4 – What will be the net impact of AI and related technologies on jobs in the UK?[1]

Key points

- AI and related technologies such as robotics, drones and driverless vehicles could displace many jobs formerly done by humans, but will also create many additional jobs as productivity and real incomes rise and new and better products are developed.

- We estimate that these countervailing displacement and income effects are likely to broadly balance each other out over the next 20 years in the UK, with the share of existing jobs displaced by AI (c.20%) likely to be approximately equal to the additional jobs that are created.

- Although the overall effect on UK jobs is estimated to be broadly neutral in our central projections, there will inevitably be 'winners' and 'losers' by industry sector.

- The sectors that we estimate will see the largest net increase in jobs in the long run include health (+22%), professional, scientific and technical services (+16%) and education (+6%). The sectors estimated to see the largest net long-term decrease in jobs due to AI include manufacturing (-25%), transport and storage (-22%) and public administration (-18%).

- Based on differences in industry structure alone, our projections do not imply large variations by region, though our central estimates imply a small net job gain in London offset by small net losses in the North and Midlands. But other factors could lead to larger regional variations than captured by our analysis.

- Although our central estimate is that the net effect of AI on jobs will be broadly neutral, there are many uncertain factors that could tip the balance towards more optimistic or pessimistic scenarios. We identify some policy areas where action could help to maximise the benefits (e.g. boosting research funding for AI, ensuring competition is adequate to ensure productivity gains are passed on to consumers) and/or mitigate the costs in terms of impacts on jobs (e.g. a national retraining programme for older workers as well as renewed efforts to build STEAM[2] skills in schools and universities).

Introduction

Societies have worried about technological unemployment ever since the Industrial Revolution of the late 18th century. These concerns have generally not been borne out by historical experience as new technologies have stimulated economic growth, creating new demand for labour to replace jobs displaced in the short term. However, the latest advances in Artificial Intelligence (AI)[3] and related technologies such as robotics have the potential to surpass human capabilities in a broader range of cognitive skills, replacing our 'minds' as well as our 'muscles'. So could this time be different?

In this article we take an objective look at the evidence on this for the UK and weigh up the potential for AI to replace human workers, which we refer to as the 'displacement effect', against the ability for AI to create additional jobs, through a mechanism we refer to as the 'income effect'.

We begin by setting out the background to, and conceptual framework for, the analysis (Section 4.1). Next, we present our estimates of the displacement effect (Section 4.2) and the income effect (Section 4.3). In Section 4.4 we weigh these effects against each other, both for the UK economy as a whole and by industry, and in Section 4.5 we present some illustrative estimates of potential regional job impacts based on differences in industry structure across regions. Section 4.6 then explores the uncertainties around our central estimates by constructing alternative optimistic and pessimistic scenarios.

In Section 4.7 we discuss potential policy implications and Section 4.8 summarises the analysis and concludes. Further details of our methodology are provided in a technical annex.

1 This article was written by John Hawksworth and Yuval Fertig of the PwC economics practice, drawing on earlier data analysis by Tom Markovitch and Richard Berriman.
2 STEAM = science, technology, engineering, art & design, and maths.
3 For brevity we sometimes refer just to 'AI' in this article, but this should be taken to encompass a broader range of technologies including not just AI per se but also robotics, drones, driverless vehicles and other digital innovations aimed at 'smart automation'.

4.1 – Background to and framework for the analysis

We are all familiar with the way in which technology can automate jobs: inventions come along that perform tasks more cheaply, better or more reliably than humans, and so firms replace humans with these labour-saving technologies. We refer to this as the 'displacement effect' and examples are everywhere. Going back in time, most UK workers in the mid-19th century were employed in agriculture and manufacturing, but together these now account for only around 10% of UK employment, which is now dominated by services. Automation has played a key role in boosting productivity both on farms and in factories, so allowing more to be produced by many fewer workers[4].

More recently, we have seen many middle management and back-office jobs automated using computers, with more to come as AI is deployed more widely across the economy. Automated trading has already displaced many jobs in financial markets and driverless vehicles have the potential to do the same in transport in the coming decades, while robots spread from factories to construction sites and warehouses in increasing numbers.

But as well as displacing jobs, new technologies like AI also create them, although the way in which this happens is more complex and less direct. The most significant effects generally come through the impact on (quality-adjusted) prices as labour-saving technologies allow firms to produce the same product at a lower cost[5].

To stay competitive, firms ultimately have to pass on most of these savings to consumers, which has the effect of increasing real income levels. Households can buy more with their money as a result and firms hire additional workers to respond to the extra demand. As well as reducing prices, labour-saving technologies also improve the quality of existing products and enable new products to be brought to market, which also create a need for additional workers. We refer to these types of mechanisms, through which technology ultimately creates jobs, as the 'income effect.

Figure 4.1 illustrates these countervailing forces. It shows how technology can lead to some job losses via the displacement effect, but also how this is counteracted by the income effect in the longer term. The question of whether AI will lead to technological unemployment boils down to whether the displacement effect of AI on jobs will exceed the income effect. We now estimate each in turn.

Figure 4.1 – How AI can both destroy and create jobs through the displacement and income effects

Sources: PwC

4 In addition, advances in transport and communications technology have allowed more food and manufactured goods to be imported from overseas, so reducing the need for UK-based production.

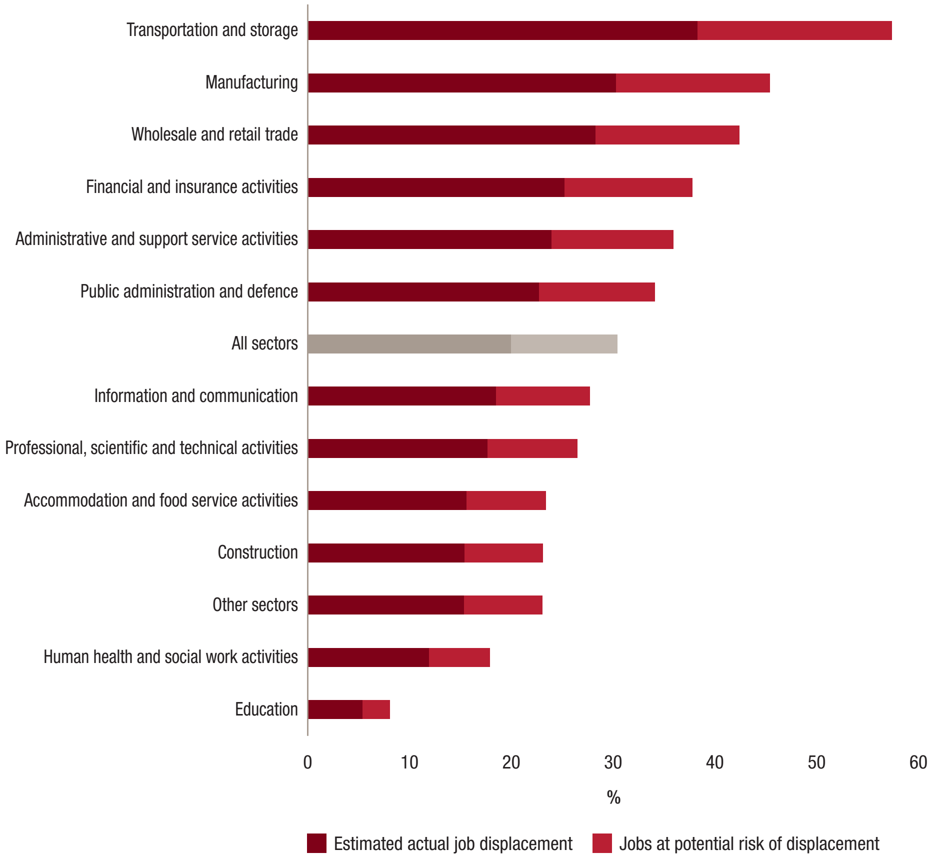
5 Or a higher quality product at the same (or lower) cost. For simplicity we refer to this as a (quality-adjusted) price reduction.

4.2 – The displacement effect

In their much-cited paper on the susceptibility of jobs to computerisation, Frey and Osborne (2013) considered a list of 702 occupations and used a mixture of expert judgement and machine learning techniques to estimate the probability that each would be automated[6]. Many analysts, including PwC, have since adopted some variant of this bottom-up approach, but estimates of the proportion of jobs at significant long-term risk of automation vary widely. Frey and Osborne's original estimate for the US was 47%, or around 35% for the UK, but more recently Arntz, Gregory and Zierahn (2016) came up with a much lower estimate of around 10% for both countries based on analysing tasks rather than occupations. Our own past estimates using the same OECD PIAAC survey data suggest that the proportion of existing UK jobs at high risk of automation could be up to 30% over the next 20 years, which places us within the range of the estimates mentioned above (see annex for more details of our methodology)[7].

Although we estimate that up to 30% of existing UK jobs could be at high risk of being automated, a job being at "high risk" of being automated does not mean that it will definitely be automated, as there could be a range of economic, legal and regulatory and organisational barriers to the adoption of these new technologies[8].

Figure 4.2 – The proportion of existing UK jobs that could be displaced in each sector over the next 20 years



Sources: PwC analysis using data from the OECD PIAAC survey

6 Frey, C.B. and M.A. Osborne (2013), 'The Future of Employment: How Susceptible are Jobs to Computerisation?', University of Oxford.
7 This is based on a detailed analysis of the task composition of UK jobs using the OECD's PIAAC database.
8 As discussed in more detail in our February 2018 report on job automation here: https://www.pwc.co.uk/services/economics-policy/insights/the-impact-of-automation-on-jobs.html

Based on our earlier probabilistic risk analysis, we think it is reasonable to scale down our estimates by a factor of two thirds to reflect these barriers, so our central estimate of the proportion of existing jobs that will actually be automated over the next 20 years is reduced to 20%. There is uncertainty over the correct scaling factor to use here, however, so we consider a range of alternative scenarios for this estimate in Section 4.6 below.

Automation rates will vary by industry sector as illustrated by our estimates in Figure 4.2. Our analysis implies that the transportation and storage sector could see the highest proportion of existing jobs at risk (nearly 40% even after scaling down as described in the previous paragraph) as driverless vehicles roll out across the economy over the next two decades. Sectors like health and education are projected to see relative low displacement effects, but no sector will be unaffected by automation.

These figures represent the total proportion of existing UK jobs (based on 2017 data) estimated to be automated by 2037, but we would expect some sectors to be hit earlier than others, due to the fact that certain types of AI will develop faster than others (e.g. algorithmic trading is already here while driverless cars will take much longer to roll out)[9]. We presented estimates of the timing of potential job losses in an earlier report, which we would expect to follow a typical 'S-curve' shape with relatively small impacts over the next few years but more substantial effects as we look a decade or more ahead[10].

In this article, however, we are concerned with the long term effects of AI, so we focus on the impact over 20 years, giving time for both the displacement and income effects to take effect fairly fully across the economy. We should recognise, however, that the precise timing of these effects is uncertain, as reflected in the scenario analysis in Section 4.6 below.

4.3 – The income effect

AI creates jobs through its effect on the cost, quality and range of products, which boosts real income levels and creates additional demand for new jobs, as described above. In PwC's 2017 'Sizing the Prize' report we evaluated thousands of potential use cases for AI across all sectors of the economy and combined these in a global econometric model to value the total impact of AI on GDP for the world economy as a whole as well as major individual economies including the US, China and the UK. For the UK, the headline estimate was that GDP could be boosted by around 10% by 2030[11] through application of AI and related technologies (the global average boost to GDP was higher at around 14%, due in particular to very high potential benefits from AI in China).

For this article we have converted this value into jobs numbers by, first, projecting UK output (GVA) growth by industry sector over the next 20 years, and second, estimating the proportion of GVA growth that is attributable to AI, as implied by the estimates in our 'Sizing the prize' report. We assume here that the projected increase in jobs due to the income effect will be the same as the projected increase in GVA since productivity gains are already accounted for through the displacement effect[12]. We explain these steps in more detail in the annex.

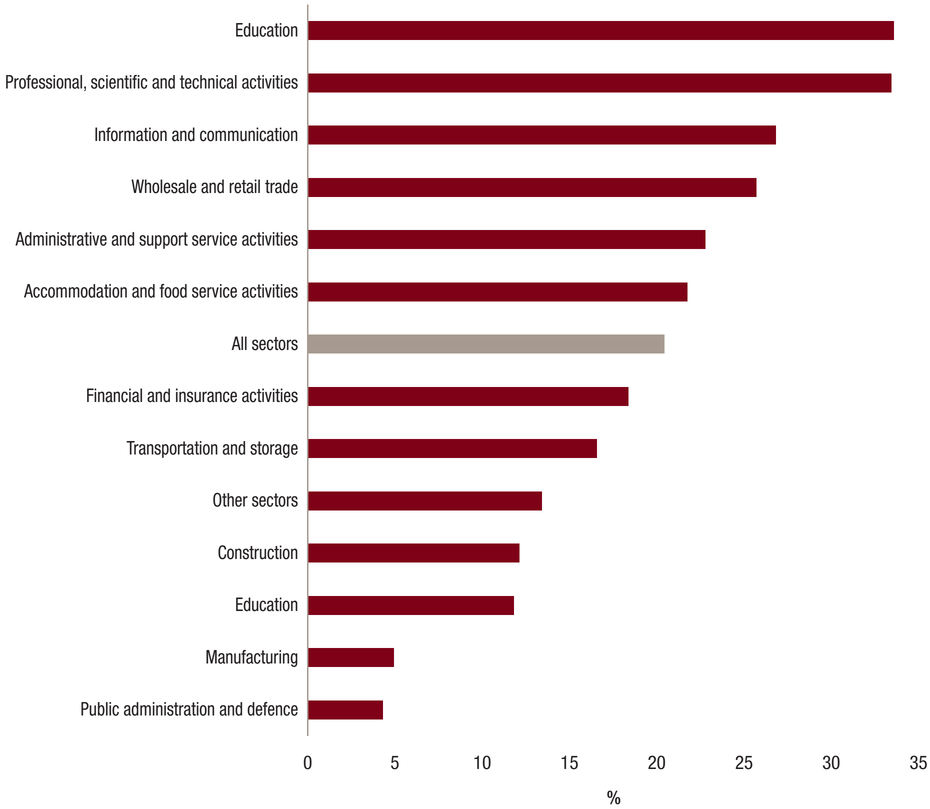
9 For example, our previous analysis finds that the financial sector will see the most job losses for its size by 2030, but will be exceeded by the transport, manufacturing and retail sectors by 2037.
10 PwC, 'Will robots really steal our jobs? (2018): https://www.pwc.co uk/economic-services/assets/international-impact-of-automation-feb-2018.pdf
11 For the present report, we extrapolate this estimate forward from 2030 to 2037.
12 Because we are capturing productivity effects on labour input through the displacement effect, we assume in estimating income effects that the potential percentage increase in jobs from this source is the same as the estimated percentage increase in GVA attributable to AI. This is the same general approach as in the Oxford Economics/Cisco report on 'The AI Paradox' (December 2017) for the US, although they further assume that the income effect on jobs exactly offsets the negative displacement effect, which is a relatively restrictive assumption to make 'a priori'.

The headline result of our analysis is that we expect 46% of long-term UK output growth will come from AI (although this may be higher or lower depending on the sector). Since we are expecting overall UK GDP (and GVA) growth of just under 2% per year on average over the next two decades, this implies that AI contributes around 0.9% growth per annum on average. Over 20 years this serves to increase the number of jobs by around 20% of current levels (after allowing for compounding effects over time). The sectoral breakdown of our income effect estimates is presented in Figure 4.3.

The analysis suggests that there are two notable outliers at both ends of the spectrum: the health sector and the professional, scientific and technical services sector stand to benefit the most from AI in terms of the proportion of additional jobs created, whilst manufacturing and public administration and defence stand to benefit the least.

In general, the sectors benefiting most are those that combine strong underlying demand growth with a relatively high propensity to see benefits from application of AI and related technologies, based on the detailed use case analysis in our 'Sizing the Prize' report.

Figure 4.3 – Estimated additional UK jobs that could be created by AI and related technologies in each sector over the next 20 years, expressed as a percentage of existing jobs in 2017



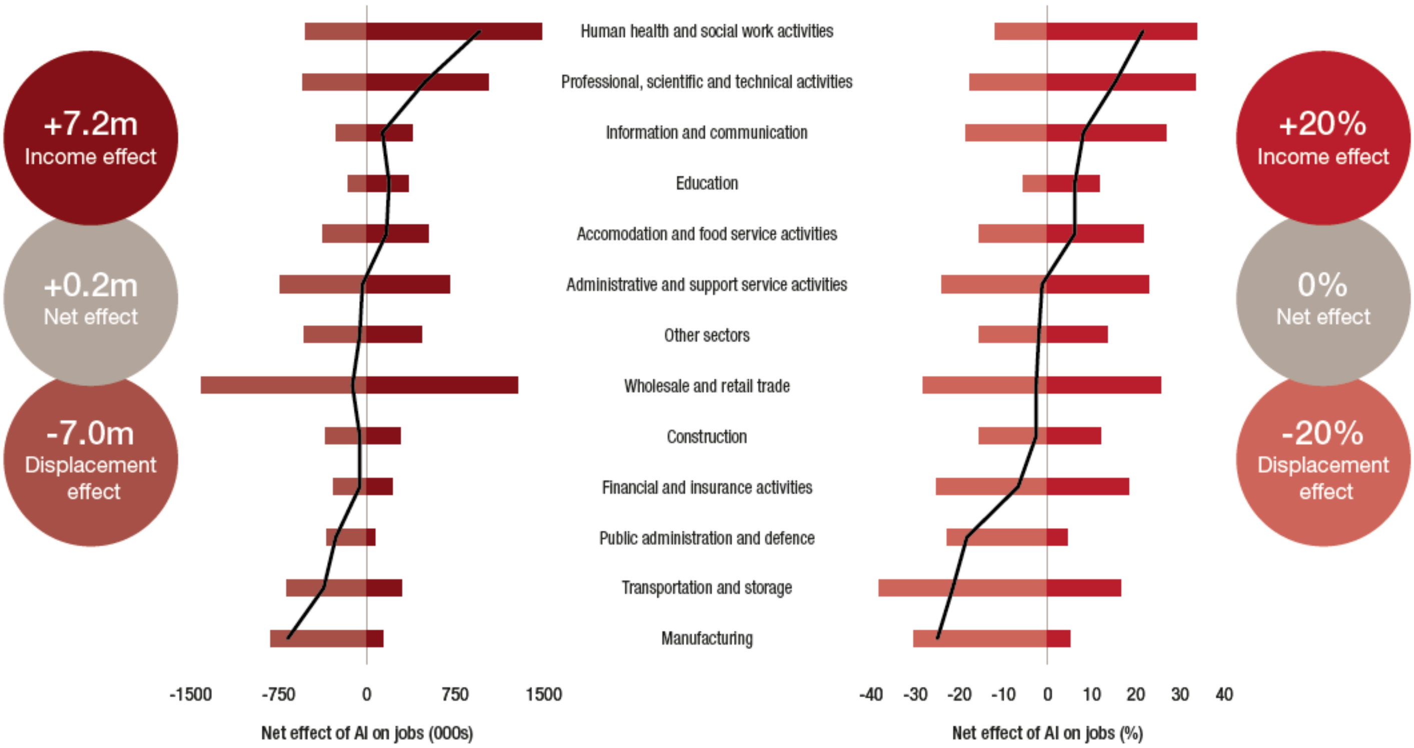
Sources: PwC analysis

4.4 – The net effect of AI on jobs

We can now combine the above estimates of the displacement and income effects to get an estimate of the net UK jobs impact of AI as shown in Figure 4.4 (the net effect is given by the solid line in the charts, with the bars showing the displacement and income effects by sector). We should stress that these are not forecasts of what will happen to total UK employment over the next 20 years: our focus in this article is just on the potential impact of AI on jobs, not on the many other factors that could affect total UK employment over this period.

Our estimates suggest that AI will not lead to technological unemployment as we project that it will displace around 20% of existing UK jobs by 2037, but create a similar number. In absolute terms, around 7 million existing jobs are projected to be displaced, but around 7.2 million are projected to be created, giving a net jobs boost of around 0.2 million. However, as our later scenario analysis shows, this net positive effect of less than 0.1% is too small to be statistically significant relative to the uncertainties surrounding any such long-term employment projections.

Figure 4.4 – Estimated net effect of AI on UK jobs by industry sector



Sources: PwC analysis

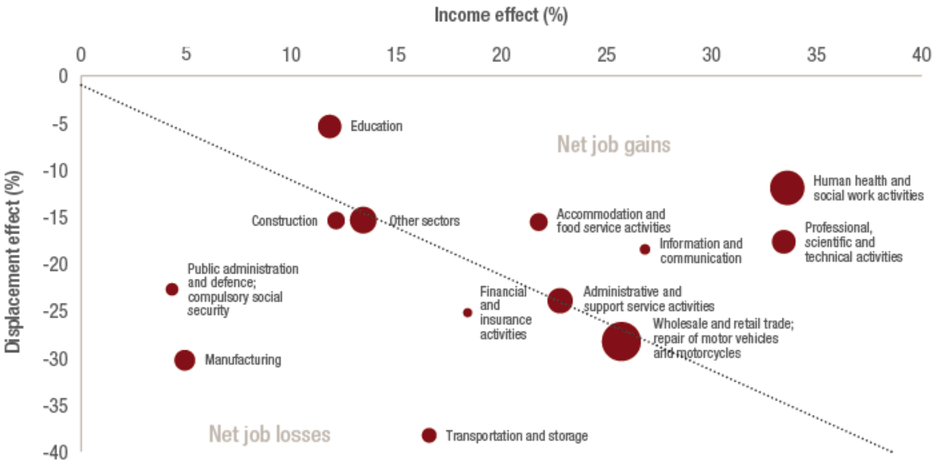
Whilst our central estimate suggests that the overall net effect of AI on UK jobs may be broadly neutral, this is not true for individual sectors. The most positive effect is seen in the health and social work sector, where we expect the number of jobs to increase by nearly 1 million, equivalent to around 20% of existing jobs in this sector. On the other hand, we estimate that the number of jobs in the manufacturing sector could be reduced by around 25% due to AI and related technologies, representing a net loss of nearly 700,000 jobs. Further details of our sectoral results are set out in Table 4.1.

Table 4.1: Estimated job displacement and creation from AI by industry sector (2017-37)

Industry sector	% of existing jobs (in 2017)			Number of jobs (000s)		
	Creation	Displacement	Net effect	Creation	Displacement	Net effect
Health and social work	34%	-12%	22%	1,481	-526	955
Professional, scientific and technical	33%	-18%	16%	1,025	-541	484
Information and communication	27%	-18%	8%	388	-267	121
Education	12%	-5%	6%	345	-158	187
Accommodation and food services	22%	-16%	6%	518	-371	147
Administrative and support services	23%	-24%	-1%	698	-733	-35
Other sectors	13%	-15%	-2%	466	-533	-67
Wholesale and retail trade	26%	-28%	-3%	1,276	-1,403	-127
Construction	12%	-15%	-3%	279	-355	-75
Financial and insurance activities	18%	-25%	-7%	209	-286	-77
Public administration and defence	4%	-23%	-18%	64	-339	-274
Transportation and storage	17%	-38%	-22%	296	-683	-387
Manufacturing	5%	-30%	-25%	133	-814	-681
Total	**20%**	**-20%**	**0%**	**7,176**	**-7,008**	**169**

Source: PwC analysis

Figure 4.5 – Income effect vs displacement effect on jobs in 2037 by sector (size of bubble is proportional to 2017 employment levels)



Sources: PwC analysis

The net job gainers and losers by sector are presented in a different format in Figure 4.5. Sectors towards the bottom left of the chart (e.g. manufacturing) are expected to have the largest percentage net loss in jobs. Sectors towards the top right of the chart (e.g. health) are expected to see the largest net job gains, while those towards the bottom right (e.g. wholesale and retail) show the largest job 'churn' with high levels of both displacement and job creation.

The sectors that are likely to benefit the most from AI are highly 'human' sectors and highly technical sectors.

Human health and social work activities

We estimate that this sector could see the largest net job gains. This is driven by a high income effect, as health is a 'superior good' that will be increasingly in demand as society becomes richer and the UK population ages. Some healthcare jobs will be displaced (e.g. in routine analysis and diagnosis) but many more are likely to be created as real incomes rise and patients still want the 'human touch' from doctors and nurses (albeit that their capabilities will be enhanced by AI and robotics).

Professional, scientific and technical activities

In this sector we estimate that AI could create about twice as many jobs as it displaces in the long run. These jobs are likely to take the form of what MIT researchers have referred to as 'explainers' and 'sustainers' – jobs involved with designing, operating and communicating AI and related technologies[13]. Based on historical evidence, this sector should show relatively fast growth in demand as real incomes rise, so the indirect income effect of AI will be critical in boosting long-term employment in this sector, even if there are automation-related job losses in some areas just involving data analysis in the shorter term. A key insight here is that, as prediction becomes cheaper due to advances in machine learning, so expert human judgement to assess what action to take for a given set of probabilistic predictions will become more valuable[14].

Education

Teaching requires high levels of interpersonal skills that cannot easily be replaced by AI systems or robots, although they can be complemented by them to meet projected rising demand for education over time. As such, we only expect around 5% of educators to be displaced by AI, more than offset by job creation of over 10%. Human teachers will tend to specialise in more 'human' areas (e.g. personal coaching, supervising group work, subjects like art, music, drama and sport), while machines take on the more routine tasks like marking homework and conducting multiple choice tests.

13 MIT, 'The Jobs that Artificial Intelligence Will Create' (2017): https://sloanreview.mit.edu/article/will-ai-create-as-many-jobs-as-it-eliminates/
14 This point is discussed at length by Ajay Agrawal, Joshua Gans and Avi Goldfarb in their excellent recent book 'Prediction Machines: The Simple Economics of Artificial Intelligence' (HBR Press, 2018).

The sectors that are more likely to see net job losses from AI/automation are those involving a high degree of repetitive and routine tasks

Transportation and storage

We estimate that automation could displace almost 40% of existing jobs in this sector by 2037 as driverless vehicles roll out across the economy and warehouses become increasingly automated, but might only create less than half this number of additional jobs through income effects.

Manufacturing

We estimate that there could be around 25% fewer jobs in the manufacturing sector by 2037 as a result of automation, continuing a long-established trend of recent decades. Many of these jobs may be displaced in early waves of AI as routine factory tasks continue to be replaced by algorithms and robots, over and above what has already happened.

Public administration and defence

Clerical tasks in the public sector are also liable to be replaced by algorithms as public finances remain under strain with an ageing population, leading to a continuing focus on efficiency gains through automation of routine tasks. There may be further use of drones, AI systems and related technologies in defence, although there will also be new job creation here for technology experts (e.g. in cybersecurity).

4.5 – Regional differences in AI job impacts

Our analysis reveals that the costs and benefits of AI are unevenly distributed across industry sectors. Since the industry mix of employment varies across different parts of the UK, this has implications for the regional impact of AI/automation on jobs.

Table 4.2 shows the results of applying our analysis at a regional level (assuming that the only difference is due to the varying industrial structure of employment across regions).

According to this analysis, the net effect of AI on jobs may not vary that much across the UK. London has the most positive estimated impact (+2%), which benefits from being home to 28% of the UK's professional, scientific and technical activities, as well as 31% of the UK's information and communication sector. In contrast, regions in the North and Midlands, with higher weightings towards relatively automatable industrial jobs, have marginally negative estimated net impacts, but always by only around 1% or less of existing job numbers.

Table 4.2: Estimated regional jobs impact of AI based only on variations in industry mix

Region	% of existing jobs (in 2017)			Number of jobs (000s)		
	Creation	Displacement	Net effect	Creation	Displacement	Net effect
London	22.0%	-19.7%	2.3%	1,297	1,159	138
South East	20.6%	-19.7%	0.8%	1,019	978	41
Wales	19.7%	-18.9%	0.7%	302	291	11
Scotland	20.2%	-19.6%	0.5%	558	544	15
South West	19.9%	-19.5%	0.4%	582	571	11
North East	20.0%	-19.8%	0.2%	239	237	2
East of England	20.4%	-20.3%	0.1%	648	646	2
North West	20.4%	-20.4%	0.0%	748	749	-1
West Midlands	20.1%	-20.4%	-0.3%	599	607	-8
Northern Ireland	19.4%	-19.8%	-0.4%	172	176	-4
Yorkshire and the Humber	20.0%	-20.4%	-0.4%	532	544	-12
East Midlands	19.5%	-20.7%	-1.1%	478	505	-27
Total	**20%**	**-20%**	**0%**	**7,176**	**-7,008**	**169**

Source: PwC analysis

The relatively small regional differences in Table 4.2 are what we would expect given that we are only looking at the effect of variations in industry structure across regions. In practice, there will also be variations due to other task characteristics of jobs within a particular sector that vary by industry sector (e.g. the typical tasks that account for financial services jobs in London may not be the same as those of financial services jobs in the North East or Northern Ireland). Unfortunately we do not have detailed data on the task composition of jobs at regional level because the OECD PIAAC data we use is only available at national level. But it is certainly possible that allowing for these other factors could lead to wider regional variations in net job impacts from AI than those shown in Table 4.2.

4.6 – Scenario analysis

In the above analysis we made two key assumptions:

1. To estimate the displacement effect, we assumed that, of the 30% of UK jobs estimated to be at potential high risk of being automated, only 2/3 will in fact be automated – i.e. 20% of existing jobs.

2. To estimate the income effect, we used an estimate from our earlier research that AI could contribute around 10% to UK GDP by 2030 and then calculated what this implied about the percentage contribution of AI to overall long-term UK GDP growth (46%).

We now vary these two key assumptions to construct a set of more and less optimistic assumptions:

1. For the displacement effect, we assume that, of the 30% of jobs at potential high risk of automation, the percentage that will in fact be automated ranges from 1/2 and 5/6, giving a range of 15-25% for the proportion of existing jobs (which seems plausible relative to other studies in this field).

2. For the income effect, we assume that AI could contribute between 7.5% and 12.5% of UK GDP by 2030, implying that the proportion of total GDP/GVA growth attributable to AI ranges from around 35% to around 57%[15].

Table 4.3 displays the estimated net effect of AI on UK jobs under each possible combination of these assumptions, giving nine possible scenarios in all. If both the pessimistic assumptions – that 25% of existing jobs are displaced, but only 35% of long-term UK GVA growth is attributable to AI – hold true, then we estimate that AI would displace around 3.6 million (10%) more jobs than it created. Conversely, if both the more optimistic assumptions hold true, we estimate that AI could create around 4 million (11%) more jobs than it displaces.

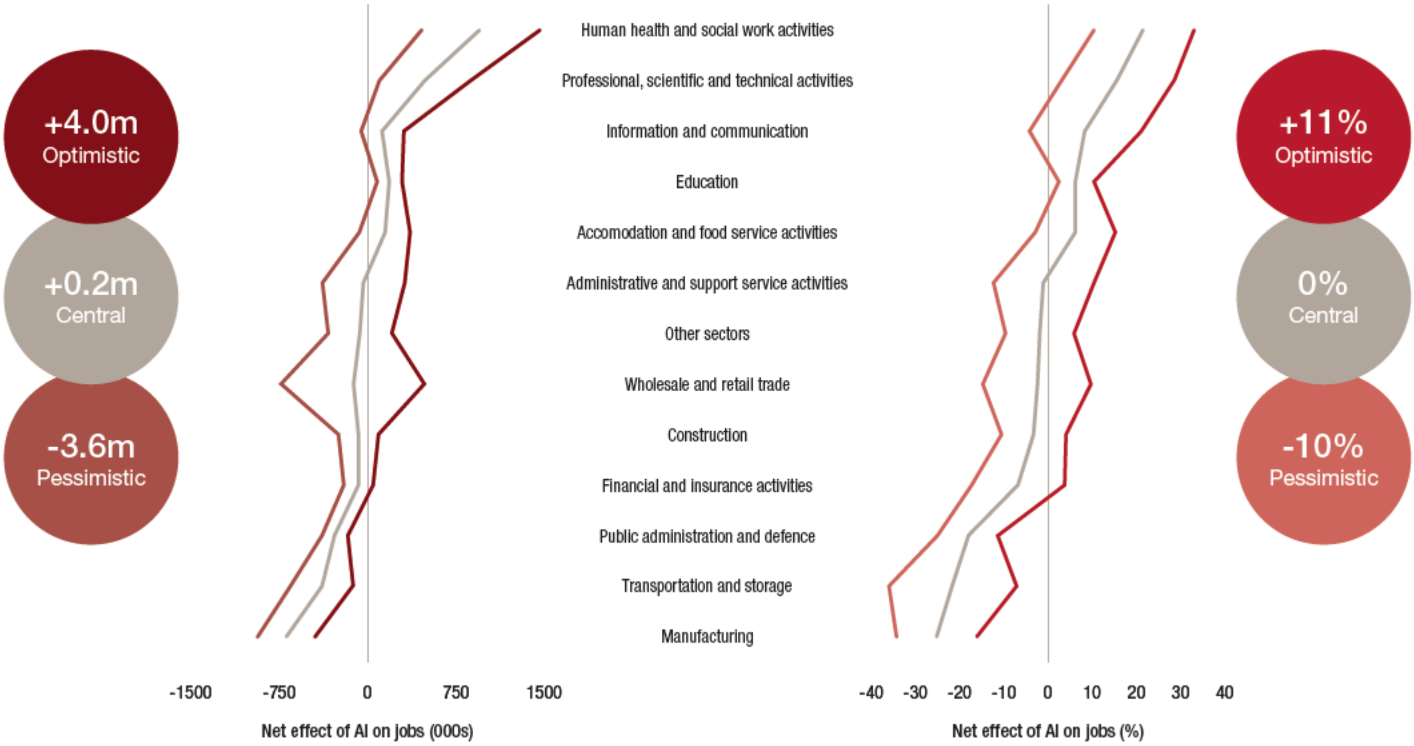
Table 4.3: Net effect of AI on UK jobs under each scenario (millions and as % existing jobs)

		Displacement effect		
		25% of existing jobs automated	20% of existing jobs automated	15% of existing jobs automated
Income effect	AI constitutes 7.5% of GDP by 2030	-3.6m (-10%)	-1.8m (-5%)	-0.1m (0%)
	AI constitutes 10% of GDP by 2030	-1.6m (-5%)	+0.2 (0%)	+1.9m (5%)
	AI constitutes 12.5% of GDP by 2030	+0.5m (1%)	+2.3m (6%)	+4.0m (11%)

Source: PwC analysis

15 As described in the annex we assumed that AI would have a 'high', 'medium' or 'low' impact on each sector, corresponding to 56%, 46% and 36% of growth. We shift these percentages along with the central assumption, e.g. in the pessimistic scenario, where only 35% of total GVA growth is attributable to AI, a 'high', 'medium' and 'low' impact corresponds to 45%, 35% and 25%.

Figure 4.6 – Net effect of AI on jobs by industry sector in the most optimistic and pessimistic scenarios



Sources: PwC analysis

We think the most likely scenarios are those towards the middle of the matrix. This is partly because the central assumptions are those we consider most plausible based on our analysis and partly because we think the uncertainties related to these assumptions may tend to be negatively correlated and so cancel out, at least in part. In particular, if there were to be a high displacement effect this would normally be assumed to be associated with higher productivity growth and so a higher income effect (and vice versa for a low displacement effect).

It is possible to come up with a plausible scenario where both assumptions are at the pessimistic end of the range (e.g. if the cost savings from job displacement accrue mostly to wealthy company executives and owners, who enjoy significant monopoly power and so do not need to pass these savings on to consumers, while not spending much of the extra profits themselves). But this kind of extreme pessimistic (or indeed optimistic) scenario seems relatively less likely.

Nonetheless, the extreme scenarios are far from impossible, bearing in mind also that outcomes beyond our range of assumptions are also possible. We therefore provide further sectoral details on the two most extreme scenarios in Figure 4.6.

The charts show how the range of job impacts depends on both the scale of employment in the sector and how susceptible a given sector is to both the direct and indirect effects of AI. For example, in the wholesale and retail sector, there is a difference of well over 1 million jobs depending on whether we are in the most pessimistic or optimistic scenario, constituting around a third of the total net swing in UK employment between the two scenarios. This is due to the fact that the wholesale and retail sector employs more people than any other sector covered here, accounting for nearly 5 million jobs in 2017, and that we anticipate large-scale disruption in this sector owing to high displacement and income effects (see Figure 4.4). Jobs in the education sector, by contrast, are not as contingent on developments in AI and related sectors, although there will be some such effects. Overall, however, Figure 4.6 suggests that the relative ranking of UK industry sectors on AI net jobs impact would be broadly consistent across the different scenarios.

4.7 – Policy implications

Our scenario analysis shows that the net impact that AI will have on jobs is uncertain, but it is also not pre-determined: it will depend on how individuals, businesses and the government engage with these new technologies. Government, in particular, can play an important role in steering the economy towards a more optimistic scenario by mitigating the costs of the displacement effect while maximising the positive income effects.

Mitigating the displacement effect

- **Government should invest more in 'STEAM' skills that will be most useful to people in this increasingly automated world.** This means focusing more on STEM subjects (science, technology, engineering and mathematics), but also exploring how art and design can feature at the heart of innovation (as is being pioneered by the 'STEAM' movement, where 'A' represents 'Art and design')[16]. Governments should also encourage workers to continually update and adapt their skills so as to stay one step ahead of the machines, for example with the introduction of lifelong learning credits[17]. In addition, job centres could benefit from AI platforms that match jobseekers with jobs.
- **Government should strengthen the safety net for those who find it hard to adjust to technological changes.** While we do not believe that mass technological unemployment is a likely scenario, it is certainly possible that these technologies could favour those who already have strong digital skills and so tend to further increase income and wealth inequality. If this is the case, then governments need to consider how to redistribute some of the significant GDP gains from AI more widely across society. Universal basic income (UBI) has been put forward as a potential way to maintain the incomes of those who lose out from automation, but there are many other options to consider here. For example, the government might make such payments conditional on some contribution to society through work, education, training, volunteering or caring roles so it is not just 'something for nothing'. They could also look again at how best to incentivise (human) work through the tax and benefit system, for example by rebalancing welfare spending back towards working age tax credits rather than state retirement benefits (the reverse of the general UK trend in recent years).

16 See, for example, this paper by the Cultural Learning Alliance and Nesta: https://culturallearningalliance.org.uk/wp-content/uploads/2017/10/CD405-CLA-STEAM-Briefing-Teachers-Notes-08.pdf
17 This point was discussed further in relation to older workers in our 2018 Golden Age Index report here: https://www.pwc.co.uk/goldenage

Maximising the income effect

- **Place-based industrial strategy should target job creation.** Central and local government bodies need to support sectors that can generate new jobs, for example through place-based strategies[18] focused on university research centres, science parks and other enablers of business growth. This place-based approach is, for example, one of the key themes in the UK government's new industrial strategy[19] and its wider devolution agenda. It also involves extending the latest digital infrastructure beyond the major urban centres to facilitate small digital start-ups in other parts of the country.

- **Government should implement its AI strategy in full.** In April 2018, the government published the AI Sector Deal[20]. The report sets out a broad range of policies to support development of the AI sector, linked into the broader industrial strategy. If implemented in full, the AI Sector Deal would go a long way to maximising the income effect of AI on jobs in the UK.

- **Promoting effective competition:** it is critical to maximising the income effect that the productivity gains from AI are passed through in large part to consumers through lower (quality-adjusted) prices. This requires competitive pressure to be maintained both in the technology sector producing the AI and in the sectors using it, so an effective competition policy will be important here that balances the need for a reasonable return to innovation with providing long term benefits to consumers.

18 For more on place-based strategies in the UK context, see also our 2017 Good Growth for Cities report: https://www.pwc.co.uk/industries/government-public-sector/good-growth.html.
19 https://www.gov.uk/government/topical-events/the-uks-industrial-strategy.
20 https://www.gov.uk/government/publications/artificial-intelligence-sector-deal/ai-sector-deal#contents

4.8 – Summary and conclusions

AI and related technologies such as robotics, drones and driverless vehicles could displace many jobs formerly done by humans, but will also create many additional jobs as productivity and real incomes rise and new and better products are developed.

We estimate that these countervailing displacement and income effects are likely to broadly balance each other out over the next 20 years, with the share of existing jobs displaced by AI (c.20%) likely to be approximately equal to the additional jobs that are created.

Although the overall effect on UK jobs is estimated to be broadly neutral in our central projections, there will inevitably be 'winners' and 'losers' by industry sector.

The sectors that we estimate could see the largest net increase in jobs in the long run include health (+22%), professional, scientific and technical services (+16%) and education (+6%). The sectors estimated to see the largest net long-term decrease in jobs due to AI include manufacturing (-25%), transport and storage (-22%) and public administration (-18%).

Based on differences in industry structure alone, our projections do not imply large variations by region, though our central estimates imply a small net job gain in London offset by small net losses in the North and Midlands. But other factors could lead to larger regional employment variations than captured by our model.

Our central estimate is that the net effect of AI on jobs will be broadly neutral, but there are many uncertain factors that could tip the balance towards more optimistic or pessimistic scenarios. We identify some policy areas where action could help to maximise the benefits (e.g. boosting research funding for AI, ensuring effective competition among companies developing and deploying AI so gains are passed on to consumers) and/or mitigate the costs in terms of impacts on jobs (e.g. a national retraining programme for older workers as well as renewed efforts to build STEAM skills in schools and universities).

Technical annex: Methodology

The displacement effect

Our analysis of the displacement effect is adapted from our study 'Will robots really steal our jobs?'[21] In this analysis we scale down the numbers to bridge the gap between the number of jobs could be automated and the number of jobs that will be automated, given the range of economic, legal and regulatory and organisational barriers to automation.

In the previous study we build on research by Frey and Osborne (2013)[22], Arntz, Gregory and Zierahn (2016)[23] and our previous research on this topic in PwC's UK Economic Outlook (March 2017)[24].

In the original study by Frey and Osborne (hereafter 'FO') a sample of occupations taken from O*NET, an online service developed for the US Department of Labor, were hand-labelled by machine learning experts at Oxford University as strictly automatable or not automatable. Using a standardised set of features of an occupation, FO were then able to use a machine learning algorithm to generate a 'probability of computerisation' across US jobs, but crucially they generated only one prediction per occupation.

Using the same outputs from the FO study, Arntz, Gregory and Zierahn (hereafter 'AGZ') conducted their analyses on the OECD Programme for the International Assessment of Adult Competencies ('PIAAC') database, which includes more detailed data on the characteristics of both particular jobs and the individuals doing them than was available to FO. This allows a critical distinction that it is not whole occupations that will be replaced by computers, algorithms and robots, but only particular tasks that are conducted as part of that occupation.

Table A4.1: Projected real GVA growth by UK industry sector over the past and next 20 years (% pa)

	Historical GVA growth	Mean reversion	Projected GVA growth
Manufacturing	0.13%	Low	0.67%
Construction	1.59%	None	1.59%
Wholesale and retail trade	2.05%	None	2.05%
Transportation and storage	3.90%	High	2.13%
Accommodation and food service activities	2.15%	None	2.15%
Information and communication	3.90%	Low	3.31%
Financial and insurance activities	1.84%	None	1.84%
Professional, scientific and technical activities	4.98%	Medium	3.15%
Administrative and support service activities	4.98%	High	2.24%
Public administration and defence	0.01%	Low	0.59%
Education	0.60%	Low	1.00%
Human health and social work activities	3.17%	None	3.17%
Other sectors	1.75%	None	1.75%
All sectors	**1.97%**	**N/A**	**1.93%**

Sources: ONS for historical data, PwC for future growth projections

Furthermore, this allows for the fact that the same occupation may be more or less susceptible to automation in different workplaces.

The PwC automation rate algorithm developed in our earlier study (PwC, March 2017) involved first taking the labels from the FO study and replicating the methodology from the AGZ study using the PIAAC dataset. The methodology was then enhanced using additional data and a refined automation-rate prediction algorithm. This model was initially trained on PIAAC data for the UK, US, Germany and Japan, but then extended to over 200,000 workers across 29 countries.

This much larger sample size gives increased confidence in our estimates of the relative automatability of jobs in different industry sectors and across different types of workers (e.g. by age, gender or education level).

21 'Will robots steal our jobs?' PwC UK Economic Outlook, March 2017, available here: https://www.pwc.co.uk/economic-services/ukeo/pwcukeo-section-4-automation-march-2017-v2.pdf.
22 Frey, C.B. and M.A. Osborne (2013), The Future of Employment: How Susceptible are Jobs to Computerization?, University of Oxford.
23 Arntz, M. T. Gregory and U. Zierahn (2016), 'The risk of automation for jobs in OECD countries: a comparative analysis', OECD Social, Employment and Migration Working Papers No 189.
24 Will robots steal our jobs?' PwC UK Economic Outlook, March 2017, available here: https://www.pwc.co.uk/economicservices/ukeo/pwcukeo-section-4-automation-march-2017-v2.pdf.

The income effect

In our 'Sizing the Prize' report we estimated the total income derived from AI over the period to 2030. For this report we have converted the potential value of AI into jobs numbers by, first, projecting UK output (GVA) growth by industry sector over the next 20 years and, second, by estimating the proportion of GVA growth that is attributable to AI based on our Sizing the Prize report for the UK.

We assume here that the projected increase in jobs will be the same as the projected increase in GVA because we are already capturing the productivity impact of AI in saving on labour inputs through our estimates of the displacement effect, so to include this again here would be double counting. This is the same broad assumption as was made in a previous report by Oxford Economics and Cisco[25], but unlike that report we do not assume that the net jobs impact is exactly zero, as this seems to be too restrictive an assumption to impose a priori.

We have projected sectoral GVA by projecting forward historical average rates and applying a mean reversion adjustment. We apply a mean reversion adjustment of either 0% ('None'), 30% ('Low'), 60% ('Medium'), or 90% ('High') based on our judgement and a constraint that implied overall GDP growth is plausible (c.2% on average over the 20 years to 2037). The resultant GVA projections are shown in Table 4A.1.

In our 'Sizing the Prize' report we estimated that AI could contribute around 10% of UK GDP by 2030. Combined this with our GDP projections, we estimate that AI could account for around 46% of cumulative UK GDP (or GVA) growth over the period to 2030, which we assume also holds over the longer period to 2037.

Table A4.2: Estimated AI contribution to projected GVA and jobs growth due to income effect (% pa over period to 2037)

	Projected GVA growth	AI impact tier	AI contribution to growth
Manufacturing	0.67%	Low	0.24%
Construction	1.59%	Low	0.57%
Wholesale and retail trade	2.05%	High	1.15%
Transportation and storage	2.13%	Low	0.77%
Accommodation and food service activities	2.15%	Medium	0.99%
Information and communication	3.31%	Low	1.20%
Financial and insurance activities	1.84%	Medium	0.85%
Professional, scientific and technical activities	3.15%	Medium	1.45%
Administrative and support service activities	2.24%	Medium	1.03%
Public administration and defence	0.59%	Low	0.21%
Education	1.00%	High	0.56%
Human health and social work activities	3.17%	Medium	1.46%
Other sectors	1.75%	Low	0.63%
All sectors	**1.93%**	**Medium**	**0.89%**

Sources: ONS for historical data, PwC for future growth projections

This impact will vary by sector, so we assume that the growth share due to AI varies from 36% ('low') to 56% ('high') by sector based on previous macroeconomic modelling results. Applying these percentages to the projected growth rates gives us the estimated GVA growth that is attributable to AI, as presented in Table A4.2.

To work out the number of jobs associated with the GVA growth attributable to AI we simply assume that the increase in jobs will be the same as the projected increase in GVA for the reasons discussed above.

For example, if we expect a 1% GVA annual growth rate in the accommodation and food sector over the next 20 years that is attributable to AI, we assume the income effect is to increase jobs by 1% per annum on average in this sector. To find the cumulative income effect we compound these growth rates over the 20 years to 2037.

25 Oxford Economics and Cisco, 'The AI Paradox', December 2017.

www.pwc.co.uk/economics

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