Artificial Intelligence (AI) can transform the productivity and GDP potential of the UK landscape, **but** we need to take the necessary steps to invest in the different types of AI technology to realise the potential gains.

The economic impact of artificial intelligence on the UK economy

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Executive summary

- UK GDP will be up to ***10.3%*** higher in 2030 as a result of AI – the equivalent of an additional ***£232bn*** – making it one of the biggest commercial opportunities in today's fast-changing economy.
- The impact over the period will come from productivity gains (1.9%) and consumption-side product enhancements and new firm entry stimulating demand (8.4%).
- There will be significant gains across all UK regions, with England, Scotland, Wales and Northern Ireland all seeing an impact from AI in 2030 at least as large as 5% of GDP, and extra spending power per household of up to £1,800-£2,300 a year by 2030.

What is AI?

Almost every aspect of our daily lives has been digitised. Internet and mobile technologies have transformed the way that we live and work. A new wave of technology is coming through, and it centres on data. Artificial intelligence (AI) will utilise data to assist us with the many tasks that we currently do ourselves today and will be able to do things that we've never even conceived of before.

AI refers to computer systems that can sense their environment, think, learn and then take action as a result. This ability to respond to the environment stands artificial intelligence apart from automation of routine tasks. Machine learning algorithms and chatbots are examples of AI that are already used by businesses today.

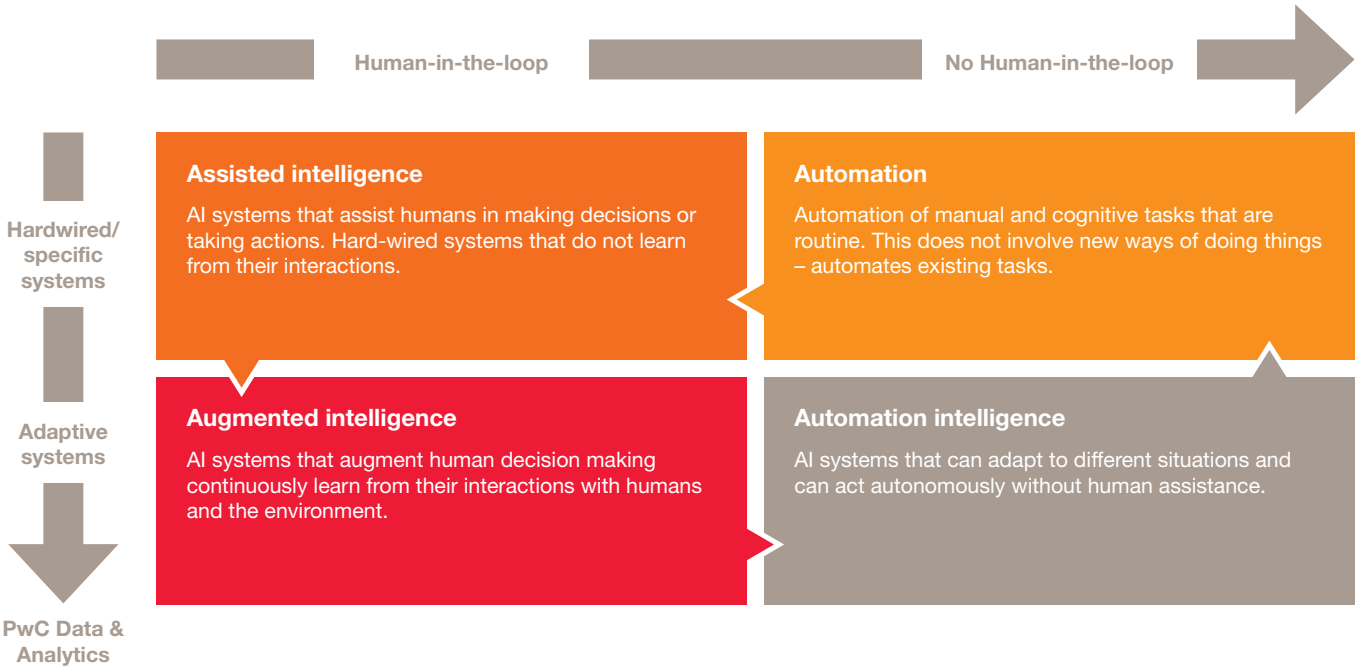
Our definition of AI, however, goes beyond this. We also include automation, the replacement of repetitive manual and cognitive tasks by machines that are not necessarily 'intelligent' and that instead have basic rules-based capabilities. We include these as we recognise that they are a key step in the progress towards advanced intelligent technologies.

AI refers to computer systems that can sense their environment, think, learn and then take action as a result.

We therefore consider four elements of artificial intelligence:

- **Automated intelligence:** Automation of manual, routine tasks
- **Assisted intelligence:** Helping to perform tasks faster and better
- **Augmented intelligence:** Helping people to make better decisions
- **Autonomous intelligence:** Automating decision-making processes without human intervention

Figure 1: The scope of artificial intelligence



With artificial intelligence set to transform the way that we live and work, it raises the inevitable question of how much it will actually impact businesses and the economy more generally.

The economics of artificial intelligence

Despite discussion on social media about the things that AI will be able to achieve, the majority of studies that have sought to answer this question have focused on the risks of artificial intelligence to employment. More recently some researchers have recognised the potential that this automation has to boost productivity,[1,2] leading to more efficient production of goods, more affordable products, and higher real incomes.

Our study aims to take further steps towards capturing the full economic potential of AI and the opportunities that it presents. In addition to the more traditionally examined productivity channel, we identify and measure impacts on the household consumption side of the economy through product enhancements resulting from AI.

In particular, we predict that AI will likely enhance available consumer products in three ways: increasing their quality, increasing consumer choice through more personalised and varieties of goods, and saving consumers time from being able to multitask better and delegate to AI technologies. As our study reveals, these product enhancements are expected to have a large impact on GDP. This is partially driven by increased consumer spending on more attractive products, but is most importantly the result of additional firms entering the market following the stimulation in consumer demand, leading to higher quantities of production and more affordable goods.

[1] McKinsey Global Institute (2017), "A future that works: Automation, employment and productivity
[2] Accenture and Frontier Economics, "Why artificial intelligence is the future of growth"

Overview of the approach

Our approach seeks to quantify the total economic impact of artificial intelligence on the UK economy via both productivity gains and consumption side impacts over the period 2017-2030. We have used a dynamic economic model of the UK economy to evaluate the 'net' impact of each channel of impact on GDP and the economy as a whole.

Evaluating the impact of AI on productivity, jobs and product innovation

We have completed a number of stages of analysis in order to ascertain the 'first-round' impacts on jobs, productivity and product enhancements that would be inputted into the dynamic economic model in order to estimate the future size of the AI prize.

- On the production side, we focus on AI's impact on labour productivity through automation. This required estimating the marginal impact of AI on productivity, the scale of automation expected to take place, the amount of AI replacing human labour and the amount of AI augmenting human labour for every industry in the UK between now and 2030.
- On the consumption side, we focus on AI's impact on product enhancements, which include increased quality, personalisation (i.e. product variety), as well as increased time available for leisure or work.

We have used a dynamic economic model of the UK economy to evaluate the 'net' impact of each channel of impact on GDP and the economy as a whole.

In line with this, we have brought together three key pieces of primary research undertaken by the global PwC network to estimate these impacts of AI on each channel:

Econometric modelling and machine learning to estimate the effect of AI on productivity

We have built an econometric panel-data model for the UK, which estimates the impact of AI uptake on labour productivity including for each industrial sector. We used the World and EU KLEMS datasets which include detailed data on labour productivity and businesses' technology spending.

The model accounts for productivity that results not only from businesses automating process but also from businesses 'augmenting' their existing labour force with human-in-the-loop AI technologies.

Our econometric model was used to evaluate the marginal impact of AI and was combined with our study on job automation and projections of investment in augmented intelligence to estimate the impact that expected AI uptake will have on productivity over the period to 2030. The job automation study, which was published in our March 2017 UK Economic Outlook[3], used a machine learning algorithm to predict the fraction of jobs within UK industry sectors at high risk of automation from AI between now and 2030 based on their task composition and the automatability of those processes.

AI Index: Measuring the effect of AI on products and services

We have also made use of the AI Impact Index which was created by PwC's Data Analytics team in the US. The index uses qualitative assessment from industry and AI experts both internally and externally to estimate the scale of product enhancements we will expect to see by 2030, by product line. The analysis sought to identify the most compelling examples of potential AI applications across industry sectors, and assessed almost 300 use cases in the process. We used measures from the index that indicate the enhancements to products through personalisation and product quality, as well as the amount of time that consumers would save, and considered how these would affect the variety of products available to consumers and the amount of utility that they would derive from them, as well the amount of labour supplied to the market.

The AI index indicates the highest potential for product enhancements in the health, automotive and financial services sectors.

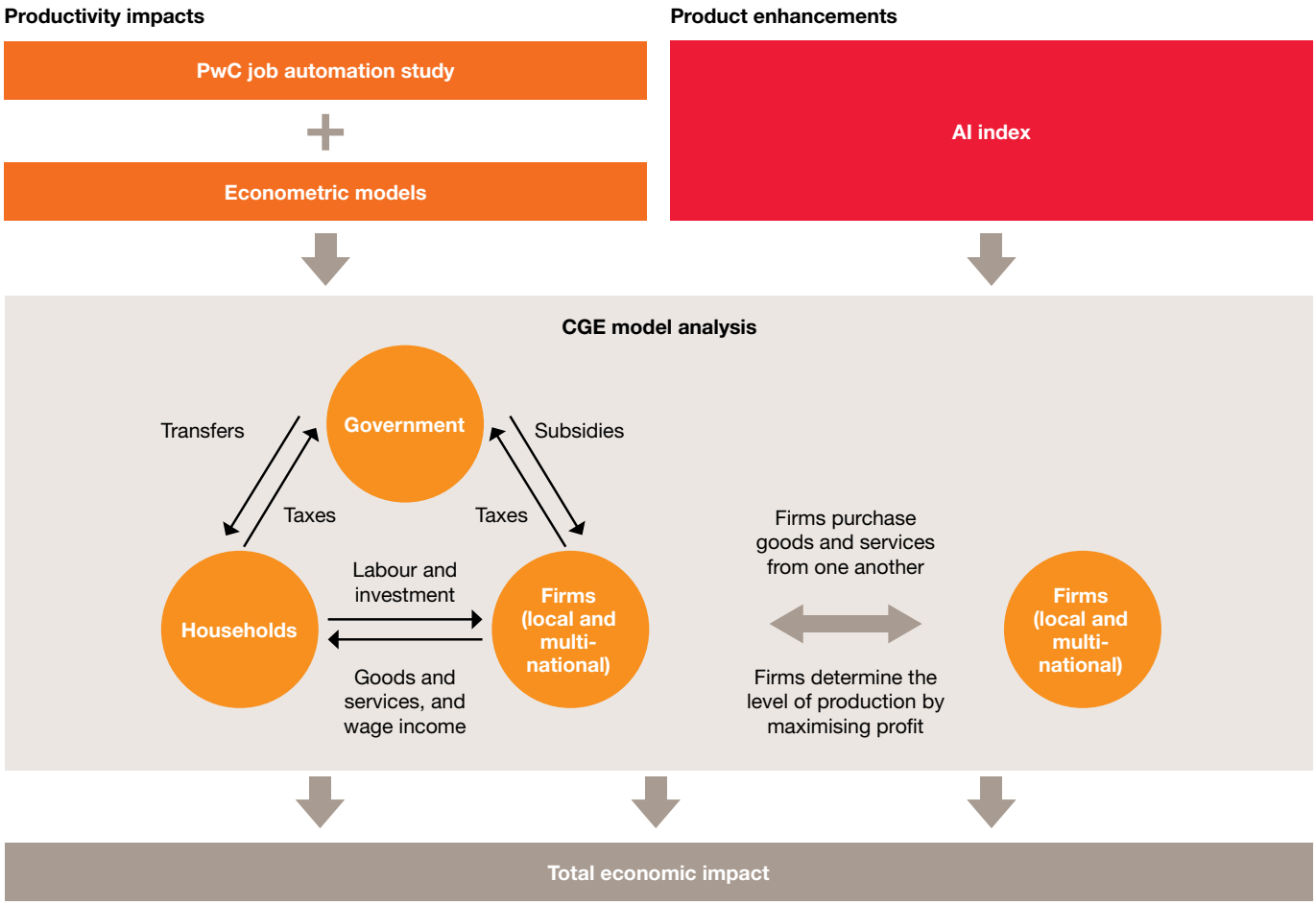
We find that AI could increase productivity by up to 14.3% by 2030.

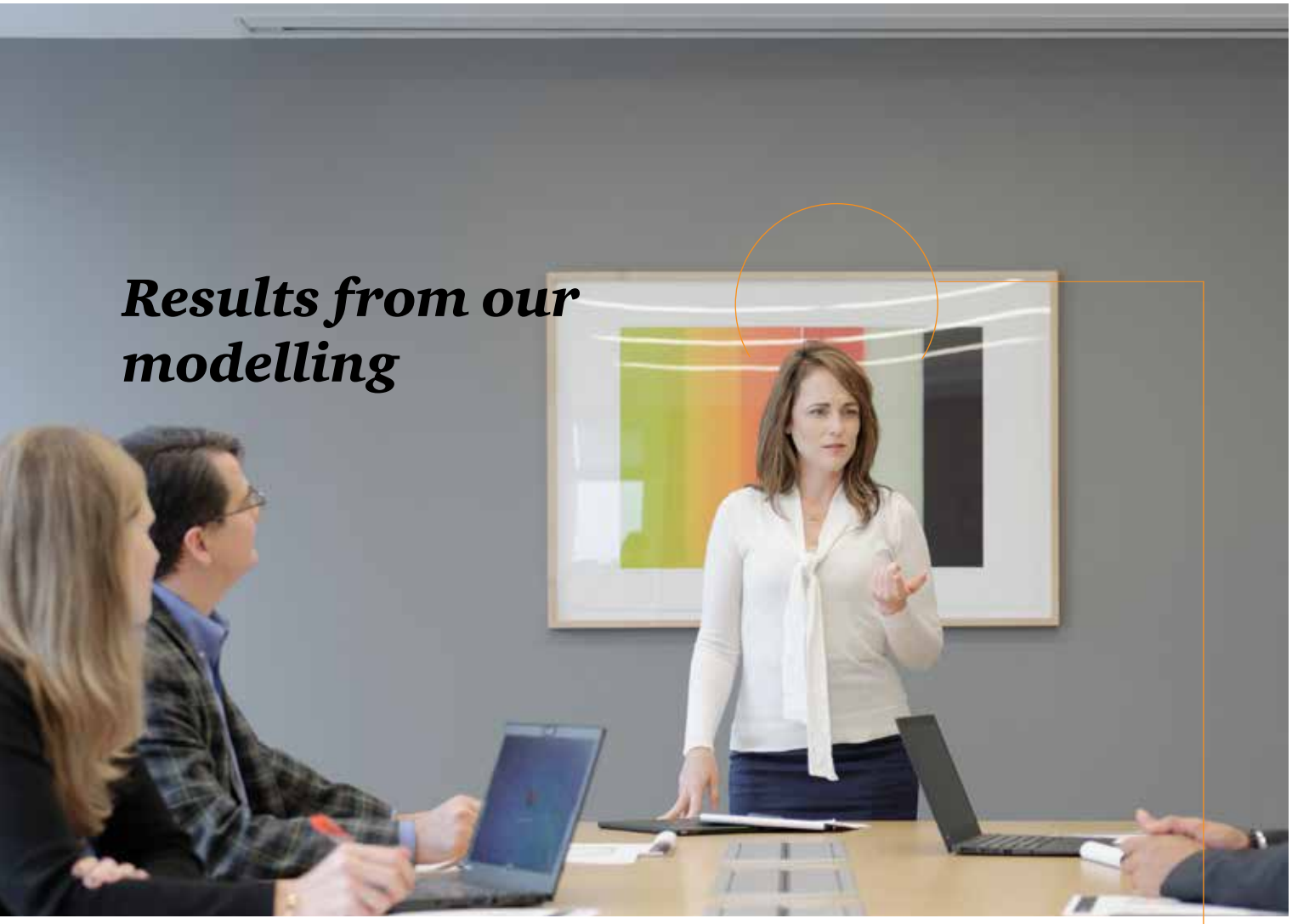
[3] PwC UK Economic Outlook March 2017, "Will robots steal our jobs: The potential impact of automation on the UK and other major economies"

Bringing it all together: the S-CGE model

In the final stage of our approach, we used each of these pieces as inputs into our dynamic economic model (known technically as a Spatial Computable General Equilibrium model (S-CGE)), to estimate the economic impact of AI on UK GDP by 2030. The S-CGE model captures all key interactions between households, firms and government in the economy, and also captures how different regions and sectors of the economy interact over time. This enables us to estimate the 'net' effect of AI's impact on the economy, accounting for the creation of new jobs, a boost to demand from product enhancements and other secondary effects.

Figure 2: Our approach to assessing the total economic impact of AI





Results from our modelling

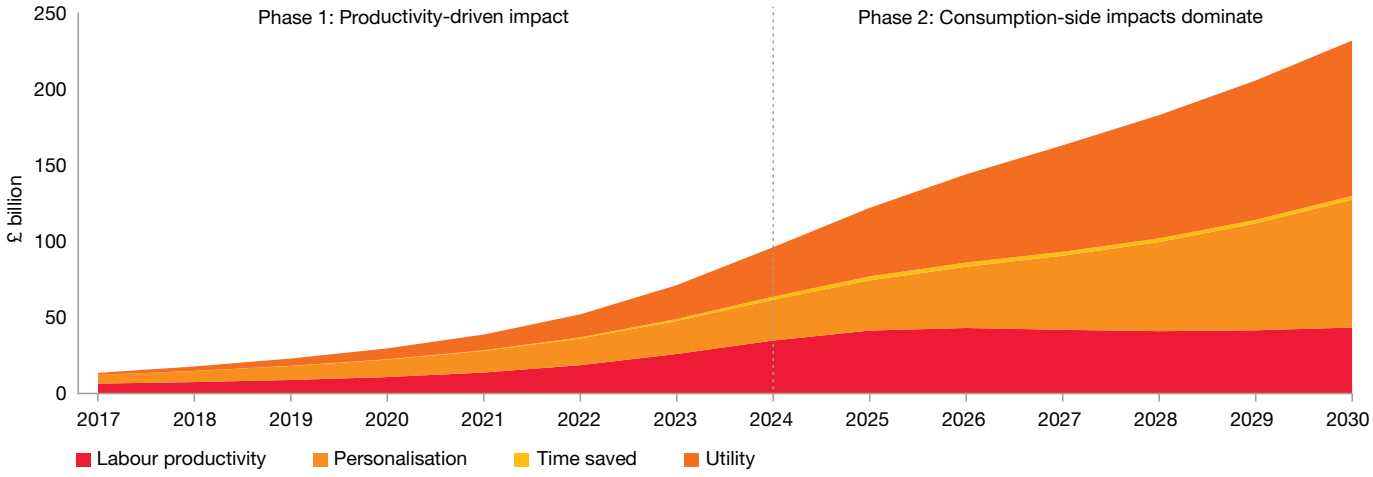
Headline impacts

UK GDP could be up to 10.3% higher in 2030 as a result of AI. The bulk of these impacts will come from consumption-side product enhancements, which stimulate consumption but most importantly bring about more consumer choice and more affordable, bespoke goods over time as a result. The efficiency gains through productivity will also have a significant impact on GDP and will serve as a facilitator for the product innovation on the consumption side.

At a more detailed level, the effects on GDP are likely to be primarily driven by increased product quality (4.5% impact in 2030), more personalised and greater variety of goods (3.7%), as well as increased productivity through augmentation of the labour force and automation of some roles (1.9%). Although welfare will increase as a result of increases in time saved, the impact on GDP is particularly small due to the small size of this effect as well as the model's prediction that most consumers will use their additional time from AI-enhanced products to relax and enjoy leisure time. This is partially explained by the fact that significant productivity and automation increases ensure large rises in the real wage, which in turn encourages workers to spend less time working as they can achieve their same income with less time spent.

UK GDP could be up to 10.3% higher in 2030 as a result of AI.

Figure 3: Where will the value gains come from with AI?



During the first phase of the impact (2017-2024), productivity growth could account for a relatively larger share of the gains than the period that follows, when the consumption-side impacts are likely to dominate. This is due to the fact that it takes time for firms to enter the marketplace and supply new varieties of AI-enhanced products to consumers following the stimulation in consumer spending from higher real wages and initial product improvements. As this takes place, competition within AI goods-producing markets increases dramatically, leading to further increases in the value of goods to consumers and therefore greater expenditure on these products as their affordability and attractiveness rises. Overall, the impact on UK GDP will likely be more heavily-weighted towards the consumption-side impacts than other countries[4]. This is partially because employment in the UK is not highly concentrated in sectors that are automatable, but is also related to the particularly large impact of new goods varieties on the affordability of products in the UK due to the competitive market structure.

Notably, although the labour productivity channel is a 'production side' effect, the GDP gain is not only restricted to increased efficiency of production. As real wages rise with productivity, consumer spending increases since goods become more affordable, regardless of the downwards price pressure from increased production efficiency.

The potential for artificial intelligence to impact the UK economy is slightly higher compared to the potential in Northern Europe more generally. Our recent report[5] assesses the global potential for AI and the likely impact for regional economies. The analysis concludes that GDP in Northern Europe could be up to 9.9% higher in 2030. The UK could see larger gains as a result of having stronger foundations in technology already – many technology companies have their EMEA headquarters located in the UK – and greater access to the talent and skills required to develop AI technologies.

On the topic of jobs, the adoption of 'no-human-in-loop' technologies will mean that some posts will inevitably become redundant, but others will be created by the shifts in productivity and consumer demand emanating from AI, and through the value chain of AI itself. Along with jobs in the development and application of AI, the technologies will need to be built, maintained, operated and regulated. For example, we will need the equivalent of air traffic controllers to control the autonomous vehicles on the road. Same day delivery and robotic packaging and warehousing are also resulting in more jobs for robots and for humans. Furthermore, the extra demand generated in the economy, as a result of artificial intelligence increasing output and incomes, will lead to the creation of jobs not directly related to AI in non-AI intensive sectors. All of this will facilitate the creation of jobs that would not have existed in a world without AI.

[4] PwC (2017), "Sizing the prize: What's the real value of AI for your business and how can you capitalise?"
[5] Ibid.

Regional impacts

There will be significant gains across all UK regions with England set to see the greatest gains from AI both as a percentage of GDP and in absolute magnitude. GDP in 2030 will be up to 10.6% higher in England as a result of AI, Scotland and Wales are likely to experience similarly high gains of around 8.4 – 9.8%, while Northern Ireland may see a more muted gain of 5.4% of GDP.

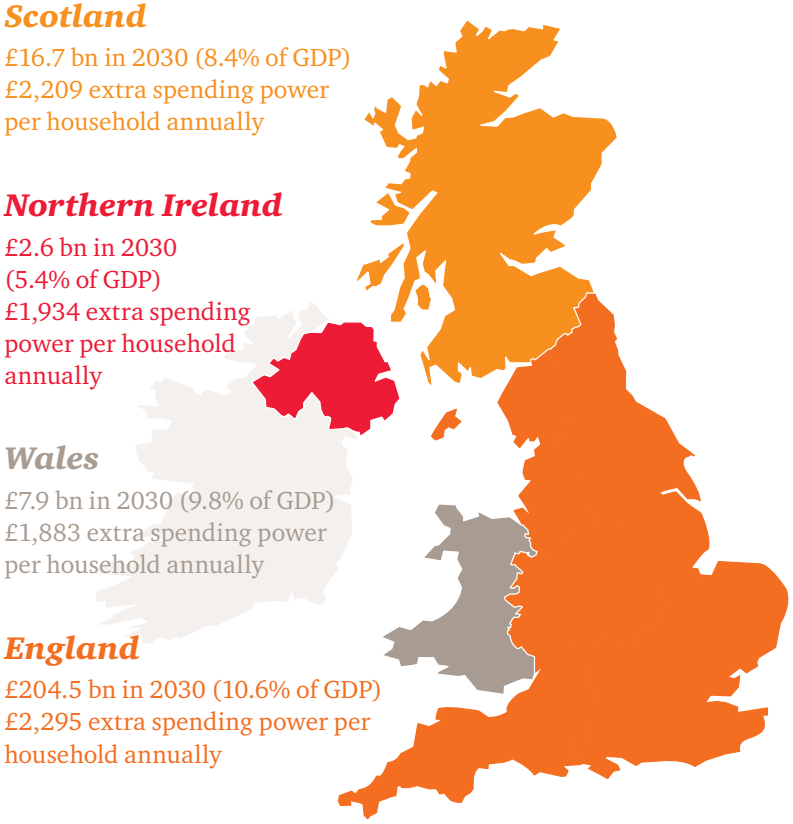
The larger total impact on GDP in some UK regions reflects the different trade patterns in each of the countries. England, and to some extent Scotland and Wales, have stronger trade links with Europe and the rest of the world. The gains through trade related to artificial intelligence are likely to put even higher upwards pressure on GDP in these countries by 2030.

However, artificial intelligence will have a similarly large impact on domestic components of GDP – consumption and investment – in each of the regions. Extra consumption per household per year could be up to £1,800-£2,300 higher in 2030. Although Northern Ireland may not experience the total GDP impacts on the same scale as the other regions because of trade links, there could be an annual spending power increase of almost £2,000 annually, only marginally less than the equivalent projected for England.

Sectoral impacts

It is important to note that the impact of artificial intelligence will not be concentrated in any one sector of the economy and will not be limited to the firms that develop and produce the AI technologies. The uptake of AI will have direct impacts in the sectors in which this uptake occurs, both through the automation and augmentation of process and the enhancement of product offerings for consumers. Furthermore, the total economic impact includes the potential indirect and induced impacts that are likely to be felt by firms and consumers throughout the economy.

Figure 4: Impact of AI on GDP and consumption per household in 2030 by UK region



Appendix

Caveats to the study's conclusions

Our results show the economic impact of AI only – our results may not show up directly into future economic growth figures, as there will be many positive or negative forces that either amplify or cancel out the potential effects of AI (e.g. shifts in global trade policy, financial booms and busts, major commodity price changes, geopolitical shocks, etc.).

Our economic model results are compared to a baseline of long-term steady state economic growth. The baseline is constructed from three key elements: population growth, growth in the capital stock and technological change. The assumed baseline rate of technological change is based on an average of historical trends. It is very difficult to separate out how far AI will just help economies to achieve long-term average growth rates (implying the contribution from existing technologies phases out over time) or simply be additional to historical average growth rates (given that these will have factored in major technological advances of earlier periods).

These two factors mean that our results should be interpreted as the potential size of the economic impact associated with AI, as opposed to direct estimates of future economic growth.

Key assumptions used

Metric	Assumptions	Source
Uptake of workforce augmenting AI	• We estimated long-run trends in emerging technologies by industry uptake that are unrelated to labour force decisions (i.e. expansion periods or automation) using econometric models • We assume all firms will at least replace depreciating AI and emerging technologies so that the net stock remains constant at minimum	PwC analysis
Uptake of workforce replacing AI	• All jobs that are at high risk of automation by 2030 as discussed in PwC's March 2017 UKEO report will be automated. These jobs have at least a probability of 0.7 of being automated by 2030 • A fraction of labour cost savings from automation are spent on replacement AI, this fraction is determined by the current fraction of capital expenditure on AI and emerging technologies	PwC UK Economic Outlook March 2017
Speed of AI uptake	• We scale the rate of AI uptake in the UK based on the Global Innovation Index as a proxy for AI readiness • The highest scoring country's rate of uptake is based on the highest GII score • The UK-specific adoption rate is delayed in reaching full AI adoption based on the UK's score vs. the highest score	WIPO, Cornell, INSEAD 2017 Global Innovation Index
Profile of AI uptake	• We have assumed an 'S-shaped' profile of AI uptake for the UK between 2017 - 2030, where some countries only reach the 'end' of the S-curve many years later, depending on their rate of AI uptake from the GII • The uptake scale and rate refers to the conceived advancements between 2017-2030, and does not refer to all future AI advancements. The study does not make predictions about the impact and state of the world beyond 2030	PwC analysis
Consumption-side impacts	***Personalisation:*** • We converted the AI index (AII) personalisation scoring to a percentage impact on variety of goods based on a number of Willingness-to-Pay and Welfare studies in the literature. Our conversion was as follows: 1 = 0%, 2 = 1.54%, 3 = 6.2%, 4 = 13.8%, 5 = 24.6% • We interpolated between these points using a second order polynomial • Personalisation captures both the increase in utility from existing goods and variety of new goods. This allows us to proxy personalisation with increased goods variety in the CGE model ***Time saved:*** • We used data on sleeping hours in the UK to estimate the increase in time saved as defined by the AII (in hours/year based on frequency of activity): 1 = 0:00, 2 = 2:00, 3 = 8:00, 4 = 180, 5 = 730 • Agents are given the 'option' to work more in the model, but in reality are not taking it as the change in relative wage is not dramatic enough, causing labour supply to shift ***Utility:*** • This is the increase in marginal utility associated with a percentage increase in 'quality' as defined by the AII • We have assumed the following scoring mechanism: 1 = 0%, 2 = 6.25%, 3 = 12.5%, 4 = 25%, 5 = 50% where the % increase is in marginal utility. We have interpolated between these points using a polynomial of order 4	"Made-to-order: The rise of mass personalisation," Deloitte 2015 Sleep alarm app data PwC analysis
Automation impact on productivity	• The marginal impact of automation on labour productivity is constant over the period per industry in the UK, where we proxy the AI impact using the available data on emerging (smart) technologies and productivity, as well as other data series used to isolate the effect of automation on labour productivity	PwC analysis EU and World KLEMS data

Scope of the study

It is important to note that whilst our study has aimed to capture the size of the economic impact of AI between now and 2030 (as measured by Market Exchange Rate measures of GDP), we have not comprehensively evaluated the following aspects of the economy and how they might change as a result of AI:

- Inequality impacts of AI
- Potential market failure and implications for redistribution resulting from AI
- Optimal government policy resulting from AI
- Welfare impacts of AI

Despite this, we recognise that AI will have wide-ranging impacts on different groups of households and firms within the UK – and globally – where for some these impacts may be more positive or negative than for others. However, the scope and aim of this study has been to estimate the aggregate economic (GDP) impact of AI following from the key channels of its impact (productivity and product enhancements).

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