figure 3.1: Why the totex and outcomes framework will lead to "industry catch-up" efficiency gains on top of normal frontier shift



The period over which these additional productivity gains can be achieved is likely to be decades, given the typical lifetime of assets in the water sector.

The adjustment period during which "industry catch-up" gains can be made will be driven by the remaining economic lifetime of the existing assets that companies had at the point in time when the totex and outcomes regime was introduced. (Note that the focus here is on the true economic lifetime of the assets, and not on any accounting assumptions that are made about asset lives for the purpose of calculating depreciation.) This is because these existing assets will reflect the capex bias that existed in the historical regulatory framework, and companies can continue to re-optimise between capex and opex and between different approaches to achieving outcomes as those assets reach the end of their life.

Some network assets have very long lifetimes, which suggests that the period in which additional efficiency gains can be made from the totex and outcomes framework may potentially extend over decades. We would certainly expect the potential for the water sector to make "industry catch-up" productivity gains to persist throughout AMP7 given there will be pre-2015 assets reaching the end of their life during this period.

The potential gains from the totex and outcomes framework may be higher over AMP7 due to current events.

The gains from the totex and outcomes framework are likely to be greatest during periods in which there has been a significant shift in the relative price of different inputs. This is because the totex and outcomes framework allows firms to reoptimise between different inputs in response to such changes in relative input prices.

There are major events currently taking place, such as the COVID-19 economic crisis and the end of the Brexit transition period, which have the potential to substantially change the relative input prices faced by water companies. This means that the potential for additional gains from the totex and outcomes could be particularly high during AMP7. For example:

- It seems likely that the COVID-19 crisis will lead to a period of mass unemployment in the UK, which is likely to put downward pressure on wages over AMP7. This could increase the cost savings from solutions which use more labour and less capital compared with the traditional approaches used by water

companies. The totex and outcomes framework would facilitate water companies in achieving these cost savings.

- The end of the Brexit transition period, along with the potential for the UK to sign free trade agreements with non-EU countries, may significantly change the relative prices of different imported inputs by changing the tariffs which have to be paid on them. This could change which solutions represent the most cost-effective approach to achieving certain outcomes. The totex and outcomes framework would assist firms in switching to whichever approach to achieving outcomes becomes the cheapest.

Implications for CMA's final decision

In the light of these theoretical considerations, we consider that the CMA should place some weight on the potential for additional productivity improvements from the totex and outcomes framework during AMP7. It could do this by treating the issue as a qualitative reason for "aiming up" when arriving at its preferred point estimate for water sector frontier shift.

This conclusion holds true regardless of the robustness or otherwise of the quantitative evidence on the size of the additional gains produced for Ofwat by KPMG.[79] We recognise that water companies and their consultants have made various critiques of KPMG's work. However, we do not think that any caveats around KPMG's analysis are a reason for ignoring the clear theoretical basis for expecting water companies to make additional "industry catch-up" efficiency gains during AMP7 due to the totex and outcomes framework.

[79] KPMG and Aqua Consultants, "Innovation and efficiency gains from the totex and outcomes framework", June 2018.

6 Conclusions

This report presented further evidence in relation to some of the issues covered in the CMA's provisional findings on the scale of frontier shift that water companies can be expected to achieve over AMP7. In particular, it provided further evidence in relation to the following:

- Economy-wide slowdown in productivity: the report presented a range of factors put forward by the academic literature as potential contributors to the productivity slowdown observed in advanced economies since the mid-2000s. We then set out various reasons why none of these factors imply lower frontier shift in the water sector. Our work also considered a number of reasons why the slowdown may not continue in the future.
- Application of gross value-added TFP estimates: we provided further evidence on why value-added TFP measures justify aiming up when selecting a point figure for frontier shift. This was in response to First Economics report for the Energy Networks Association which argued that a frontier shift figure based on value added TFP growth can only be applied to costs excluding intermediate inputs to be consistent with the way in which the TFP figure has been estimated.
- Size of uplift for embodied technical change: we presented some additional quantitative evidence on the potential size of the uplift needed for a traditional TFP estimate to account for embodied technical shift, showing that our previous illustrative estimate of 60 per cent should be considered as a lower bound and that the actual uplift that is required may as high as 140 per cent.
- Additional productivity gains from totex and outcomes regime: we put forward theoretical reasons for why additional efficiency gains from the totex and outcomes framework are likely to continue in future, and explain why such efficiency gains may be greater in the light of the ongoing COVID-19 economic crisis and the end of the Brexit transition period.

We summarise the additional evidence results for each of these areas below.

6.1 Economy-wide slowdown in productivity

The academic literature has put forward a range of possible explanations for the economy-wide slowdown in productivity observed in advanced economies, including in the UK, since the mid-2000s.

In the context of assessing the scale of frontier shift water companies can be expected to achieve over AMP7, this has two implications.

First, we cannot be sure whether the slowdown will continue throughout AMP7. This is because we cannot be sure what has caused the historical slowdown given the number of competing explanations put forward by the literature with no consensus about which explanation is the correct one. Further, a significant minority of the explanations that have been put forward suggest a much more optimistic picture about future productivity growth, including a reversion of the slowdown.

Second, the factors that may have contributed to the economy-wide slowdown in productivity do not imply lower frontier shift for the water sector. The reasons for this are summarised in the table below.

Table 6.1: Summary of factors contributing to the slowdown in productivity

Factor driving slowdown in productivity	Why this factor does not imply lower frontier shift in the water sector
Underestimation of productivity growth in ICT and digital services	Factor has small effect and is not relevant to water sector; in any case, it would mean that true productivity growth was higher than reported figures.
End of temporary period of faster productivity growth driven by ICT and associated business reorganization	No reason why new technologies (e.g. smart water networks) will not materialise in the water sector over AMP7.
Slowdown is confined to specific sectors, including manufacturing and financial services	Productivity slowdowns in finance and manufacturing were driven by idiosyncratic factors not relevant to water sector (measurement issue in finance sector, reduced capital deepening in manufacturing) .
Labour hoarding following 2008-09 crisis	Even for the economy as a whole, unlikely still to apply this many years after the 2008-09 crisis; in any case, water sector not affected in the same way due to stable demand and revenues.
Lax monetary policy and low interest rates led to higher survival of less efficient ('zombie') firms	Capital misallocation less likely in the UK due to a more efficient financial system; none of the regulated water companies bear any resemblance to 'zombie' firms (where current profits do not cover debt interest costs over extended period); regulated framework requires laggard firms to catch up, regardless of monetary environment.
Credit constraints prevented firms investing to increase productivity	Ofwat is allowing substantial capex within allowed revenues at PR19, and has a financeability duty which means efficient water companies should not face credit constraints.
Weak anticipated consumption growth weakens investment incentives	Demand faced by water companies is less affected in periods of downturn and revenues are protected through revenue cap; further, firms have ability and incentive to invest due to funding for allowed capex programme within allowed revenue and the RCV mechanism which guarantees cost recovery and a return on investment.
Increase in industry concentration reduces aggregate productivity and causes TFP measurement problems	No significant changes in industry concentration or market power in water sector; in any case, regulation seeks to set frontier shift on basis of what would be achieved in competitive market.
While frontier firms have continued to increase productivity, laggard firms have fallen further behind	Frontier shift ideally measured on basis of performance of frontier firms in comparator sectors; hence, this explanation implies that our frontier shift estimate (based on sectoral averages) is an underestimate of true frontier shift.
Regional differences in productivity growth between London / the South East and the rest of the country	Water companies identified as efficient by Ofwat's assessment of efficient costs cover a range of geographical areas across England and Wales.

6.2 Application of gross value-added TFP estimates

Our report sets out three points in response to First Economics' argument that a frontier shift figure based on value added productivity growth can only be applied to costs excluding intermediate inputs to be consistent with the way in which the TFP figure has been estimated.

First, First Economics has itself applied value-added TFP to all components of totex in a report for South East Water at PR14.

Second, only some purchases of inputs from other sectors are relevant to the point that First Economics makes. For example, in our view it would be inappropriate to apply First Economics' point to outsourced water sector activities since this would – illogically – lead to a lower frontier shift challenge for a firm which has outsourced more of its operational activities.

Finally, and crucially, a more detailed analysis of how TFP is calculated continues to show that value-added TFP estimates imply higher frontier shift than gross output TFP measures, even after accounting for the point made by First Economics. In particular, in the area of capital, the relevant input into TFP calculations is the total capital stock and not just capex. A given percentage TFP growth rate therefore implies a much larger reduction in capex in order to achieve the required reduction to the firm's total capital stock. This effect will be much greater in the case of value-added TFP growth rates given that mathematically they will always be greater than gross output TFP growth rates, meaning the value-added TFP estimates will imply higher frontier shift even after accounting for the point made by First Economics.

6.3 Further evidence on size of uplift for embodied technical change

Our previous report suggested a traditional TFP estimate would need to be uplifted by a further 60 per cent to account for embodied technical change. In particular, Uri (1983) suggested that embodied and disembodied technical change are of the same order of magnitude.

Further evidence by Sakellaris and Wilson (2004) suggest that embodied technical shift may account for around two-thirds of total technological change, a much larger share than previously assumed. This implies that embodied technical shift is twice as high as disembodied technical shift, and that our previously suggested uplift of 60 per cent should be taken as a lower bound for the size of uplift needed to account for embodied technical change. Combined with our previous assumption from Hulten (1992) that 20 per cent of TFP represents embodied technical shift that has "leaked" into TFP due to measurement error, this new academic evidence could justify an uplift as high as 140 per cent to a TFP estimate to account for embodied technical change.

6.4 Additional productivity gains from totex and outcomes regime

There are theoretical reasons for thinking that the additional "industry catch-up" productivity gains that the water sector can achieve due to the totex and outcome framework are likely to last into AMP7 (and beyond).

First, the residual lifetime of assets in the sector is a crucial driver of the time period over which gains can continue to be made, given that firms may only replace existing capex solutions with superior solutions when the existing assets reach the end of their life. Hence, given that the typical lifetime of assets in the water sector spans decades, there are strong reasons to expect water sector to continue to make "industry catch-up" productivity gains throughout AMP7.

Further, current major events such as the COVID-19 crisis and the end of the Brexit transition period may suggest higher potential gains from the totex and outcomes framework over AMP7 due to potential shifts in the relative price of different inputs.

6.5 Conclusions

In summary, our overall conclusions are:

- The academic literature puts forward a range of competing explanations for the economy-wide productivity slowdown which for various reasons do not imply lower frontier shift in the water sector.

- Even when we take into account First Economics' argument that value added productivity growth can only be applied to costs excluding intermediate inputs, gross value-added TPF growth continues to imply a higher frontier shift assumption than gross output TFP growth.
- Further academic evidence regarding the size of uplift needed to account for embodied technical change suggests that our previous estimate of a 60 per cent uplift should be taken as a lower bound, since the new evidence could justify an uplift as high as 140 per cent.
- There are theoretical reasons for thinking that the additional productivity gains that water companies can achieve due to the totex and outcome framework are likely to last into AMP7 (and beyond).

Taken together, these qualitative and quantitative arguments regarding the scale of frontier shift water companies can be expected to achieve over AMP7 justify an overall frontier shift figure higher than the 1 per cent figure stated in the CMA's provisional findings.