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Will Artificial Intelligence qualify as a General Purpose Technology (GPT)? Can the theory of GPTs be used to predict the potential impacts on labour productivity and employment of AI?

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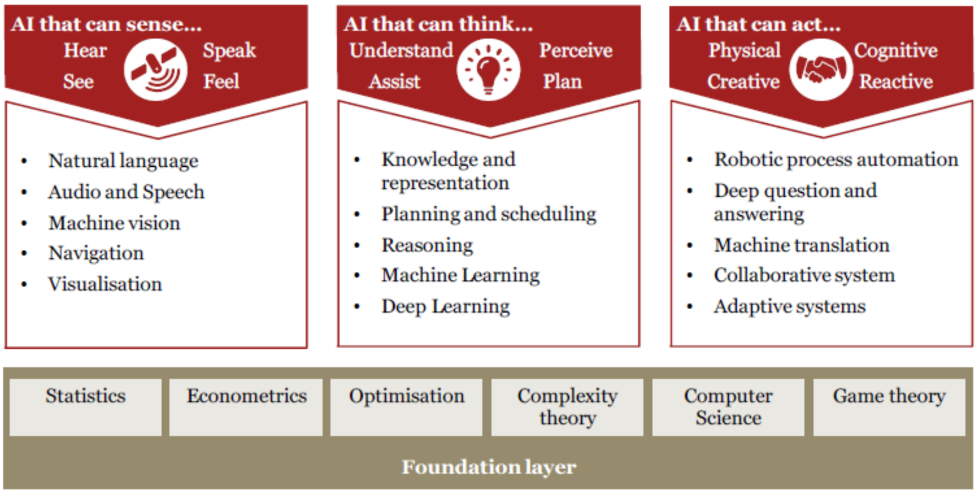
Abstract

General Purpose Technologies (GPTs) are new methods of producing and inventing which have a significant aggregate effect on the economy. This paper tests if Artificial Intelligence is likely to qualify as a GPT in the future and uses this as a framework to predict its potential economic impacts, especially relating to labour productivity and employment. It is argued that AI very probably does qualify as a GPT and as such could potentially address the supply-side demographic issues developed economies will face in coming years, especially ageing populations. It is also argued that AI may have consumption side-effects that could generate growth and significant employment. AI innovation will result in new products and processes increasing consumer consumption. Workers displaced by AI automation could be re-employed in growth sectors. While AI will improve productivity as it diffuses through the economy, resulting in technological unemployment (at least in the short-term), studies predicting mass unemployment fail to account for the UK's future demographic challenges and AI-enabled growth effects. Like with other GPTs throughout history, AI may well result in increased long-term employment as the economy restructures.

Introduction

The Oxford English Dictionary (Knowles, 2005) defines Artificial Intelligence (AI) as "The theory and development of computer systems able to perform tasks normally requiring human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages."



PwC. (2018), The macroeconomic impact of Artificial Intelligence (PwC-C, 2018)

Artificial Intelligence (AI) and its numerous potential applications[1] have become a rapidly growing industry[2] which many predict will completely transform the way we live and work, with Microsoft co-founder Bill Gates predicting AI is "on the verge of making our lives more productive and creative." (Gates, 2017)

From an economic standpoint, studies suggest 54% of EU jobs and 375 million global jobs will be impacted by AI automation.[3] This paper aims to test whether AI could emerge as a General Purpose Technology (GPT)[4] and uses the historic diffusion of GPTs to model the potential effects of it on the UK economy, especially relating to productivity[5] and employment. These forecasts are compared to other predictions.

[1]'Does AI qualify as a GPT?' section covers specific examples of potential applications of AI.
[2] Revenues from AI enterprise applications are expected to rise from approximately US $0.8 billion to over US $31.2 billion by 2025 (Forbes, 2018)
[3] According to Frey and Osborne (2013), approximately 47% of total US jobs are at high risk of being automated and analysis by Bruegel of a European application of Frey and Osborne's findings concluded that 54% of EU jobs are also classed as high-risk. Additionally, a report (McKinsey and Company-B, 2018) estimated 375 million jobs worldwide will be affected by AI.
[4] 'What is a GPT?' section covers the meaning of this term and the required characteristics for AI to become a GPT.
[5] References to productivity refer to labour productivity specifically.

What is a GPT?

A GPT describes a new method of producing and inventing, which has a protracted aggregate impact (Jovanovic and Rousseau, 2005) like electricity, ICT and steam.[1] For AI to have a significant economic impact, it would need to develop into a GPT. GPTs are not new phenomena; there have been multiple per millennium over the last 10,000 years. The rate of diffusion of GPTs has been accelerating and 23 transforming GPTs have been identified[2].

Bresnahan and Trajtenberg (1996) identified 3 main characteristics for a technology to qualify as a GPT:

1. **Pervasiveness** – The GPT is used in a wide range of downstream sectors.
2. **Improvement –** The GPT should get better over time, increasing efficiency and hence experiencing reductions in its price/performance ratio.
3. **Innovation** – Complementary innovations mean that the GPT should make it easier to produce new products or processes.

Evidence suggests that the introduction of GPTs into an economy results in increases in productivity growth[3], so if AI does develop into a GPT, productivity growth can be expected.

Does AI qualify as a GPT?

Comparing the characteristics of AI to two of the most pervasive and recent GPTs, Electrification and Information & Communication Technology (ICT)[4] can provide an assessment of whether AI has the potential to be a GPT. This assessment is done using UK data: You need to reference all the information in this table.

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[1] The aggregate effects of GPTs on economies can be investigated, for example:

- Electrification – took 50 years to go from a crude and narrowly applied technology to a GPT impacting the entire economy, especially as technological problems were solved, uses expanded and a range of new products and industries resulted.

- Information and Communication Technologies (ICT) – has had a significant productivity effect which is increasing over time. In order to boost productivity ICT has to be embedded in complementary organisational investments.
- Steam engine – transformed Britain from an agricultural society and resulting new wealth ushered in the age of the entrepreneur. Initially the steam engine only performed tasks that were already done with existing technologies, so it only began to become a GPT as new uses emerged.

[2] According to Lipsey et al (2005) there have been 23 GPTs throughout history (from the domestication of plants and animals (9000-7500 BCE) and the steam engine (late 18th to early 19th century) to the Internet (20th century)) and they predict nanotechnology will also become a GPT in the 21st century.

[3] Basu and Fernald (2006) found a positive correlation between ICT investment in the US economy and the Total Factor Productivity accelerations of the 2000s. Additionally, Crafts (2003) found that the introduction of Steam had the greatest impact on productivity in the UK in the second half of the 19th century. However, it is important to note that as pointed out by David (1999), the productivity benefits of GPTs have a lag effect and productivity improvements do not appear immediately.

[4] Whereas there has been some debate on whether Electricity and IT are GPTs, this has now been generally accepted. Numerous studies have compared the aggregate effects of both technologies. Jovanovic and Rousseau (2005) assessed Electricity and IT as GPTs and found that the similar except in the rate of resulting productivity growth. Morin (2014) compared the ability of Electricity and IT as GPTs to substitute jobs in the first half of the 20th century and the second half of the 20th century respectively. Finally, Electricity and IT are identified by Lipsey et al (2005) in their book on GPTs and Economic Transformations as two of the 24 transforming-GPTs of history.

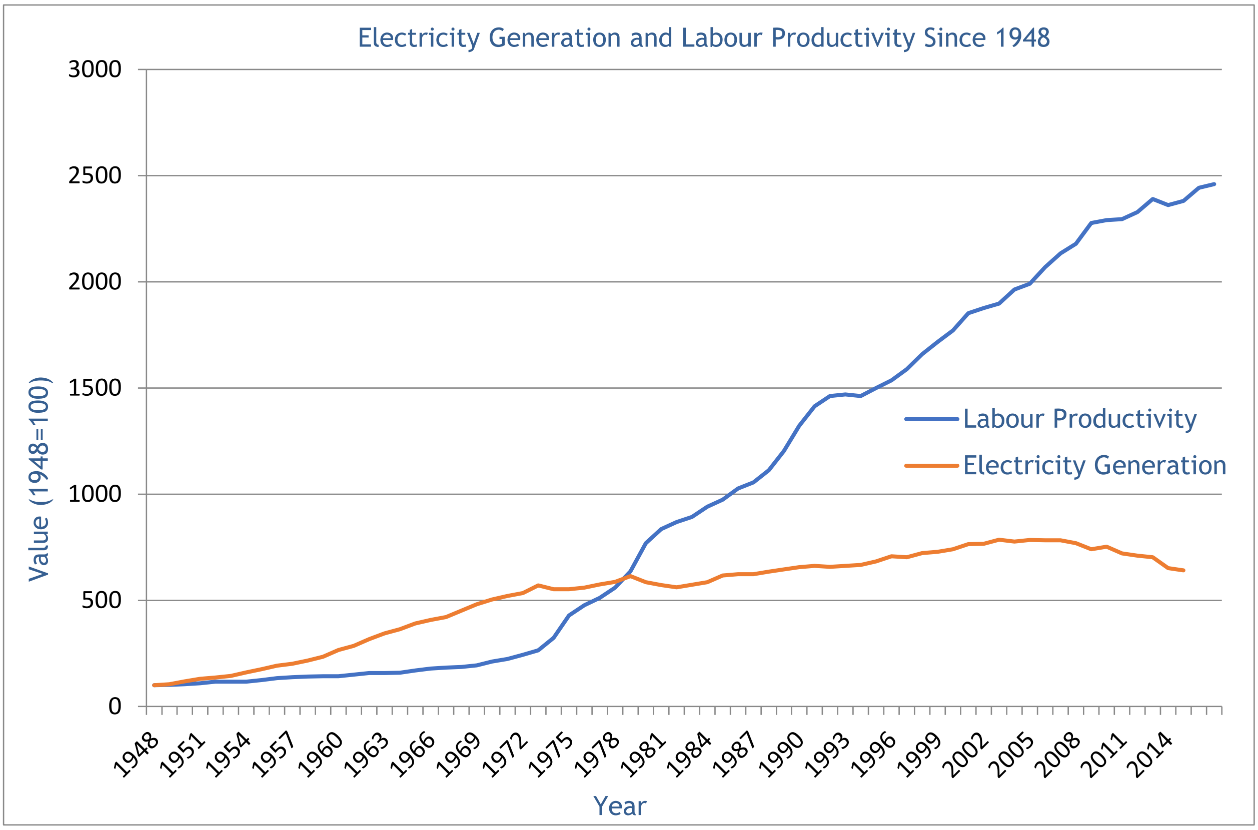
Technology:	Features of GPTs: Pervasiveness	Improvement	Innovation
Electrification	• Electricity 17.5% of energy consumption (Department for Business, Energy and Industrial Strategy-B, 2016) • Electricity 22% of domestic use and 19% business use (Department for Business, Energy and Industrial Strategy-B, 2016)	• Real price/KWh of electricity reduces from £25.74 to £5.37 between 1920 and 1990 (Department for Business, Energy and Industrial Strategy-B, 2016)	• Electric lighting / Appliances • Communications: Telegraph / Telephone • Broadcast: Radio / TV
ICT	• 84% of businesses and 90% of households had internet access in 2016 (Office for National Statistics-B, 2018) • 76% of adults had a smartphone (Office for National Statistics-B, 2018)	• Price of IT devices, adjusted for quality and inflation declined 16% a year on average (1959 - 2009) (en.wikipedia.org, 2018)	• Personal Computers • Office software (word processor, spreadsheet) • Smartphone
AI (potential)	• PwC predicts that AI could increase UK GDP by up to 10.3% by 2030 (PwC-C, 2018) • Accenture forecasts that AI could increase growth rates from 2.5% to 3.9% in 2035 (Accenture, 2016) • PwC's analysis suggests up to 30% of jobs could be at risk of automation by 2030 (PwC-C, 2018) • A sector-based analysis by McKinsey and Company (2017: 46) showed that between 41-56% of global wages could be automated (McKinsey and Company-B, 2018)	• Error rate in human-level image and speech recognition reduced to 5% (PwC-C, 2018) • Data is being used to train AI systems - 90% of all data has been created in the last 24 months (PwC-C, 2018) • Graphical Processing Units (GPUs) are providing the processing power - 60x improvement in 3 years (McKinsey and Company-B, 2018)	• Autonomous cars and trucks • Unmanned aircraft • Humanoid robots • Medical diagnosis • Speech and image recognition • Drug discovery and toxicology • Gene analysis

AI shares many characteristics with Electrification and ICT and could diffuse rapidly through the economy, developing into a GPT[1].

[1] A number of studies, including Trajtenberg (2017), have concluded that AI will become a GPT and it will bring about a wave of complementary innovations, sweeping transformative processes and widespread economic disruption. The extent to which this occurs will in part be dependent upon the future improvement in AI technology and the development of human-like capabilities. As these capabilities develop, AI could diffuse rapidly through the economy, become pervasive and develop into a GPT.

Modelling AI's Productivity Impact

Assuming AI develops into a GPT it will have an aggregate impact. According to Bresnahan & Trajtenberg (1992), as a GPT diffuses through the economy, it brings about generalised productivity gains. The likely productivity effect of AI in the UK can be modelled using the diffusion rate of the two most recent GPTs – electricity and ICT[1].



Electricity Generation and Labour Productivity Since 1948 (Office for National Statistics-D, 2017 and Department of Business, Energy and Industrial Strategy-A, 2017)

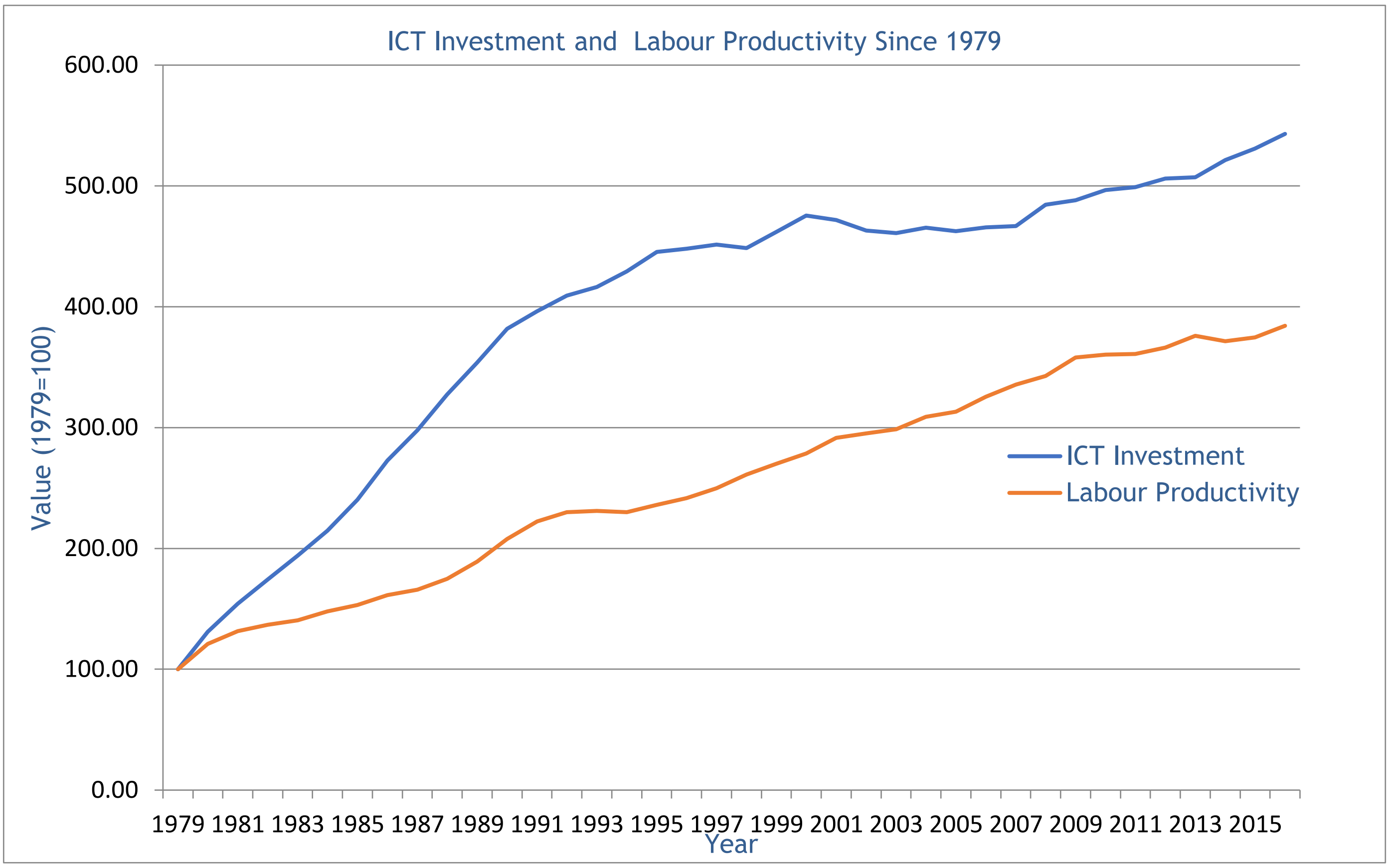
Plotting electricity generation against productivity since 1948[2], a clear time lag can be seen between the diffusion of electricity into the economy and resulting aggregate productivity gains[3]. Initial growth in electricity generation (1948-1972) can be seen to have had little effect

[1] A number of studies have shown that there have been similarities in the diffusion and economic effects of previous GPTs, such as electricity and ICT. Chen et al (2016) proposed diffusion rates as a basis to forecast the economic gains from AI. Forecasts were developed using diffusion rates for AI sector investments, IT Investment and adoption rates for Broadband and Internet, mobile phones and industrial robots. Jovanovic & Rousseau (2005) compared the US economic effects of electrification and IT and found that both delivered productivity improvements albeit at different rates, but observed that "Electrification and IT adoption are manifestations of the same force at work, namely the introduction of a GPT".

[2] Plotted using productivity figures from the Office for National Statistics and electricity generation figures from the Department of Business, Energy and Industrial Strategy (all subsequently converted into index numbers).

[3] Initially hypothesised by David (1999), it is now well documented that a GPT does not deliver productivity gains initially upon arrival, only when it becomes increasingly pervasive, improves and is used to produce new products or processes.

on labour productivity; however, from 1972 labour productivity growth can in part be attributed to electricity.



ICT Investment and Labour Productivity since 1979 (Office for National Statistics-D, 2017, Office for National Statistics-B, 2018 and Bank of England, 2001)

Plotting ICT investment against labour productivity it is more difficult to observe the same relationship due to relatively constant productivity growth over the period since 1979. Initial rapid growth in ICT investment (1979-1989) may have supported the continued labour productivity growth rate later (1990+) despite supply-side issues[1] (observed time lag similar to other GPTs). ICT also diffused through the economy at a slower rate than electricity[2].

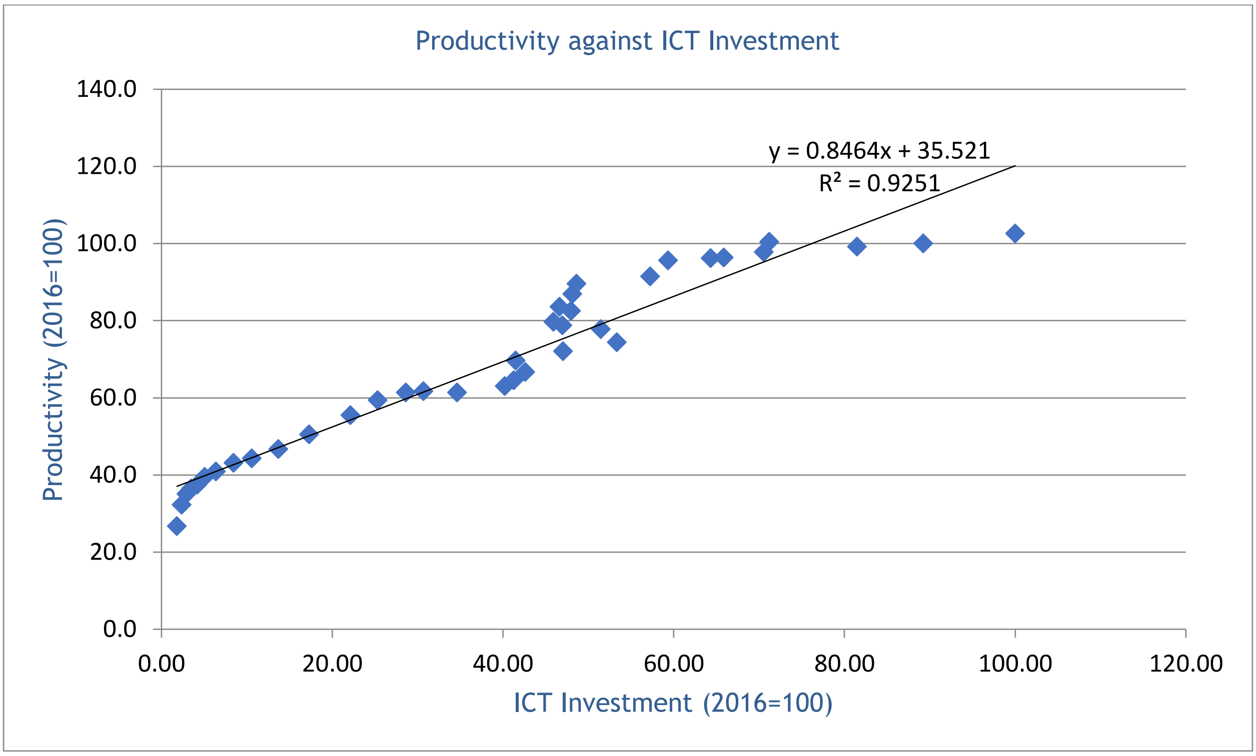
The earlier part of the graph seems to affirm Solow's Productivity Paradox, which was first suggested in 1987[3]. This can be seen in the rapid initial rise in ICT investment having little aggregate effect on productivity growth over the same period.

[1] Factors such as an ageing population, generally falling interest rates (which allows unproductive companies to remain competitive and not go bust) and falling investment have meant that it could be argued that ICT facilitated much of the productivity growth shown in the period on the graph as without the introduction of this GPT, productivity growth would have suffered significantly.

[2] Jovanovic and Rousseau (2005) studied and compared the aggregate impacts of electrification and IT and concluded that electrification and IT are manifestations of the same force at work, the introduction of a GPT. They found that ICT is diffusing into the economy at a slower rate (hence less effect on annual productivity changes) than electricity and additionally the productivity slowdown is greater in the IT era, as shown by the graphs.

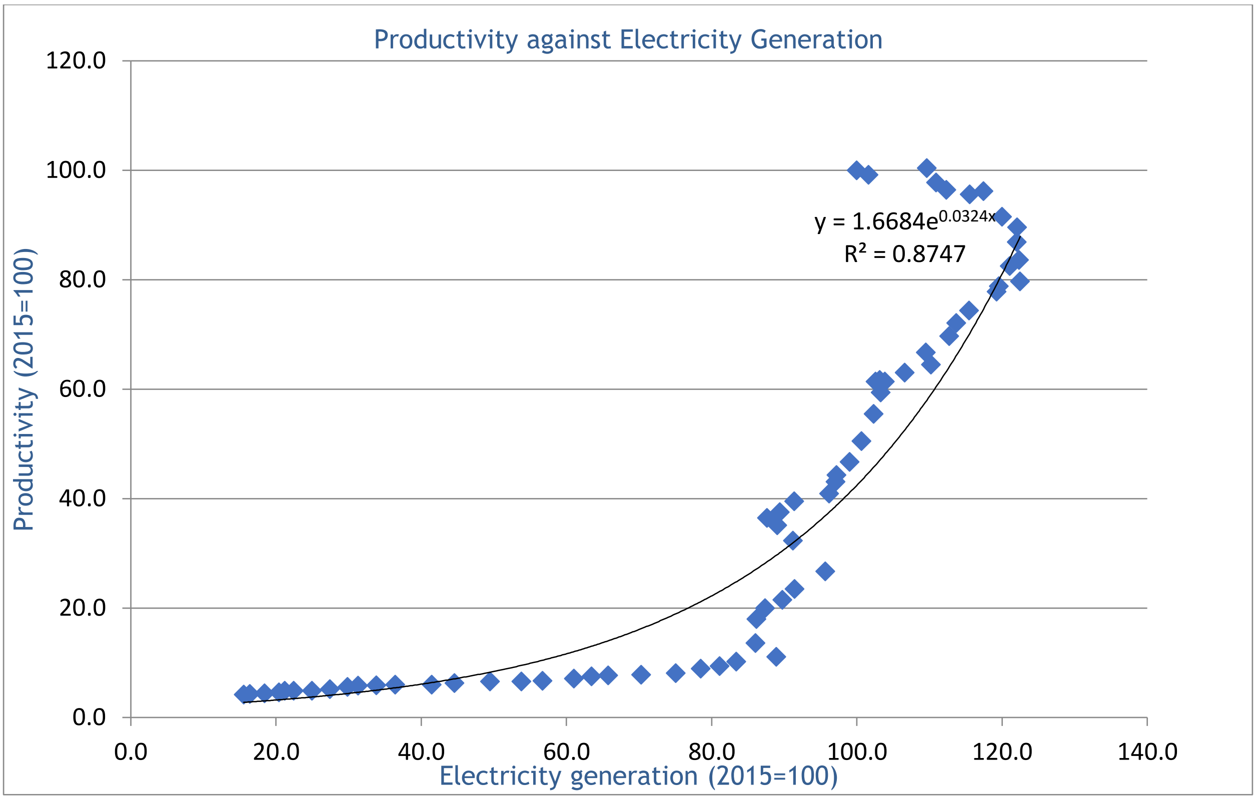
[3] Robert Solow (1987) suggested that ICT diffusion could be seen everywhere in the economy but in the productivity statistics.

Regression analysis has been used to determine the relationship between electricity, ICT and productivity over the period[1], suggesting a linear relationship between ICT and productivity and an exponential relationship between electricity and productivity.



Productivity against ICT Investment (Office for National Statistics-D, 2017, Office for National Statistics-B, 2018 and Oulton, 2001)

[1] Indexed productivity was plotted against indexed electricity generation and ICT investment. Using different regression techniques in order to find potential relationships (e.g. exponential and linear), and calculating the corresponding R-squared values, the relationships between these variables was determined. An exponential relationship between electricity generation (x) and productivity (y) was determined in the form $y = ke^{cx}$ where k=1.67 (3sf) and c=0.0324 (3sf). A linear relationship between ICT investment (x) and productivity (y) was determined in the form $y = bx + a$ where b=0.846 (3sf) and a=35.5 (3sf). This was then used to predict the productivity impact of AI using the diffusion statistics of electricity and ICT.

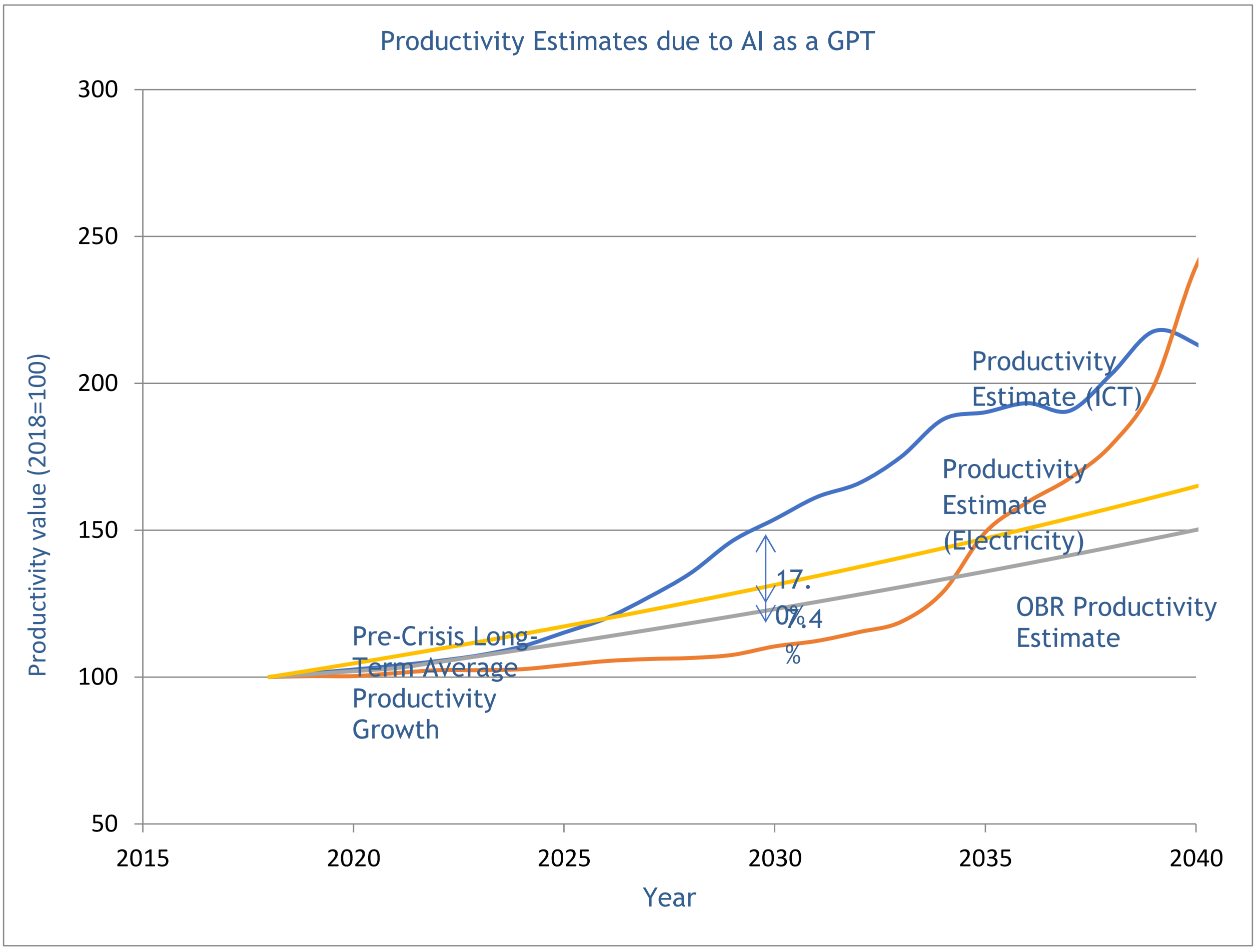


Productivity against Electricity Generation (Office for National Statistics-D, 2017 and Department of Business, Energy and Industrial Strategy-A, 2017)

Assuming AI diffuses through the economy at the same rate as electricity, the starting point of large-scale adoption of electricity and AI can be used to forecast the productivity impact based upon electricity diffusion[1]. For ICT, forecast spending on AI can be used to forecast the productivity impact using the developed linear model[2].

[1] AI began to be implemented within the technology sector in the early 1980s (while most of this success was primarily due to increasing processing power associated with AI and was heavily isolated to use on specific problems within technology, this was the start of significant commercial usages of AI) with the introduction of expert systems. This was at similar levels of initial diffusion as the usage of electricity in the early 1920s, especially the use of electric motors to assist the production process. Therefore, assuming AI as a GPT may follow a similar diffusion pattern to electricity, using diffusion rates from 1920 as a basis can be used to predict the diffusion (and resulting productivity effects) of AI. AI generation in 2018 (approximately 38 years of diffusion) can be modelled using electricity generation in 1958 (approx. 38 years from 1920s). Assuming AI diffusion continues to follow the same pattern, its generation and therefore resulting productivity impacts (using the exponential equation above) can be predicted.

[2] Using analysis from the International Data Corporation (2018) on worldwide spending on AI systems, it can be seen that the rapid growth in such investment experienced today (and the forecasted reduction in the rate of growth in coming years) is similar to that of ICT investment in the late 1970s to early 1980s. Therefore, assuming AI spending has the same impact as ICT spending, the linear relationship $y = bx + a$ used to predict the productivity effects of AI investment and diffusion.



Productivity Estimates due to AI as a GPT (Office for National Statistics-D, 2017 and Department of Business, Energy and Industrial Strategy-A, 2017, Office for National Statistics -B, 2018 and Oulton, 2001)

The OBR Estimate and Pre-Crisis Long-term Average productivity growth are assumed to be the baseline level of productivity without the effect of AI[1].

Using the ICT-based forecast, additional productivity growth in the UK (due to AI) is forecast to be 17.0%-24.9% in 2030 rising to 29.4%-42.2% in 2040 as AI diffuses through the economy.

Using the electricity-based forecast, AI-related productivity growth is calculated to be a loss of 10.3%-15.9% in 2030 rising to a gain of 45.4%-59.8% in 2040 as AI diffuses through the economy.

[1] A baseline level of productivity is required based upon the case where AI had not diffused through the economy. The Office for Budget Responsibility productivity over the period from 2018 is assumed as one estimate (OBR, 2018). The pre-crisis long-term productivity growth average is assumed to be another. Additional productivity growth shown on the model must therefore result from the introduction of AI as a GPT. In order to compare this model to others, these are taken as potential productivity baselines with added productivity therefore assumed to be due to the introduction of AI as a GPT (which can then be compared to other estimates).

The low rate of UK productivity growth in the post-war 1940s and 50s may be more related to factors such as re-building the economy[1] (unrelated to GPTs). Therefore, the low forecasted productivity is unlikely to occur. There may also be other changes during these periods unrelated to the introduction of these GPTs, reducing the reliability of the model (e.g. privatisation making firms more productive).

Employment Predictions

The significant forecasted productivity improvements should, in the short-term, result in rising unemployment from the diffusion of AI as a GPT[2]. However, longer-term, other sectors should grow and develop, leading many of these unemployed workers to find new jobs, reducing unemployment. The 19th century shift from agriculture-based employment in the US illustrates this[3].

This suggests that many of the predictions that AI will lead to long-term mass unemployment are unfounded. Most likely, short-term technological unemployment will occur until the economy restructures, as with other GPTs.

Comparison with other forecasts

The few UK studies[4] into the impacts of AI have a range of likely productivity improvements from 2030 – 2035 of between 1.9% and 20% of GDP[5].
McKinsey's productivity growth estimates are in a similar range to those forecasted using ICT as a basis for AI diffusion (24.9% compared to 25%), while Accenture estimates are broadly aligned with those calculated using electricity (9.8% compared to 10%). The PwC study's projections are outside of the forecasted range at 1.9%.

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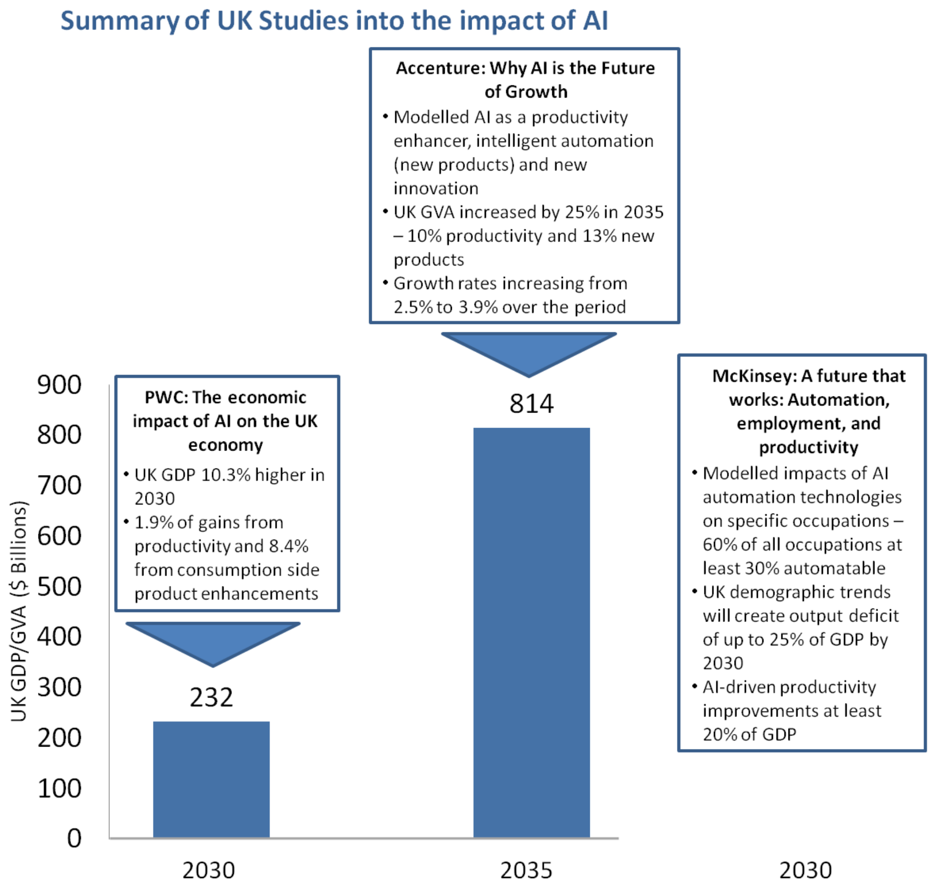
[1] Baily and Kirkegaard (2004) suggest UK post-war productivity was low due to re-building the economy after 2 world wars, chronic high unemployment, the nationalisation of industries and the introduction of the welfare state.

[2] Jobs get automated and workers get replaced, without significant growth in other sectors to accommodate these displaced workers. However, this is not a prolonged phenomenon, which is shown by the Luddite Fallacy: the observation that new technology does not lead to higher unemployment in an economy.

[3] Increased used of machinery and automation within agriculture has meant less workers have been required over time. This has led to a reduction in employment within this sector and a fall in the proportion of jobs in this sector. However, this has not resulted in long-term large-scale unemployment. Instead, other sectors (e.g. manufacturing throughout much of the 1900s) grew and absorbed the workers, meaning the automation led to no increase in overall unemployment, the economy simply restructured to accommodate the workers. Some workers can be left without the skills necessary to re-enter the labour market after automation and face extended unemployment, however, overall throughout the economy this is not seen. The same idea can be seen with the decline of manufacturing towards the end of the 20th century, as this was accompanied by the growth of sectors such as professional services, healthcare, education and financial services.

[4] The various studies have used different methodologies to build forecasts and look to assess the impacts from either a GDP (PwC-C, 2018 and Accenture, 2016) or labour impacts (McKinsey and Company-B, 2018). Both the PwC and Accenture studies predict that the largest impacts to UK GDP will be from increases in consumption through the development of new AI-enabled products and services.

[5] The PwC and Accenture studies find that the largest impact(s) will be from increased consumption. The McKinsey study focuses on the impact of Automation on occupations and finds that AI-driven productivity increases are required to counter the effects the shrinking workforce in the UK due to demographics. This forecast suggests that in the UK there would be an FTE gap (number of FTE required to maintain current GDP per capita) of 4% by 2030 driving an economic output deficit against growth targets. It argues that AI-driven automation is actually required meet existing GDP targets. The analysis shows that AI-driven automation would just not fill the output deficit, but also increase GDP by 20% by 2030.

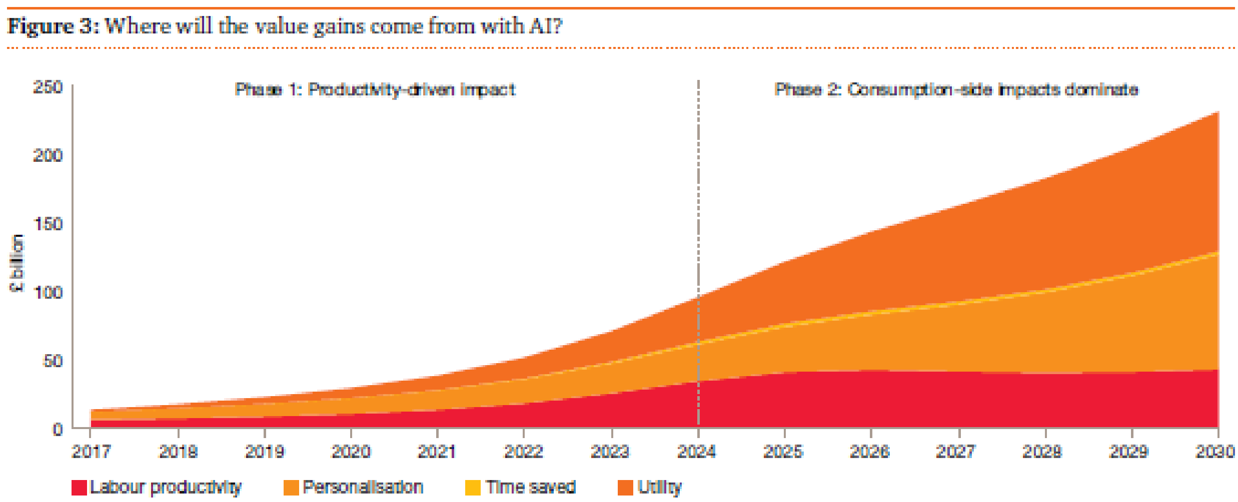


Summary of UK Studies into the impact of AI (PwC, 2018, Accenture, 2016, McKinsey and Company, 2018)

Conclusion

Assuming it qualifies as a GPT (as is likely), AI could potentially address the supply-side demographic issues developed economies will face in coming years, especially ageing populations. For the UK to maintain growth and living standards as the workforce reduces, productivity growth will be necessary. AI-enabled productivity growth may be the answer.

A future that works: Automation, employment and productivity (McKinsey and Company-A, 2017)



The macroeconomic impact of Artificial Intelligence (PwC-C, 2018)

AI may also have consumption side-effects that could generate growth and significant employment. AI innovation will result in new products and processes increasing consumer consumption as they look to consume these. Labour is a derived demand from that of products, so this should lead to increased employment. Workers displaced by AI automation could be re-employed in growth sectors.

AI will improve productivity as it diffuses through the economy resulting in technological unemployment, at least in the short-term. However, the many studies predicting mass unemployment fail to account for the UK's future demographic challenges and AI-enabled growth effects. Like with other GPTs throughout history, AI may well result in increased long-term employment as the economy restructures.

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