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# The UK Productivity Puzzle is a TFP Puzzle: Current Data and Future Predictions\*

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## Abstract

This paper revisits the UK productivity puzzle using a new set of data on outputs and inputs and clarifying the role of output mismeasurement, input growth and industry effects. Our data indicates an implied productivity gap of 12.6% in 2011 relative to the productivity level on pre-recession trends. We find (a) the labour productivity puzzle is a TFP puzzle, since it is not explained by the contributions of labour or capital services (b) the re-allocation of labour between industries deepens rather than explains the puzzle (i.e. there has been actually been a re-allocation of hours away from low-productivity industries and toward high productivity industries (c) capitalisation of R&D does not explain the puzzle (d) assuming extremely (unrealistically) high increased scrapping rates since the recession (a 50% growth) can potentially explain 33% of the puzzle and (e) industry data shows 33% of the TFP puzzle can be explained weak TFP growth in the oil and gas and financial services sectors. Continued weakness in finance would suggest a future lowering of TFP growth from 1.2% to 1%, but historical data does not show a long period of zero or negative TFP growth.

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## 1. Introduction

This paper revisits the UK productivity puzzle by using a new set of data on outputs and inputs and clarifying the role of output mismeasurement, input growth and industry effects. We shall argue that the productivity puzzle is a TFP puzzle and use this observation to try to make some predictions about the longer range prospects for UK productivity.<sup>1</sup>

The UK productivity puzzle is well known. Before the 2008 financial crisis, value added per hour worked grew in the UK relatively quickly, at around 2.5%pa (2000-07). Since the crisis, it has hardly grown at all. This can be expressed in terms of a productivity gap: the level of UK productivity is 12.6 percentage points below what it would have been had value added per hour continued at a 2.5%pa rate. This is the gap we seek to account for using growth accounting techniques<sup>2</sup>.

Firstly, at the time of writing, the ONS are in the process of capitalising R&D into the National Accounts. We update our datasets to incorporate this development. The capitalisation of R&D changes both GDP, since value added changes, and TFP, since inputs change. Existing datasets do not capitalise R&D and so cannot examine the impact of capitalisation on productivity. This is of interest in at least two regards. First, it is widely alleged that the UK has had falling R&D relative to competitors and so it is of interest to see how R&D capitalisation affects TFP growth. Second, in recent years, R&D investment has held up relative to other forms of investment (Goodridge et al, 2013) and so it is of interest to see if this explains part of the productivity puzzle (if R&D output is not included in GDP then measured output growth is too low in periods of relatively fast growth in R&D investment, which shows up as low measured productivity growth). We shall argue this does not actually explain any of the puzzle.

Second, it has been argued that labour composition has played a role in the puzzle, with growth in employment since the recession being in low-skilled, less productive, labour (Martin and Rowthorn, 2012). We examine the data on labour composition, both the skills within industries and the reallocation of labour between industries. We find that this deepens rather than explains the puzzle:

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<sup>1</sup> Predictions of future productivity have been debated for the US in, for example, Gordon (2012), Mokyr (2013) and Brynjolfsson and McAfee (2014). Gordon (2012) is commonly represented as predicting a slowdown in technological progress but as noted particularly in Gordon (2014) it is other headwinds, such as demographics, education and public debt, which leads to Gordon's prediction of weak per capita growth of which technical progress is but one part.

<sup>2</sup> We consider the scale of the productivity puzzle in relation to TFP growth between 2000 and 2007 rather than the more common assumption to include the 1990s. We do this because TFP growth in the 1990s was high by historical standards. Had we used 1990-2007, the implied TFP gap would be 13.3 percentage points as opposed to 12.9.

since 2008, upskilling has gained in pace and labour has been allocated towards high-productivity industries.<sup>3</sup>

Third, a number of authors (e.g. Pessoa and Van Reenen (2013)) have argued that the recent fall in UK productivity has been due to labour-capital substitution (capital shallowing) as real wages have fallen in the recession. Proponents of the view that the UK has lost output permanently are often challenged as to where the output capacity in the economy has gone: falls in capital seem like an obvious hypothesis to be investigated. Pessoa and Van Reenen (2013) calculate new UK capital *stocks* under the assumption of premature scrapping and substitution away from capital and towards labour. Oulton (2013) criticises their calculations and suggests that capital *services* would be a more appropriate concept for productivity analysis (capital services data were not available to him). We set out new capital services data, including R&D capital, and growth accounting results that allow for premature scrapping over the recent crisis: to the best of our knowledge we are the first to do this.

Our new capital services data reject the capital shallowing view. Using conventional depreciation rates, there has been no capital shallowing (that is, growth in capital services per hour has continued to rise). We therefore look at increased depreciation rates. We show that if deprecation has risen by 25% (50%) since 2008 then there has been capital capital shallowing and this can account for 16% (33%) of the TFP gap. Thus even with these raised depreciation rates, the labour productivity puzzle is a TFP puzzle (a conclusion robust to utilisation measures too).

Fourth, since the labour productivity puzzle is a TFP puzzle, what explains TFP growth? Some have argued it is due to the slowdown in particular industries such as a maturing oil and gas sector or an increasingly regulated financial services sector. To examine this we use an industry data set, with consistent measures of labour and capital services to look at productivity and TFP growth at industry level and its contributions to the total. We find 33% of the TFP productivity puzzle can be explained by the weakness of TFP growth in the oil and gas; and financial services sectors.

Readers wishing to skip to our main findings will find them summarised in Table 1. Row 1 shows labour productivity growth (market sector value added per hour,  $D\ln V/H$ ) pre- and post recession, at 2.54%pa and -0.47%pa, the deceleration giving an implied gap of 12.6% in 2011 relative to the productivity level on pre-recession trends. The other rows show the components of  $D\ln V/H$ : in row 2 and 3 for example, the contribution of labour services per hour and capital services per hour accelerated and decelerated. Our findings are then

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<sup>3</sup> The allocation of labour between industries depends of course upon the definition of industries: due to data availability, we have nine industries. Thus we cannot rule out allocation of labour within our broad industries as a driver of productivity growth.

- (a) labour services per hour accelerated and so are not an explanatory part of the productivity puzzle, rather they add another 1.7 points to the puzzle (row 2)
- (b) capital services per hour account for 0.6 out of the gap (row 3)
- (c) therefore the labour productivity puzzle is a TFP puzzle (row 4)
- (d) re-allocation of labour between industries deepens rather than explains the puzzle (i.e. there has been actually been a re-allocation of hours away from low-productivity industries and toward high productivity industries (row 5),
- (e) capitalisation of R&D does not explain the puzzle (row 6)
- (f) 16% (33%) of the TFP puzzle could be explained by increased scrapping of 25% (50%) (row 7 and 8).
- (g) 33% of the TFP productivity puzzle can be explained by the weakness of TFP growth in the oil and gas and financial services sectors.

Thus an aggressive assumption on premature scrapping and a “structural” weakness in TFP can account for 66% of the productivity gap.

**Table 1: The productivity puzzle<sup>^</sup> (growth rates pre- and post-crisis and implied gaps relative to pre-crisis growth)**

		Before (00-07)	After (07-11)	Implied gap	% of gap explained
1	DlnV/H*	2.54%	-0.47%	12.6	
	Components				
2	Labour	0.22%	0.63%	-1.7	
3	Capital	1.13%	0.99%	0.6	
4	TFP	1.19%	-2.09%	12.9	0%
5	Labour re-allocation	-0.26%	0.23%	-1.9	
	<b>R&amp;D</b>				
6	TFP: without R&D capitalised	1.21%	-2.10%	13.0	-1%
	<b>Capital: premature scrapping</b>				
7	TFP: raise dep rates by 1.25 after 2009	1.19%	-1.53%	10.8	16%
8	TFP: raise dep rates by 1.5 after 2009	1.19%	-0.95%	8.6	33%
	<b>Structural</b>				
9	TFP without Ag/Min/Utils & Financial Services**	1.11%	-1.05%	8.7	33%

**Notes to table:** Sources of growth decomposition for UK Market Sector, comparing the period before the recession (2000-07) to the period since (2007-11). Columns 1 and 2 are per annum log differences rates. The implied gap, column 3 is the level predicted by the three year growth rate in the post-crisis second column, as a proportion of the level predicted by a three year growth rate in the pre-crisis column. Decomposition carried out at the market sector level. In row 5, the term for the re-allocation of labour is that from a decomposition carried out at industry-level and aggregated up to the market sector and shows the implied growth rate due to the actual reallocation of labour between sectors of differing productivity. . In row 1, \* signifies that R&D has been capitalised. ^ All rows except 2, 3 and 5 are TFP growth rates. \*\* Here we take the share of TFP accounted for by Agriculture, Mining and Utilities (Ag/Min/Utils) and Financial Services, and use those shares to adjust market sector TFP.

**Source:** authors' calculations.

What of the longer term? We start with the 1.2%pa growth rate of TFP 2000-07. This already includes the drag from the oil and gas sector, which we expect to continue. Suppose that TFP growth

will be half what it was pre-crisis due to increased regulation.<sup>4</sup> The pre-crisis contribution to total TFP from the financial sector (i.e. its share in value added times its TFP growth rate) was around a third of aggregate TFP and so this assumption would reduce TFP growth by 1/6<sup>th</sup> i.e. to 1% (assuming that all other sectors restore their TFP growth to the pre-crisis rates and the value-added structure of the economy does not vary too much).

The 1% prediction assumes no catch-up of the productivity gap due to the uncertainty around the extent of any catch-up. Of course, if there is a catch up then there will be a temporary rise in the growth rate. At most, assuming full catch-up, this could add around 1 percentage point per annum to TFP growth and this would leave TFP growth close to its average growth rate in the decade after the 1990s recession. Oulton and Sebastia-Barriel (2013) find that banking crises reduce short short-term productivity growth such that the long-term level is lower than it would have been had the crisis not occurred. In other words, the level of labour productivity does not fully ‘catch-up’. Although they do not work with TFP, their results suggest a permanent reduction in the level of UK TFP following the crisis.

## 2. Our data

Our dataset is that from Goodridge, Haskel and Wallis (2014), without additional intangibles not capitalised in the National Accounts but including R&D, and consistent with 2013 Blue Book. More details are available in that paper, but are briefly summarised here. Our output data are built bottom-up using ONS industry data, to a market sector definition comprising of SIC07 sections A-K, MN and R-T, thus excluding real estate<sup>5</sup>, public administration & defence, health and education services. Data on capital services are from Oulton and Wallis (2014), built using ONS data on nominal investment and asset prices. We also incorporate a full set of tax adjustment factors (based on Wallis (2012)) for each (tangible and intangible, including R&D) asset to better estimate rental prices, income shares and capital deepening contributions. Data on labour input are taken from the ONS release on quality-adjusted labour input (QALI) (Franklin and Mistry, 2013). For National Accounts intangibles we use ONS GFCF and for R&D, we build our own estimates using the Business Enterprise R&D (BERD) release.<sup>67</sup> All nominal data is aggregated by simple addition. Real variables are aggregated as share-weighted superlative indices. We work with nine disaggregated industries, with data for the period 1997 to 2011. For our market sector analysis, we extend our aggregates back using data from

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<sup>4</sup> Although note, increased spreads could strengthen measured output and TFP growth in financial services.

<sup>5</sup> We exclude real estate as dwellings are not productive capital from the perspective of productivity analysis and so we must also exclude the output associated with them (actual and imputed rents).

<sup>6</sup> Our R&D data therefore pre-dates the latest ONS data on R&D investment and so is not 100% consistent with that. Any differences will however be minimal.

<sup>7</sup> In doing so we correctly convert capital expenditure to user costs, and we also use shares implied by the Input-Output tables to allocate R&D that takes place in the R&D industry to the purchasing industries.

Goodridge, Haskel and Wallis (2012), which are also built bottom-up but using data from the previous Standard Industrial Classification (SIC03).

In what follows, we analyse the gap set out in Table 1 in more detail.

### 3. Choice of baseline

To understand the gap, we must however establish a baseline. To do this, Table 2 sets out productivity since 1990. It does so by decomposing productivity growth into the contributions of various inputs and assigning the residual to TFP growth. We set out below some industry data, but using market sector data, the underlying accounting behind Table 2 is

$$\Delta \ln(V / H) \equiv \sum_n \left( \frac{P_{K,n} K_n}{P_V V} \Delta \ln(K / H)_n \right) + \sum_m \left( \frac{P_{L,m} L_m}{P_V V} \Delta \ln(L / H)_m \right) + \Delta \ln TFP \quad (1)$$

Where V is real value added, H hours, there are  $n$  types of capital asset  $K_n$  with rental rate  $P_{K_n}$ , and  $m$  types of labour  $L_m$  with wage (rental) price  $P_{L_m}$  and  $\Delta \ln TFP$  is calculated residually.

**Table 2: UK growth in market sector value added ( $\Delta \ln V$ ), labour productivity ( $\Delta \ln V/H$ ) and the capitalisation of R&D, 1990-2011**

	1	2	3	4	5	6	7	8
<b>Panel 1: <math>\Delta \ln(V/H)</math></b>								
	<b>DlnV/H</b>	<b>sDln(L/H)</b>	<b>sDln(K/H) cmp</b>	<b>sDln(K/H) othtan</b>	<b>sDln(K/H) NA intan</b>	<b>sDln(K/H) rd</b>	<b>DlnTFP</b>	<b>Memo: sLAB</b>
<i>a) With National Accounts Intangibles: software, mineral exploration and artistic originals</i>								
1990-00	2.95%	0.22%	0.31%	0.82%	0.24%	0.00%	1.36%	0.63
2000-07	2.55%	0.23%	0.12%	0.76%	0.24%	0.00%	1.21%	0.66
2007-11	-0.50%	0.64%	0.01%	0.91%	0.05%	0.00%	-2.10%	0.65
<i>b) With National Accounts Intangibles plus R&amp;D</i>								
1990-00	2.94%	0.21%	0.31%	0.80%	0.23%	0.04%	1.34%	0.62
2000-07	2.54%	0.22%	0.12%	0.74%	0.23%	0.04%	1.19%	0.65
2007-11	-0.47%	0.63%	0.01%	0.88%	0.05%	0.05%	-2.09%	0.64
<b>Panel 2: <math>\Delta \ln(V)</math></b>								
	<b>DlnV</b>	<b>sDlnL</b>	<b>sDlnK cmp</b>	<b>sDlnK othtan</b>	<b>sDlnK intan</b>	<b>sDlnK rd</b>	<b>DlnTFP</b>	<b>Memo: DlnH</b>
<i>a) With National Accounts Intangibles: software, mineral exploration and artistic originals</i>								
1990-00	2.69%	0.02%	0.31%	0.76%	0.24%	0.00%	1.36%	-0.26%
2000-07	2.80%	0.38%	0.12%	0.84%	0.25%	0.00%	1.21%	0.25%
2007-11	-1.54%	-0.03%	0.00%	0.59%	0.00%	0.00%	-2.10%	-1.04%
<i>b) With National Accounts Intangibles plus R&amp;D</i>								
1990-00	2.68%	0.02%	0.31%	0.74%	0.23%	0.04%	1.34%	-0.26%
2000-07	2.79%	0.38%	0.12%	0.81%	0.24%	0.05%	1.19%	0.25%
2007-11	-1.51%	-0.03%	0.00%	0.57%	0.00%	0.03%	-2.09%	-1.04%

**Notes to table.** Data are average growth rates per year for intervals shown, calculated as changes in natural logs. Contributions are Tornqvist indices. In panel 1, data are a decomposition of labour productivity in per hour terms. In panel 2, data are a decomposition of growth in value-added. First column is growth in value-added (in



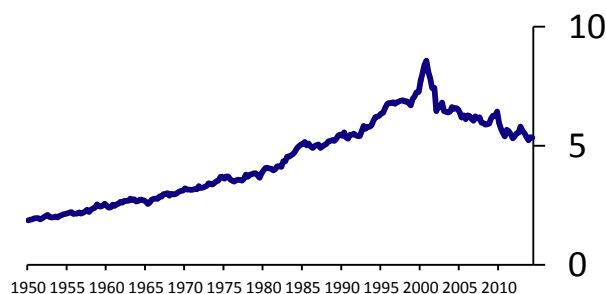
per hour terms in panel 1). Column 2 is the contribution of labour services (per hour in panel 1), namely growth in labour services (per hour) times share of labour in MSGVA. Column 3 is growth in computer capital services (per hour) times share in MSGVA. Column 4 is growth in other tangible capital services (buildings, plant, vehicles) (per hour) times share in MSGVA. Column 5 is growth in intangible capital services (per hour) times share in MSGVA, where intangibles are those already capitalised in the national accounts, namely software, mineral exploration and artistic originals. Column 6 is R&D capital services (per hour) times share in MSGVA, with R&D due to be capitalised in the UK accounts in 2014. The price index used for R&D is the implied market sector GVA deflator. Column 7 is TFP, namely column 1 minus the sum of columns 2 to 6. Column 8 presents memo items, in the first panel we show the share of labour payments in MSGVA, and in the second panel we show average changes in market sector hours.

**Source:** authors' calculations

The top rows in panels (a) and (b), without and with R&D capitalisation, show  $\Delta \ln(V/H)$  was 2.94%pa 1990-2000, and 2.54%pa 2000-07. In Table 1 we took this latter figure for our baseline and so already assumes a productivity growth deceleration relative to 1990-2000 (had we chosen the full period of 1990-2007 with average labour productivity growth of 2.77% pa for our baseline then the gap would be 13.3 percentage points).

There are a number of points worth noting regarding our 2000-07 choice of baseline, which is lower than pre-2000  $\Delta \ln(V/H)$ . First, both ICT use and ICT production contributed strongly to productivity growth in the late 1990s. As column 3 shows, our baseline is a period of substantially slower ICT capital deepening. This is a result of both weaker nominal investment in ICT but also slower declines in the measured prices of ICT products. Figure 1 shows that the share of ICT manufacturing value added in total manufacturing has also fallen since 2000 meaning that any productivity boost from ICT production will also have fallen.<sup>8</sup> For these reasons we exclude the “ICT boom” from our baseline. So excluding the peak ICT contribution period from the baseline assumes a future contribution will not be of the magnitude seen during the late 1990s, which might not be true of course.

**Figure 1: Share of ICT manufacturing value-added in total manufacturing (%)**



**Source:** authors' calculations using ONS data

<sup>8</sup> Oulton (2010) finds that main boost to growth is from use (due to fall in prices and improved terms of trade) not production i.e. even if the ICT sector has declined, economy benefits from falling import prices. So can get benefit from ICT production if TFP in ICT production is higher than in rest of the economy. But even if no domestic ICT production, domestic growth is still increased due to falls in relative price of ICT.

#### 4. Impact of the capitalisation of R&D and R&D spillovers

The 2014 ONS National Accounts Blue Book treated R&D as investment for the first time. As shown in Table 1 above, if we do not capitalise R&D the TFP gap is 13.0%, so for the purposes of this paper, it will not explain the TFP gap. The Appendix explores the robustness of this finding to a relatively neglected issue, namely the choice of R&D deflator. As Table 2 shows, the contribution of R&D is around 0.04%pa, an estimate that assumes that R&D prices grow at the GDP deflator, as in conventional.<sup>9</sup> But one might assume that the process of R&D has changed with the introduction of the ICT: computers have made simulations quicker and easier and the internet has made research collaboration and information gathering cheaper. In this case, the price of performing R&D might have fallen, possibly dramatically and so the Appendix looks at the case where that price falls in line with MFP in high-productivity industries and in line with packaged software. In the software case, the contribution of R&D rises very substantially, to 0.14%pa, but for our purposes the productivity puzzle is not explained. The reason is that  $\Delta \ln V/H$  is slightly larger with R&D capitalisation and by about the same amount as the increase in contribution from  $\Delta \ln K^{R\&D}$  so that  $\Delta \ln TFP$  remains the same.

R&D may however help understand the productivity slowdown in the following sense.  $\Delta \ln TFP$  was relatively fast in the 1990s (1.34%pa, 1990-2000) but this is a considerable slowdown from the 1980s (2.00%, 1980-1990). As is well-documented, R&D spending has slowed very considerably as well over this long period ( $\Delta \ln K^{R\&D}$  grew at 4.6% pa in 1980-90, 2.1%pa 1990-2000, 2.2%pa 2000-10). Such a fall in  $\Delta \ln K^{R\&D}$  might help explain a fall in  $\Delta \ln TFP$  if  $\Delta \ln K^{R\&D}$  is associated with spillovers, for which there is some evidence ((see e.g. surveys by Hall, Mairesse and Mohnen (2009) and Griliches (1973)). If spillovers take a very long time, then the fall in  $\Delta \ln K^{R\&D}$  between the 1980s to 1990s might lead to some fall in the 2000s. If the lag operates within the decade, then the fall in  $\Delta \ln K^{R\&D}$  between the 1980s to 1990s would have contributed to the fall in  $\Delta \ln TFP$  between the 1980s to 1990s. This then would be another reason to benchmark the underlying  $\Delta \ln TFP$  rate to the 2000s.<sup>10</sup>

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<sup>9</sup> Ker (2014) explains that the UK R&D deflator is derived from a price index of UK R&D costs (mostly labour). Following Eurostat recommendations, this is not adjusted for productivity and so the price index rises, as labour costs do, around 2pppa slightly faster than the GDP deflator. The US adjust their price index by average US TFP growth, which at around 2%pa means their index is roughly in line with the GDP deflator. The pre-packaged software deflator falls at around 5%pa.

<sup>10</sup> Using industry data, Goodridge, Haskel and Wallis (2014) estimate an elasticity of  $\Delta \ln TFP$  to  $\Delta \ln K^{R\&D}$  of 0.31 (which includes within-industry spillovers and spillovers derived from knowledge external to the industry, and excludes the private contribution already accounted for in the estimation of TFP). Thus, using that estimate, we may expect TFP growth in the post-1990 period to be lowered by around  $(0.31*(4.6-2.1))=0.78\%$  pa, remarkably close to the actual slowdown of  $2.00\%-1.34\%=0.66\%$ pa.

## **5. Labour composition**

As we can see from the tables above, the inclusion of labour quality (composition) deepens the productivity puzzle. As Table 2, panel 1)b, column 3, shows, its contribution sped up from an average of 0.22% pa in 2000-07, to an historically very large 0.63% pa in 2007-11. Thus it is not the case in the recession that, for example, there was a move to low skilled workers, either in terms of quantity or price, that lowered the composition of labour and so slowed productivity growth. Rather, the opposite occurred.

Why? Labour composition is a wage-bill weighted share of changes in the hours per worker and number of workers of different skills, ages and gender. Thus it can change for a number of different reasons. In the Appendix, using newly released data from ONS, we document that the faster growth in labour composition since the recession is due to the fall in quantity of low-skilled workers employed, as opposed to changes in income weights (relative wages) or changes in hours per worker.

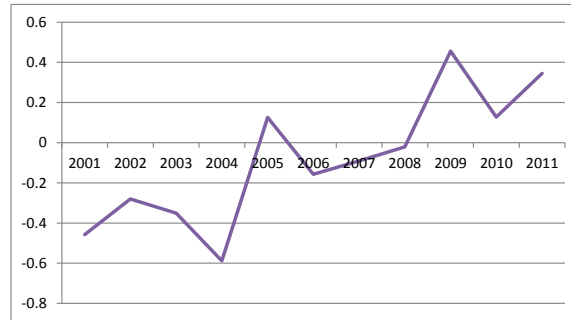
## **6. Labour reallocation**

Having looked at changes in the characteristics of labour within industries (labour composition) we turn to the effect of labour reallocation, that is, the movement of labour from low to high productivity industries that might raise the overall average. As Appendix 1 shows, total output per hour is a value-added-weighted average of output per hour in each industry. Thus total productivity can rise if (a) industry productivity rises and (b) hours are reallocated to above-average productivity industries.

We can measure this term using industry data, which we describe in the appendix. One observation is that the extent of reallocation depends upon the industries one has, since there can always be reallocation between firms in the same industry. Figure 2 shows the reallocation term in our data.

As Figure 2 shows, with the exception of 2005, the re-allocation term was negative in every year from 2001 to 2008. Then in 2009 it turned, and has remained positive. Positive values mean that labour has been re-allocated toward high-productivity industries. Therefore, as with labour composition, the data on labour reallocation deepen rather than explain the productivity puzzle.

**Figure 2: Labour re-allocation term**



**Note to figure:** Labour re-allocation term ( $R^H$ ) as set out in Appendix 1. A positive term implies movement of labour toward high-productivity industries.

**Source:** authors' calculations, see Appendix

## 7. Labour-capital substitution and premature scrapping

Another suggested explanation for the puzzle, as argued by Pessoa and Van Reenen (2013) is a possible fall in the capital-labour (K/L) ratio. As equation (1) shows, a fall in  $D\ln K/H$  would account for lower  $D\ln V/H$ . As we have seen, at conventional depreciation rates, and measuring capital services, this is not enough to account for the productivity puzzle. Is this conclusion robust however to increased depreciation rates? Such rates might be a way of modelling increased disposals of assets after the 2008 recession. The effect of this on capital services is not clear however. Capital stocks will fall since for each asset  $n$ ,  $K_n$  is built using a perpetual inventory model ( $K_{n,t} = I_{n,t} + (1 - \delta_n)K_{n,t-1}$ ). Capital services weights this by rental prices,  $P_{K,n}$  however where  $P_{K,n} = \tau_{k,n} (r + \delta_{k,n} - \pi_{k,n}) P_{I,n}$ <sup>11</sup> and a rise in  $\delta$  therefore raises the weight on that asset. The overall effect on  $\Delta \ln K$  is therefore an empirical matter and so we calculate  $\Delta \ln K$  using different capital scrapping assumptions. Table 3 sets out details.

Table 3 suggests the following. Consider first the income shares in the first column for each asset. Note that these are shares of value-added and so sum to the market sector share for capital compensation (0.36 in 2000-07). Around one-third of this is from buildings, which also accounts for over 40% of the total capital contribution in 2000-07 due to strong growth in the stock of buildings throughout the commercial property boom in the 2000s. Non-computer plant & machinery (P&M) has a similarly high share but a smaller contribution as the growth in the stock of P&M is lower.

Looking at the first panel, our baseline estimates with no additional assumption for premature scrapping, we notice is that, for each asset,  $\Delta \ln K_n$  has declined since the recession. Total  $\Delta \ln K$  in the

<sup>11</sup> Where  $\tau_k$  is an asset-specific tax-adjustment factor,  $\pi^k$  is a capital gains term and  $P_{I,k}$  is the investment price.

later period is therefore lower, by around a half, but remains positive. In terms of the contributions, the total contribution from capital is also halved, but within that we note that the contribution for buildings actually rose, due to its increased income share in the later period.

The second panel increases all depreciation rates by a factor of 1.25 post-2009. This further reduces  $\Delta \ln K_n$  in the later period, with that from computers, P&M, intangibles (including R&D) all turning negative. Total  $\Delta \ln K$  is, and the contribution from capital, remains slightly positive.

The third panel makes the aggressive assumption on capital scrapping, increasing all depreciation rates by a factor of 1.5 from 2009. We note that  $\Delta \ln K_n$  from buildings remains positive but that for all other assets is negative. Thus total  $\Delta \ln K$  (-1.51% pa) and the contribution of capital (-0.53% pa) are both negative.

**Table 3: Capital services under different assumptions around premature scrapping**

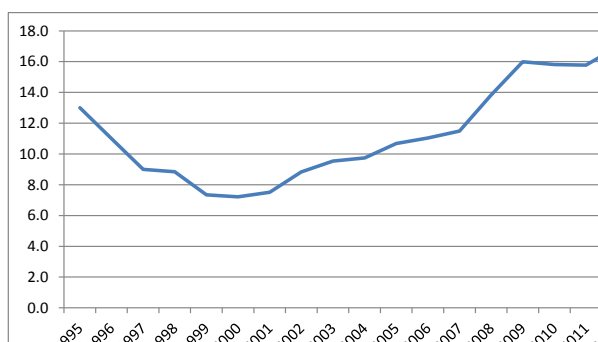
	Buildings			Computers			Non-computer P&M			Vehicles			NA Intangibles (soft, min, cop)			R&D			Total		
	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution	Income share	Growth in capital services	Contribution
	sK(b)	DlnK(b)	sK(b).DlnK(b)	sK(cmp)	DlnK(cmp)	sK(cmp).DlnK(cmp)	sK(p)	DlnK(p)	sK(p).DlnK(p)	sK(v)	DlnK(v)	sK(v).DlnK(v)	sK(int)	DlnK(int)	sK(int).DlnK(int)	sK(rd)	DlnK(rd)	sK(rd).DlnK(rd)	sK	DlnK	sK.DlnK
2000-07	0.11	4.35%	0.50%	0.01	10.61%	0.12%	0.14	2.06%	0.27%	0.03	1.53%	0.04%	0.04	5.06%	0.24%	0.02	2.32%	0.05%	0.35	3.47%	1.22%
2007-11	0.17	3.44%	0.57%	0.01	0.14%	0.00%	0.10	1.11%	0.12%	0.03	-4.44%	-0.11%	0.04	0.07%	0.00%	0.02	1.53%	0.03%	0.36	1.68%	0.61%
<b>Increased capital scrapping: Increase all depreciation rates by 1.25 from 2009</b>																					
2000-07	0.11	4.35%	0.50%	0.01	10.61%	0.12%	0.14	2.06%	0.27%	0.03	1.53%	0.04%	0.04	5.06%	0.24%	0.02	2.32%	0.05%	0.35	3.47%	1.22%
2007-11	0.16	3.13%	0.49%	0.01	-4.55%	-0.04%	0.11	-0.05%	0.00%	0.03	-7.79%	-0.20%	0.04	-3.95%	-0.17%	0.02	-1.45%	-0.03%	0.36	0.12%	0.05%
<b>Increased capital scrapping: Increase all depreciation rates by 1.5 from 2009</b>																					
2000-07	0.11	4.35%	0.50%	0.01	10.61%	0.12%	0.14	2.06%	0.27%	0.03	1.53%	0.04%	0.04	5.06%	0.24%	0.02	2.32%	0.05%	0.35	3.47%	1.22%
2007-11	0.15	2.82%	0.43%	0.01	-8.90%	-0.08%	0.11	-1.22%	-0.14%	0.03	-11.24%	-0.31%	0.04	-7.89%	-0.35%	0.02	-4.45%	-0.09%	0.36	-1.51%	-0.53%

Note to table: Data, by asset, for the income share, capital service and capital contribution to value-added. Note, not in per hour terms. First panel are baseline estimates with no additional assumption for premature scrapping. Panel 2 assumes extensive scrapping, with all depreciation rates increased by a factor of 1.25 from 2009. Panel 3 makes an even more aggressive assumption, with all depreciation rates increased by a factor of 1.5 from 2009.

Empirical evidence on scrapping rates is limited, particularly recent evidence. Harris and Drinkwater (2000) estimate that adjusting the manufacturing capital stock for plant closures over the period 1970 to 1993 leaves the capital stock 44% lower in 1993 compared with making no allowance for plant closures. Their estimated annual rate of premature scrapping is consistent with scaling up depreciation rates by a factor of 1.5 over post-2009. But their scrapping rate is estimated for an industry that was in secular decline over their estimation period with manufacturing’s share of the net capital stock falling from 32% to 23%, suggesting that it may be an overestimate.

Thus even with strong assumptions on capital scrapping, capital shallowing does not appear to explain the puzzle. What Table 3 emphasises however is the dominance of buildings in the measurement of  $\Delta \ln K$  and thus the contribution of capital. As shown in the third panel, even when we increase depreciation rates by a factor of 1.5 post-2009,  $\Delta \ln K_n$  from buildings still grow on average at 2.82% pa in the 2007-11 period, and the contribution from buildings capital deepening to labour productivity is still 0.43% pa. But what if there is an excess supply of buildings capital following the commercial property boom earlier in the 2000s, such that buildings are less utilised than in earlier periods? According to the Berndt-Fuss-Hulten theorem, utilisation is captured in the rental price, via a reduced rate of return ( $r$ ) and the asset price ( $P_1$ ). However, if that is not the case, the contribution of buildings may be over-estimated. Therefore it is of interest to look at some data on the utilisation of buildings. Figure 3 presents data on UK commercial property vacancies.

**Figure 3: Commercial property vacancies (as % of total commercial property)**



**Notes to figure:** Data on IPD annual void rates.

**Source:** IPD UK Annual Property Index.

The data show vacancy rates increasing from 11% in 2006 to 16% in 2009, and remaining at a similar level before increasing to 17% in 2012. If such a series accounts for the utilisation of buildings then the “true” contribution of buildings is:  $(1 - v)s^B \Delta \ln K^B$  where  $v$  is the vacancy rate. In 2012,  $(1 - v) = 83\%$ . Therefore, TFP may be over-estimated by  $(0.17 * 0.43) = 0.07\%$  pa due to overestimation of

the utilisation of buildings. Therefore even if under-utilisation is not captured in the rental price, this also does not appear to provide a significant explanation of the TFP puzzle.

With these capital service data in mind, we turn to the impact on labour productivity. To look at the impact of capital scrapping, we start with the data we have calculated using standard depreciation assumptions. Those results are shown in the top panel of Table 4. The table is set out as follows. Panel 1 are our baseline estimates with no assumption for capital scrapping. Panel 2 presents results when we increase all depreciation rates by a factor of 1.25 from 2009. As shown in columns 3 to 6, this reduces the contribution of  $\Delta \ln K/H$  for all assets, such that those for computers, national accounts intangibles and also R&D turn negative, and that for other tangibles is reduced by around a third. TFP thus increases by around a quarter to -1.53% pa. Note 1.25 is considered to proxy for the upper bound of potential capital scrapping. Panel 3 takes this further, increasing all depreciation rates by a factor of 1.5 post-2009, an assumption far stronger than available evidence would suggest. Here, the contributions of  $\Delta \ln K/H$  are reduced further, and TFP increases to -0.95% pa.

Note that the rise of depreciation rates is consistent with both increased scrapping in a physical sense, but also higher obsolescence. That might be due to, say a fall in demand, rendering some goods, particularly intangibles like software etc useless.

**Table 4: Estimates of potential impact of capital scrapping**

	1	2	3	4	5	6	7	8
<b><math>\Delta \ln(V/H)</math>: With National Accounts Intangibles plus R&amp;D</b>								
	$D \ln V/H$	$s D \ln(L/H)$	$s D \ln(K/H)$ cmp	$s D \ln(K/H)$ othtan	$s D \ln(K/H)$ NA intan	$s D \ln(K/H)$ rd	$D \ln TFP$	Memo: sLAB
<i>a) Baseline (no scrapping)</i>								
1990-00	2.94%	0.21%	0.31%	0.80%	0.23%	0.04%	1.34%	0.62
2000-07	2.54%	0.22%	0.12%	0.74%	0.23%	0.04%	1.19%	0.65
2007-11	-0.47%	0.63%	0.01%	0.88%	0.05%	0.05%	-2.09%	0.64
<i>b) Increase depreciation rates by 1.25 from 2009</i>								
1990-00	2.94%	0.21%	0.31%	0.80%	0.23%	0.04%	1.34%	0.62
2000-07	2.54%	0.22%	0.12%	0.74%	0.23%	0.04%	1.19%	0.65
2007-11	-0.47%	0.63%	-0.03%	0.59%	-0.13%	-0.01%	-1.53%	0.64
<i>c) Increase depreciation rates by 1.5 from 2009</i>								
1990-00	2.94%	0.21%	0.31%	0.80%	0.23%	0.04%	1.34%	0.62
2000-07	2.54%	0.22%	0.12%	0.74%	0.23%	0.04%	1.19%	0.65
2007-11	-0.47%	0.63%	-0.07%	0.29%	-0.30%	-0.07%	-0.95%	0.64

**Notes to table.** Data are average growth rates per year for intervals shown, calculated as changes in natural logs. Contributions are Tornqvist indices. In panel 1, data are a decomposition of labour productivity in per hour terms, with no assumption on premature scrapping. In panel 2, depreciation rates are increased by a factor of 1.25 from 2009. In panel 3, depreciation rates are increased by a factor of 1.5 from 2009. First column is growth in value-added per hour. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MSGVA. Column 3 is growth in computer capital services per hour times share in MSGVA. Column 4 is growth in other tangible capital services (buildings, plant, vehicles) per hour times share in MSGVA. Column 5 is growth in intangible capital services per hour times share in MSGVA, where intangibles are those already capitalised in the national accounts, namely software, mineral



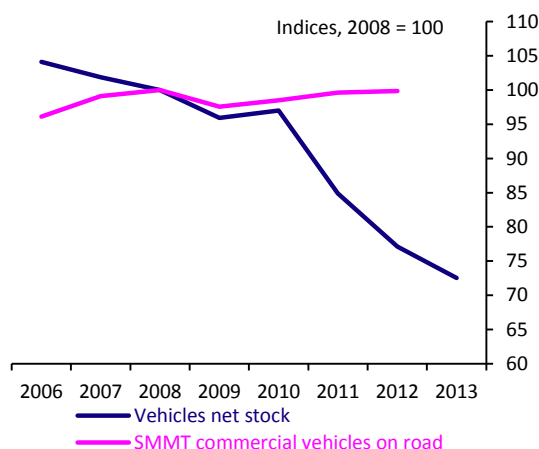
exploration and artistic originals. Column 6 is R&D capital services per hour times share in MSGVA, with R&D due to be capitalised in the UK accounts at the time of writing. The price index used for R&D is the implied MSGVA deflator. Column 7 is TFP, namely column 1 minus the sum of columns 2 to 6. Column 8 presents the share of labour payments in MSGVA.

Do we have any independent evidence for premature scrapping? An indicator that is commonly used as a proxy for premature scrapping is the corporate insolvency rate. Indeed, the ONS adjust their capital stock estimates for firm bankruptcy using data on corporate insolvency. They assume that 50% of a bankrupt firm's capital stock is lost from the aggregate measure. But this only captures capital stock lost due to firm bankruptcy and not premature scrapping by continuing firms. The corporate insolvency rate has remained very low by historical standards during the crisis.

Disposals are not a direct measure of premature scrapping because a disposal is a sale to another firm or household. However, they are an indicator of firms actively disposing of assets and trying to reduce their capital stock. Disposals have remained very low since 2009 and the fall in business investment during the crisis reflects a sharp fall in acquisitions rather than an increase in disposals. This could be regarded as evidence of limited premature scrapping although it could just be a result of a very limited market for used capital goods.

A failure to account for premature scrapping would lead to  $\Delta \ln K/H$  being too high. But there are also reasons to believe  $\Delta \ln K/H$  may be too low. During recessions, when firms are credit constrained or because uncertainty has risen, they may choose not to replace older assets at the same rate as usual. To examine this, Figure 4 shows new evidence on life lengthening. Our capital stock data shows a sharp fall in the net stock of vehicles over the crisis but SMMT data shows that the number of commercial vehicles on the road has stayed the same. This tells us nothing about the efficiency of those vehicles on road but it does suggest that firms have been holding on to assets (vehicles at least) for longer. This is consistent with the lack of any increase in secondary capital markets (low disposals).

**Figure 4: Evidence of life-lengthening in capital (vehicles)**



**Source:** Bank of England

Therefore, as shown in Table 1, even using a strong assumption of increased depreciation rates by a factor of 1.25 post-2009, capital shallowing only explains 16% of the TFP gap. Using the even stronger assumption of increased rates by a factor of 1.5, for which there is no precedent, capital shallowing only explains 33% of the TFP gap.

To summarise, we have now considered measurement (R&D), labour composition, labour reallocation, and capital shallowing as potential explanations of the productivity puzzle. We have found the omission of R&D explains little, labour composition and reallocation deepen the puzzle, and capital shallowing explains at most 16% of the TFP gap. We have therefore shown that the productivity puzzle is in fact a TFP puzzle. In the next section we look at industry data, in particular industry TFP, to examine some of the structural explanations that have been put forward.

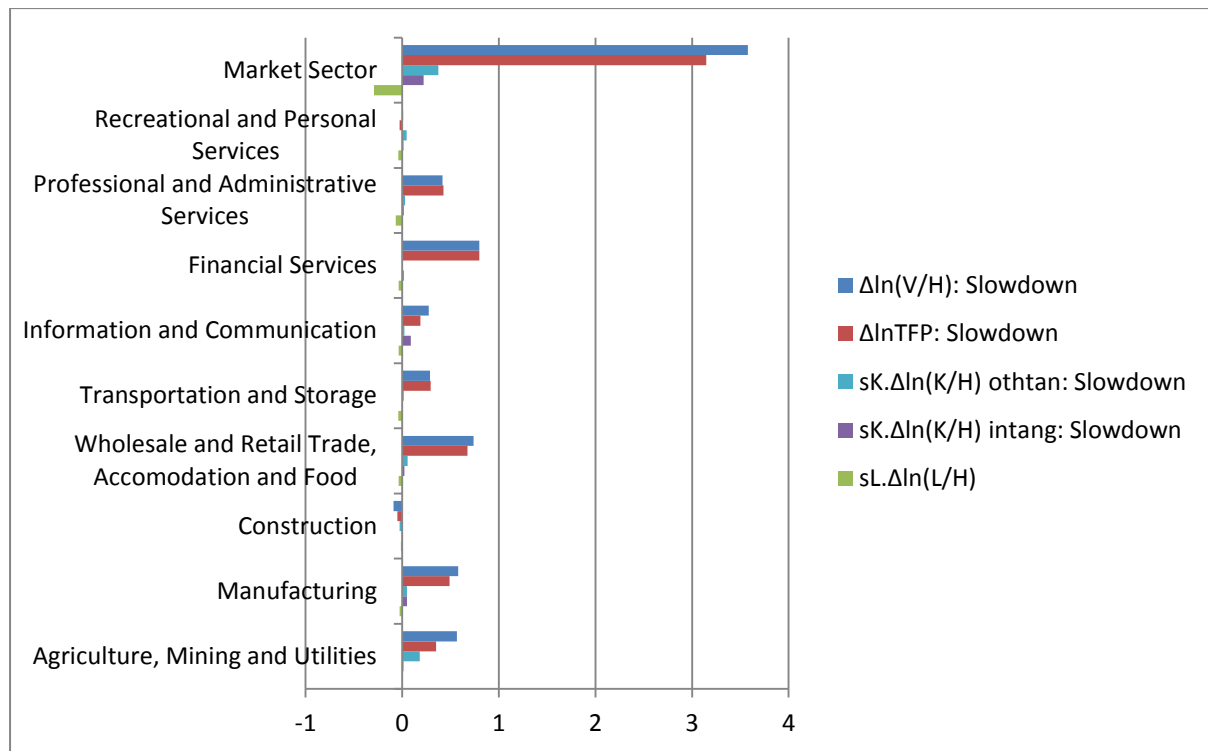
## **8. Structural weakness in $\Delta \ln TFP$**

We turn now to industry level analysis to try to better understand which sectors account for the weakness of TFP growth during the crisis. To do this we need to set out the relations between market-sector and industry levels of analysis. This is done in Appendix 1, which also includes a table which compares results from the two datasets. The two are slightly different because of the way in which they are aggregated. Briefly, as set out in the appendix, when working with the industry data, aggregated labour productivity is the weighted sum of industry labour productivity. Thus changes in the numerator (value-added) and the denominator (hours worked), are aggregated using nominal value-added weights. At the market sector level, labour productivity is aggregated value-added less aggregate hours worked. The difference between the two approaches captures the re-allocation of

labour between industries with different levels of labour productivity. Similar differences occur in the contributions of labour composition and capital deepening. In some years this re-allocation term is quite large causing differences between the two datasets.<sup>12</sup>

Figure 5 sets out our industry results. The top histogram is for the whole market sector using our industry data and, in the top two bars shows the slowdown in  $\Delta \ln V/H = \Delta(\Delta \ln V/H)$  and in  $\Delta \ln TFP$  (that is  $\Delta(\Delta \ln V/H) = \Delta \ln V/H^{00-07} - \Delta \ln V/H^{07-11}$ ). On these data,  $\Delta(\Delta \ln V/H) = 3.58\%$ , most of which was explained by  $\Delta(\Delta \ln TFP) = 3.15$ , which is  $(3.15/3.58) = 88\%$  of the productivity slowdown. This is slightly less than on the market sector data for reasons set out immediately above. The rest of the bars in the top part of Figure 5 confirm that slowdowns  $\Delta \ln K/H$  and  $\Delta \ln L/H$  do not explain  $\Delta \ln V/H$ .

**Figure 5: Industry productivity slowdowns (top panel = market sector; following panels = nine underlying industries)**



**Note to table:** data show slowdowns for each industry, where each bar is  $\Delta(\Delta \ln X) = \Delta \ln X^{00-07} - \Delta \ln X^{07-11}$ . Note these slowdowns do not add up to the overall slowdown since they have to be weighted to do so: these are unweighted data.

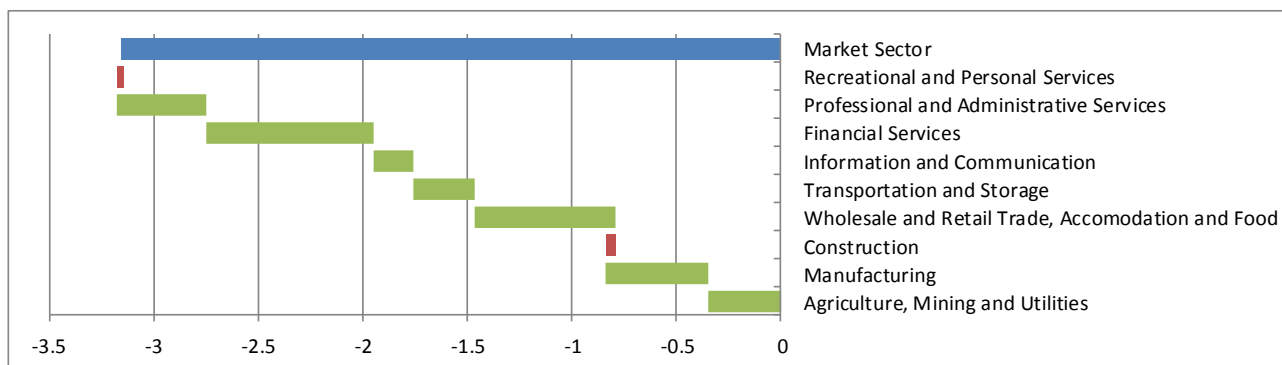
**Source:** authors' calculations, see text.

<sup>12</sup> For instance, consider capital deepening. At the aggregate level, capital deepening is:  $(\Delta \ln K - \Delta \ln H)$ , where H is a simple addition of hours worked i.e.  $H = \sum H_i$ . Similarly at the industry-level, industry capital deepening is:  $(\Delta \ln K_i - \Delta \ln H_i)$ . However, when we aggregate industry capital deepening to the market sector, that is:  $s_i^V s_i^K (\Delta \ln K_i - \Delta \ln H_i)$ , the estimates are different as  $\sum s_i^V \Delta \ln H_i \neq \Delta \ln \sum H_i$ . The same is true for the aggregation of labour composition. There is a further slight differences between the datasets, as explained in the appendix.

The data for each industry (note these are the actual slowdown data; the contributions of the sectors to the whole require these data to be multiplied by value added shares of each sector which we set out below). The red (TFP) and blue (labour productivity) lines are the highest in each case, again stressing that the  $\Delta \ln V/H$  slowdown is accounted for in each industry mostly by a  $\Delta \ln TFP$  slowdown. The only exception to this is in Agriculture, Mining and Utilities, where the slowdown in tangible capital (the blue line) accounts for 32% of the  $\Delta \ln V/H$  slowdown.

To study the contributions of each industry to the market sector slowdown in each sources-of-growth component we have to weight the data Figure 5, which is done in Figure 6 for TFP (the appendix contains the comparable graphs for  $\Delta \ln K/H$  and  $\Delta \ln K/H$ ). We see that the largest contributions were as follows: financial services,  $(-0.8/-3.15=)25\%$ ; wholesale/retail,  $(-0.68/-3.15=)22\%$ ; manufacturing,  $(-0.49/-3.15=)16\%$ ; professional & administrative services,  $(-0.43/-3.15=)14\%$ ; and agriculture, mining & utilities,  $(-0.35/-3.15=)11\%$ . Note that industry TFP contributions from construction and recreational & personal services actually sped up.

**Figure 6: Market sector slowdown in TFP and industry contributions, 2000-07 to 2007-11**



**Note to figure:** Figure shows industry contributions to market sector TFP slowdown. The market sector TFP slowdown is estimated as mean TFP in 2007-11 less mean TFP in 2000-07. Industry contributions to the slowdown are therefore the industry contribution to TFP in 2007-11 less the industry contribution to TFP in 2000-07. Red data points are positive and therefore represent a speed-up in the industry contribution.

To summarise, the industry data do support the suggestions of structural weakness in the financial and mining sectors. Together, financial services; and agriculture, mining & utilities account for over a third (36%) of the TFP slowdown; but note also a large contributions to the slowdown from wholesale/retail, manufacturing and professional & administrative services

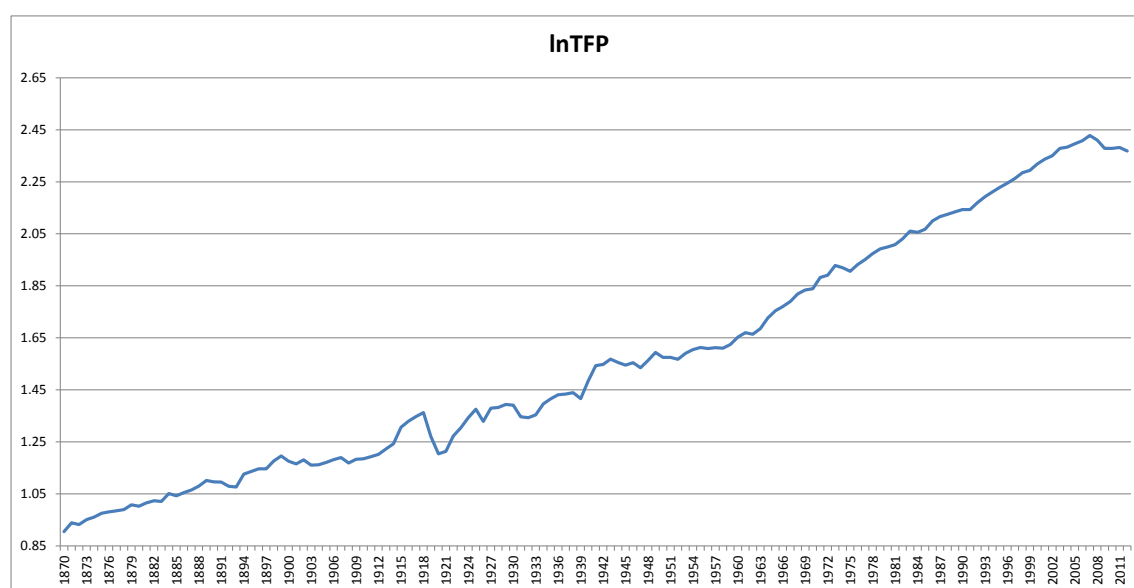
## 9. The outlook for TFP growth

McCafferty (2014) suggests possible productivity declines due to declining fecundity of North Sea Oil as well as minimum staffing requirements in what is a very capital-intensive industry. In finance, he notes the move away from riskier types of activity, the necessity of maintaining a minimum operating scale, and increased staffing required to meet stricter regulation and maintain a greater focus on risk management. In transportation and storage, he argues that continuing tightening of security regulation might harm future productivity.

If we consider the future path of  $\Delta \ln TFP$ , starting from 1.2%pa 2000-07 period, this already includes the drag from the oil and gas sector, which we might expect to continue. Suppose that TFP growth in the financial sector will be lower than it was pre-crisis due to increased regulation. According to our industry data, contribution to total TFP of the financial sector was 26% of aggregate TFP, 2000-07. If this contribution drops by one-half to 13%, then future  $\Delta \ln TFP$  slows to 1.0%pa ( $1.2\%pa \cdot (1-0.13)$ ). This could of course be higher in the short run if there was a catch-up effect.

Figure 9 looks at our prediction in historical context using data on UK  $\ln TFP$  from Bergeaud et al (2014).<sup>13</sup> The exceptional nature of the 2007 downturn is evident: whilst there is historical precedent for falls in  $\ln TFP$  e.g. in 1930 and 1973, there is little historical precedent for a sustained period of no TFP growth (with the possible exception of 1900 to around World War 1). This graph then suggests that  $\Delta \ln TFP$  growth tends to rebound, unless we are in a historically unprecedented era.

Figure 7: UK  $\ln TFP$ , 1870-2012



Source: Bergeaud et al (2014)

<sup>13</sup> Data kindly provided by Antonin Bergeaud.

## **10. Summary and the outlook for TFP growth**

We have revisited the UK productivity puzzle using a new set of data on outputs and inputs and clarifying the role of output mismeasurement, input growth and industry effects. The productivity puzzle is a TFP puzzle: the productivity slowdown cannot plausibly be explained by slowdowns in labour and capital services, conventionally measured. So the TFP puzzle is a 12.9% gap with respect to pre-crisis TFP levels. The inclusion of R&D makes very little difference, and labour composition and labour reallocation only serve to deepen the puzzle. We find that 34% of the TFP productivity puzzle can be explained by arguably structural weakness in the oil and gas and financial sectors. A further 16% could be explained by premature scrapping. Finally, continued weakness in finance would suggest a future lowering of TFP growth from 1.2% to 1%, but historical data does not show a long period of zero or negative TFP growth.

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## Appendix 1: Relations between industry and aggregate labour productivity

### 1a. Industry and aggregate labour productivity

Following Stiroh (2012), Jorgenson et al (2003), define labour productivity as value-added per hour where unsubscripted variables are aggregates and subscript j refers to industry

$$\begin{aligned} ALP^V &= V / H \\ ALP_j^V &= V_j / H_j \end{aligned} \quad (2)$$

Define changes in aggregate real value added as a weighted sum of changes in industry real value added:

$$\Delta \ln V \equiv \sum_j \bar{w}_j \Delta \ln V_j, \quad w_j = \frac{P_{V,j} V_j}{\sum_j (P_{V,j} V_j)}, \quad \bar{w}_j = 0.5(w_{j,t} + w_{j,t-1}) \quad (3)$$

Aggregate labour hours aggregate as a simple sum of industry hours since they are in natural units

$$H \equiv \sum_j H_j \quad (4)$$

Rewriting (2) in terms of growth rates gives the relation between  $\Delta \ln ALP$  and  $\Delta \ln ALP_j$  as

$$\begin{aligned} \Delta \ln ALP &= \sum_j \bar{w}_j \Delta \ln ALP_j + \left( \sum_j \bar{w}_j \Delta \ln H_j - \Delta \ln H \right) \\ &= \sum_j \bar{w}_j \Delta \ln ALP_j + R^H \end{aligned} \quad (5)$$

Where  $R^H$  arises because total value added per hour can grow via growth in all industry value added per hour but also with a reallocation of hours towards high-productivity industries (to see this, note that the final term in (5),  $\Delta \ln H$  can be written as an hours weighted sum of  $\Delta \ln H_j$  so  $R^H > 0$  if the value added weight,  $w_j$ , is above the hours weight i.e. that industry is above average productivity).

### 1b. industry and market-sector total factor productivity growth

Consider labour and capital of types l and k. Define a labour and capital services as a share-weighted aggregate, where the shares are averages over adjacent years as follows:

$$\begin{aligned} \Delta \ln K &= \sum_k \bar{w}_k \Delta \ln K_k, \quad \text{capital type } k \\ \Delta \ln L &= \sum_l \bar{w}_l \Delta \ln L_l, \quad \text{labour type } l \end{aligned} \quad (6)$$

$$\bar{w}_k = P_{K,k} K_k / \sum_k (P_{K,k} K_k), \quad \bar{w}_l = P_{L,l} L_l / \sum_l P_{L,l} L_l, \quad K_j = \sum_k K_{k,j} \forall j, \quad L_j = \sum_l L_{l,j} \forall j,$$

$$\bar{w}_t = 0.5(w_t + w_{t-1})$$

Suppose that for industry j capital and labour (respectively  $K_j$  and  $L_j$ ) produce (value-added) output  $V_j$ . That capital asset might or might not include intangible capital. Thus for each industry, we have the following value-added defined  $\Delta \ln TFP_j$

$$\Delta \ln TFP_j \equiv \Delta \ln V_j - \bar{v}_{K,j} \Delta \ln K_j - \bar{v}_{L,j} \Delta \ln L_j \quad (7)$$

Where the terms in “v” are shares of factor costs in industry nominal value-added, averaged over two periods and  $K_j$  and  $L_j$  refer to aggregates of capital and labour types for that industry according to (6). For the economy as a whole, the definition of economy wide  $\Delta \ln TFP$  based on value added is the same, that is:

$$\Delta \ln TFP \equiv \Delta \ln V - \bar{v}_K \Delta \ln K - \bar{v}_L \Delta \ln L \quad (8)$$

Where the “v” terms here, that are not subscripted by “j”, are shares of K and L payments in economy wide nominal value added.

We are now in position to write down our desired relationship, that is the relation between economy-wide real value added growth and its industry contributions

$$\Delta \ln V \equiv \sum_j \bar{w}_j \Delta \ln V_j = \left( \sum_j \bar{w}_j \bar{v}_{K,j} \Delta \ln K_j \right) + \left( \sum_j \bar{w}_j \bar{v}_{L,j} \Delta \ln L_j \right) + \sum_j \bar{w}_j \Delta \ln TFP_j \quad (9)$$

Which says that the contributions of  $K_j$  and  $L_j$  to whole-economy value added growth depend upon the share of  $V_j$  in total  $V$  ( $w_j$ ) and the shares of  $K_j$  and  $L_j$  in  $V_j$  ( $v_{K,j}$  and  $v_{L,j}$ ) (which multiply out to be the shares of each capital and labour payment into market sector value added). Thus, if we perform industry level growth accounting, we can see the contributions of  $\Delta \ln L_j$  and  $\Delta \ln K_j$  to industry value added ( $v_{L,j} \Delta \ln L_j$  and  $v_{K,j} \Delta \ln K_j$ ). but their contributions to total value added have then to be multiplied by  $w_j$ , namely the share of that industry in total value added.

Turning finally to labour productivity we may write

$$\begin{aligned} \Delta \ln(V / H) &\equiv \sum_j \bar{w}_j \Delta \ln V_j - \Delta \ln H \\ &= \left( \sum_j \bar{w}_j \bar{v}_{K,j} \Delta \ln(K / H)_j \right) + \left( \sum_j \bar{w}_j \bar{v}_{L,j} \Delta \ln(L / H)_j \right) + \sum_j \bar{w}_j \Delta \ln TFP_j + R^H \end{aligned} \quad (10)$$

Finally, we build a real capital stock via the perpetual inventory method whereby for any capital asset  $n$ , the stock of that assets evolves according to

$$K_{n,t} = I_{n,t} + (1 - \delta_{n,t}) K_{n,t-1} \quad (11)$$

Where  $I$  is real investment over the relevant period and  $\delta$  the geometric rate of depreciation. Real investment comes from nominal tangible investment deflated by an investment price index. Second, that investment price is converted into a rental price using the Hall-Jorgenson relation, where we assume an economy-wide net rate of return such that the capital rental price times the capital stock equals the total economy-wide operating surplus (on all of this, see for example, Oulton and Srinivasan, (2003).

As set out above, the different methods to aggregate hours in the two datasets (value-added weighted sum in the industry file versus a pure aggregation in the market sector file) produce labour re-allocation terms that mean estimates of labour productivity and the sources of growth differ between the two datasets.

However, as well as the re-allocation term(s), there are also other differences between our industry dataset and that for the market sector. First, value-added growth in the two datasets is very slightly

different, but differences are very small. The reason is that in the industry file, R&D is capitalised at the industry-level, thus changing real-industry output growth. The nominal weights also change as nominal industry value-added changes. In contrast, in the market sector file we aggregate measured real industry growth using measured nominal value-added as weights. The measured data are based on Blue Book 2013 and so R&D is not already capitalised. Then we capitalise R&D after the aggregation. The two methods give slightly different results. Second, the capital data differs slightly. In the industry-file, the capital data are constructed using industry and asset-specific depreciation rates. In the market sector file, depreciation rates are asset specific but are implicitly the same across industries.

**Table A1.1: Growth-accounting decomposition, 2000-11, Aggregate market sector vs industry aggregation**

	1	2	3	4	5	6	7
<b>2000-2011</b>	<b>Capital deepening contributions:</b>						
	ALPG	Total	Computers	Other tang	Intangibles	Labour Composition	
	DlnV/H	sDln(K/H)	sDln(K/H) cmp	sDln(K/H) othtan	sDln(K/H) intan	sDln(L/H)	DlnTFP
Market Sector data, with R&D	1.45%	1.08%	0.08%	0.79%	0.21%	0.37%	0.00%
Aggregated Industry data, with R&D	1.58%	1.31%	0.09%	0.97%	0.24%	0.46%	-0.18%

**Notes to table:** All figures are average annual percentages. The contribution of an output or input is the growth rate weighted by the corresponding average share. Columns are annual average change in natural logs of: column 1, real value added per hour, column 2, contribution of total capital (which is the sum of the next three columns), column 3, contribution of IT hardware capital, column 4, contribution of other non-IT tangible capital, column 5, contribution of intangibles, column 6, contribution of labour services per person hour, column 7, TFP, being column 1 less the sum of columns 2 to 6. Row 1 is based on ONS data for the market sector, with R&D capitalised. Row 2 is ONS industry data, with R&D capitalised in each industry, 2000-11, aggregated to the market sector. In each the market sector is defined using our definition of SIC(2007) A-K, MN, R-T. **Source:** authors' calculations

## Appendix 2: The impact of labour composition during and since the recession

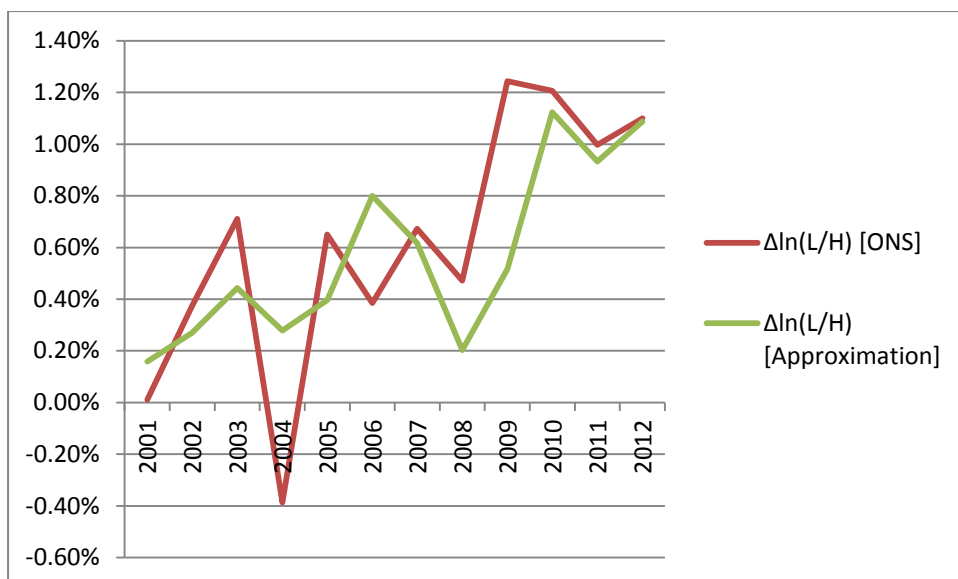
As shown in the tables in the main text, 2007-11 saw a strong increase in the contribution of labour composition. It rose from 0.22% pa in 2000-07 to 0.63% pa in 2007-11. The following tries to unpick the reasons behind this rise.

Our series for QALI, based on ONS data, is derived from data for (9\*6\*3\*2=324 worker types i.e. 9 industries, 6 qualification levels, 3 age-groups and 2 genders. Our previous work (supplementary appendices to Haskel et al, 2011) showed that QALI is primarily driven by the qualification category. We therefore collapse the six qualification levels into 3 groups: high, medium and low (HS, MS and LS); and use that single characteristic to approximate labour services. Using this reduced method, growth in labour composition, or labour services per hour, can be written as:

$$\underbrace{\Delta \ln(L / HN)}_{\text{Growth in labour composition}} = \left\{ \underbrace{\frac{w^{HS} HN^{HS}}{\sum wHN} \Delta \ln HN^{HS} + \frac{w^{MS} HN^{MS}}{\sum wHN} \Delta \ln HN^{MS} + \frac{w^{LS} HN^{LS}}{\sum wHN} \Delta \ln HN^{LS}}_{\text{Growth in labour services}} - \underbrace{\Delta \ln HN}_{\text{Growth in hours}} \right\} \quad (12)$$

Where L are labour services, H is hours per person, N is persons, thus HN is person-hours, and w is an hourly wage. We have data for each of these terms. Therefore Figure A1 compares official ONS estimates of labour composition (red line, based on 324 worker types) with those using equation (12) (green line, based on just 3 worker types).

Figure A1: Re-estimating growth in labour composition



Note to figure: Red line is official data on growth in labour composition. Green line is an approximation based on equation (12).

We now look in detail at the terms in equation (12) to understand what has changed and what drives the growth in labour composition from 2008. The following table presents averages for each term.

Table A1: Period averages for terms in equation (12)

	Growth in labour composition	Income weight: High skilled	Growth in Hours: High skilled	Income weight: medium skilled	Growth in Hours: Medium skilled	Income weight: Low skilled	Growth in Hours: Low skilled	Growth in aggregate hours	Memo: contribution of labour composition
	$\Delta \ln(L/HN)$	$\frac{w^{HS} HN^{HS}}{\Sigma wHN}$	$\Delta \ln HN^{HS}$	$\frac{w^{MS} HN^{MS}}{\Sigma wHN}$	$\Delta \ln HN^{MS}$	$\frac{w^{LS} HN^{LS}}{\Sigma wHN}$	$\Delta \ln HN^{LS}$	$\Delta \ln HN$	$\bar{s}^{-L} \Delta \ln(L/HN)$
<b>2000-07</b>	0.35%	0.27	4.16%	0.35	-0.88%	0.37	-0.50%	0.25%	0.22%
<b>2007-11</b>	1.00%	0.33	3.50%	0.33	-0.79%	0.34	-3.76%	-0.37%	0.63%

**Note to table:** period averages (before and after recession) for all terms in equation (12)

**Source:** ONS data

What has changed according to Table A1? First, we see that the income share for the high-skilled has increased, at the expense of both the medium-skilled and low-skilled. Second, there is a strong fall in the growth of low-skilled hours, falling from -0.5% pa to -3.76% pa. Let us first consider the change in the income shares. In principle, this change could be driven by either: (a) changes in relative wages; or (b) changes in employment shares. Table A2 compares annual income and employment shares for each of our three worker types over the period in question.

Table A2: Income and employment shares: HS, MS, LS

year	(1) Employment share: High skilled	(2) Income share: High skilled	(3) Difference: High skilled	(4) Employment share: Medium skilled	(5) Income share: Medium skilled	(6) Difference: Medium skilled	(7) Employment share: Low skilled	(8) Income share: Low skilled	(9) Difference: Low skilled
	$\frac{HN^{HS}}{\Sigma HN}$	$\frac{w^{HS} HN^{HS}}{\Sigma wHN}$	=(1)-(2)	$\frac{HN^{MS}}{\Sigma HN}$	$\frac{w^{MS} HN^{MS}}{\Sigma wHN}$	=(4)-(5)	$\frac{HN^{LS}}{\Sigma HN}$	$\frac{w^{LS} HN^{LS}}{\Sigma wHN}$	=(7)-(8)
2001	0.17	0.26	0.09	0.35	0.36	0.01	0.48	0.38	-0.09
2002	0.17	0.26	0.09	0.36	0.36	0.00	0.47	0.38	-0.09
2003	0.18	0.27	0.09	0.35	0.35	0.00	0.47	0.38	-0.09
2004	0.18	0.27	0.09	0.35	0.35	0.00	0.46	0.37	-0.09
2005	0.19	0.28	0.09	0.35	0.35	0.00	0.46	0.37	-0.09
2006	0.20	0.29	0.08	0.34	0.35	0.01	0.46	0.36	-0.09
2007	0.22	0.30	0.08	0.33	0.34	0.01	0.45	0.36	-0.09
2008	0.22	0.31	0.09	0.33	0.33	0.00	0.45	0.36	-0.09
2009	0.23	0.32	0.09	0.33	0.32	-0.01	0.44	0.35	-0.09
2010	0.24	0.33	0.09	0.34	0.33	-0.01	0.42	0.34	-0.08
2011	0.26	0.35	0.09	0.34	0.33	-0.01	0.40	0.32	-0.08

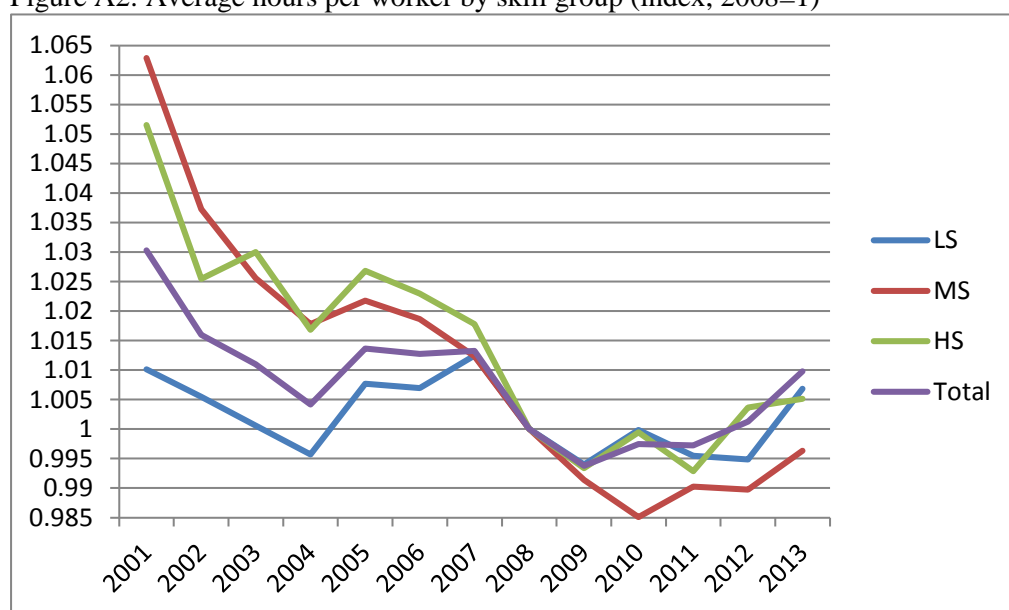
Source: ONS data

The first thing to note is that the employment share of the high-skilled has increased significantly over the period, and that of the low-skilled has decreased. Second, the income shares have changed similarly, such that the difference between the income and employment shares is very stable over the whole period. Any changes in relative wages have therefore been small.

Therefore, relating this to Table A1, increased growth in labour composition is driven by (a) an increased employment share for the high-skilled, and (b) strong falls in hours worked of the low-skilled. Of course, these two things are related, with employment consisting of more hours worked by the former at the expense of the latter.

Growth in labour composition is therefore driven by the fall in low-skilled hours worked, first through the fall in  $\Delta \ln H^{LS}$ , and second through the reduced employment (and hence income) income share for the low-skilled, and the higher employment (and hence income) share for the high-skilled. In principle, the fall in low-skilled hours could come from two sources. The first is reduced hours-per-worker, and the second is reduced employment. The ONS have kindly supplied us with data on the former from the QALI source data. The following chart presents estimates of hours per worker for each of our three skill groups.<sup>14</sup>

Figure A2: Average hours per worker by skill group (index, 2008=1)



**Note to figure:** Index of average hours worked per job (2008=1) by skill group. HS=high-skilled, MS=medium skilled, LS=low-skilled. The line Total is an average across all individuals.

Source: ONS data

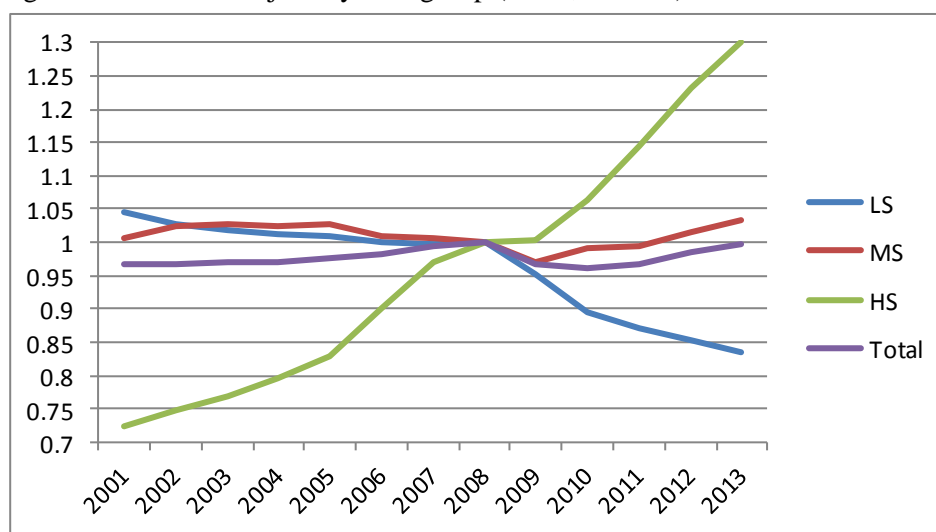
As Figure A2 shows, between the years 2008 and 2011, there has been a fall in hours per worker, but this is true for all skilled groups, and the profile for low-skilled workers does not stand out. In fact, the fall among the low-skilled was similar to that of the high-skilled, and less marked than that of the medium-skilled. Post-2011, average hours per worker have increased for all skill groups.

Figure A3 presents an index of the number of jobs by skill group and shows that since 2008, growth in the number of jobs has largely been among the high-skilled with some increase also evident for the

<sup>14</sup> We thank Mark Franklin and Joe Murphy for publishing these data. The data are actually hours per job since the QALI methodology is based on jobs rather than workers.

medium-skilled. In the case of the high-skilled, this is part of a long-term trend, hence the similarity in growth in high skilled hours in both 2000-07 and 2007-11, shown in Table A1.

Figure A3: Number of jobs by skill group (index, 2008=1)



Note to figure: Index of number of jobs (2008=1) by skill group. HS=high-skilled, MS=medium-skilled, LS=low-skilled. The line Total is an average across all individuals.

Thus we conclude that increased growth in labour composition in the 2007-11 period reflects reduced employment of low-skilled workers.

### Appendix 3: The impact of labour re-allocation during and since the recession

It has also been suggested that one of the reasons behind the productivity puzzle is the re-allocation of labour from high- to low-productivity industries. In the context of an argument around labour hoarding, Martin and Rowthorn (2012) argue that increased employment since the recession is derived from increases in low-skilled labour in low-productivity industries. Our study of the data on labour composition (see Appendix 2) shows however that this is not the case. Appendix 1 also shows another term we can examine to look specifically at the effect of reallocation of labour between industries. Table 2 was based on a decomposition of aggregate market sector value-added. However, we also work with an industry dataset. As shown in Appendix 1, aggregation of industry productivity produces a reallocation term, showing the effect on aggregated labour productivity of the changing distribution of hours worked across industries.

Figure A3.1 presents a comparison of changes in aggregate person-hours worked ( $\Delta \ln HN$ ) with changes in a value-added weighted aggregate across industries ( $\sum v_j \Delta \ln HN_j$ ). The difference between the two is the labour reallocation term shown in Appendix 1 ( $R^H$ ).

Figure A3.1: Aggregate hours worked and a weighted industry total: Labour re-allocation



**Note to figure:**  $\Delta \ln HN$  are changes in aggregate hours worked in the UK market sector.  $\Sigma v_j \Delta \ln HN_j$  is a value-added weighted aggregate of industry changes. The difference between them is the labour reallocation term set out in Appendix 1.

**Source:** authors' calculations

#### Appendix 4: Impact of capitalisation of R&D

Table 2 provides some more details. Comparing panel 1 to panel 2, capitalisation of R&D means  $D \ln V/H$  is hardly affected. But R&D generates a new asset thus adding to the share of  $D \ln V/H$  accounted for by capital inputs, and the table shows it accounts for around 0.04%pa. There is rise in this contribution since 2007, but only to 0.05%pa and hence TFP growth is similar.

How robust is this finding? Of course capitalisation of R&D requires some estimate of the price of R&D. In Table 2 we assumed that the price of R&D can be approximated using the implied market sector GVA (MSGVA) deflator. In the official measurement the current plan is to employ a share-weighted input price index for R&D, which is likely well approximated by the MSGVA deflator. Three observations suggest that using the MSGVA deflator overstates the price deflator for R&D, and so understates the impact of R&D on the economy. First, many knowledge-intensive prices have been falling relative to wider GVA. Second, the advent of the internet and computers would seem to be a potential large rise in the capability of innovators to innovate, which would again suggest a lowering of the price of knowledge, in contrast to the rise in prices implied by the MSGVA deflator. Third, this second effect may have been enhanced by the emergence of (big) data and increased use of data analytics, which may also have positive effects on productivity in R&D production. Thus use of the MSGVA deflator almost certainly understates the importance of knowledge assets.

Therefore in Table 5 we experiment with alternative deflators. In panel 1 we use the MSGVA deflator. In panel 2 we use the R&D deflator developed by the US BEA, which is a share-weighted input price index but with an adjustment for assumed productivity growth in R&D production. In panel 3 we use a deflator that implies even stronger productivity growth in R&D production than is implicitly assumed in the BEA R&D price index. One knowledge intensive output with fast-falling prices is pre-packaged software. We therefore use the BEA deflator for pre-packaged software to test just how much that effects the estimated contribution of R&D.

**Table 5: Alternative deflators for R&D, 1990-2011**

	1	2	3	4	5	6	7	8
	DlnV/H	sDln(L/H)	sDln(K/H) cmp	sDln(K/H) othtan	sDln(K/H) NA intan	sDln(K/H) rd	DlnTFP	Memo: sLAB
<b>Panel 1: Using UK MSGVA deflator for R&amp;D</b>								
1990-00	2.94%	0.21%	0.31%	0.80%	0.23%	0.04%	1.34%	0.62
2000-07	2.54%	0.22%	0.12%	0.74%	0.23%	0.04%	1.19%	0.65
2007-11	-0.47%	0.63%	0.01%	0.88%	0.05%	0.05%	-2.09%	0.64
<b>Panel 2: Using BEA price index for R&amp;D</b>								
1990-00	2.93%	0.21%	0.31%	0.80%	0.23%	0.05%	1.32%	0.62
2000-07	2.55%	0.22%	0.12%	0.74%	0.23%	0.04%	1.20%	0.65
2007-11	-0.47%	0.63%	0.01%	0.88%	0.05%	0.05%	-2.08%	0.64
<b>Panel 3: Using BEA price index for pre-packaged software, for R&amp;D</b>								
1990-00	3.09%	0.21%	0.31%	0.80%	0.23%	0.25%	1.28%	0.62
2000-07	2.63%	0.22%	0.12%	0.74%	0.23%	0.15%	1.17%	0.65
2007-11	-0.39%	0.63%	0.01%	0.88%	0.05%	0.14%	-2.10%	0.64

**Notes to table.** Data are average growth rates per year for intervals shown, calculated as changes in natural logs. Contributions are Tornqvist indices. First column is growth in value-added per hour. Column 2 is the contribution of labour services per hour, namely growth in labour services per hour times share of labour in MSGVA. Column 3 is growth in computer capital services per hour times share in MSGVA. Column 4 is growth in other tangible capital services (buildings, plant, vehicles) per hour times share in MSGVA. Column 5 is growth in intangible capital services per hour times share in MSGVA, where intangibles are those already capitalised in the national accounts, namely software, mineral exploration and artistic originals. Column 6 is R&D capital services per hour times share in MSGVA, with R&D due to be capitalised in the UK accounts in 2014. The three panels use alternative deflators for R&D. Column 7 is TFP, namely column 1 minus the sum of columns 2 to 6. Column 8 is the share of labour payments in MSGVA.

Looking at each panel in Table 5, the first panel repeats the decomposition of labour productivity using the implied MSGVA index to deflate R&D. The contribution of R&D is 0.04 to 0.05 pppa. The second panel uses the BEA index for R&D, the impact of which is to slightly reduce Dln(V/H) in the 1990s and increase it in the 2000s prior to the recession. On the input side, the contribution of R&D is raised slightly in the 1990s and is unaffected in the 2000s. Thus TFP falls slightly in the 1990s and rises slightly in the 2000s.

Panel 3 uses the BEA price index for pre-packaged software as a proxy for the price of R&D. The impact on the decomposition is large. First, Dln(V/H) is stronger, particularly in the earlier periods, by 0.16 pppa in the 1990s, 0.09 pppa in 2000-07, and 0.07 pppa post-recession. The contribution of R&D is also very strong, increasing around five-fold in the 1990s and around three-fold in the 2000s. Thus TFP is slightly reduced in all periods.

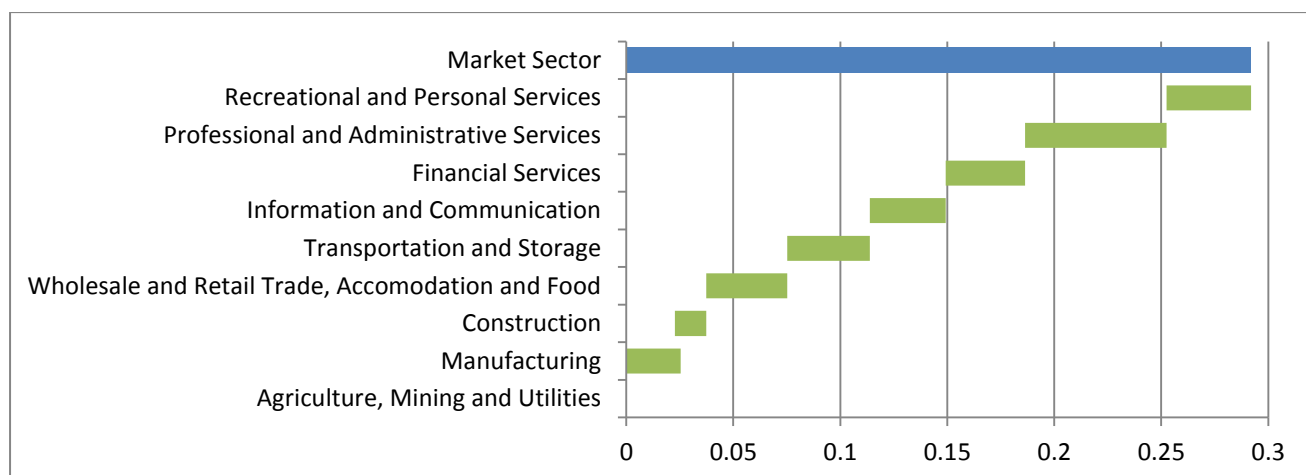
A few other points to note from Table 5. First, notice that in the third period, the contributions of computer and software (plus mineral exploration and artistic originals) capital deepening both collapse between 2000-07 and 2007-11. In contrast, the contribution of R&D barely slows at all, partly due to the relative strength of R&D investment since 2007, as noted in Goodridge, Haskel et al. (2013), and partly due to the aggressive price index used to deflate R&D. Second, if the price of R&D has been falling fast as in panel 3, then Dln(V/H) is estimated as less weak post-recession than currently measured. Third, although the slowdown in Dln(V/H) is less, the slowdown in TFP is less affected. Thus, whilst a more accurate price index for R&D could explain a small part of the labour productivity puzzle, it does not explain the sustained slowdown in TFP.

## **Appendix 5. Industry contributions to the overall productivity slowdown: capital and labour services**

The text above sets out the contributions of TFP. Below are charts of industry contributions to the market sector slowdown for labour composition in Figure 8, which is actually a speedup.



**Figure 8: Market sector speed-up in the contribution of labour composition ( $s^L \text{Dln}(L/H)$ ), 2000-07 to 2007-11**

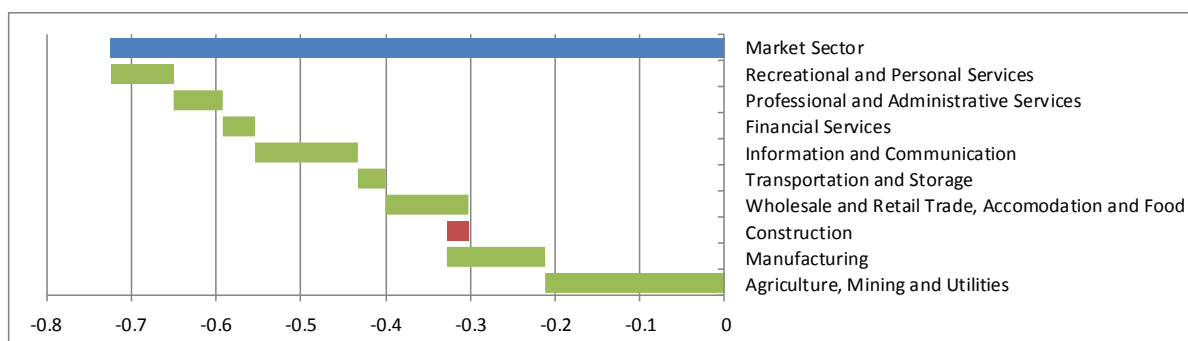


**Note to figure:** Figure shows industry contributions to the speed-up in the contribution of market sector labour composition. The market sector labour composition speed-up is estimated as the mean contribution of labour composition in 2007-11 less the mean contribution in 2000-07. Industry contributions to the speed-up are therefore the industry contribution in 2007-11 less the industry contribution in 2000-07. Red data points are negative and therefore represent a slowdown in the industry contribution (the estimate for Agriculture, Mining and Utilities is marginally negative).

The data show that industry contributions to the speedup in labour composition are dispersed across a number of sectors. In particular, professional & administrative services contributed  $(0.07/0.29=)23\%$  of the speedup. Wholesale/retail, transportation & storage, information & communication, financial services and recreational & personal services each contributed  $(0.04/0.29)=13.5\%$  of the speedup.

Next, Figure 9 looks at the industry contributions to the slowdown in the contribution of capital deepening. It shows that Agriculture, Mining & Utilities accounts for  $(-0.21/-0.72=)29\%$  of the total capital deepening contribution slowdown. Information & communication and wholesale/retail also contribute  $(-0.12/-0.72=)17\%$  and  $(-0.1/-0.72=)14\%$  respectively. The contribution of capital deepening in construction actually speeds up.

**Figure 9: Market sector slowdown in the contribution of capital deepening ( $s^K \text{Dln}(K/H)$ ), 2000-07 to 2007-11**



**Note to figure:** Figure shows industry contributions to the slowdown in the contribution of market sector capital deepening. The market sector capital deepening slowdown is estimated as the mean contribution of capital deepening in 2007-11 less the mean contribution in 2000-07. Industry contributions to the slowdown are therefore the industry contribution in 2007-11 less the industry contribution in 2000-07. Red data points are positive and therefore represent a speed-up in the industry contribution.

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