1 DEFINITION OF AI AND LITERATURE REVIEW OF ADOPTION AND EXPENDITURE

In this chapter, we review the definitions of AI used in the existing literature and define AI for the purposes of this report and modelling exercise. The section also includes a review of evidence on the current scale and nature of the use of AI in businesses globally and in the United Kingdom specifically.

1.1 Definition of AI

In broad terms AI refers to the simulation of human intelligence processes by machines; it is a technology process that can learn from experience. However, there is no clear-cut unifying definition of AI and which technologies it encompasses. There are four key aspects that make it hard to develop a single, comprehensive definition of AI.

First, AI is evolving, making definitions more complicated. Rapidly increasing computing power has made it possible to compile and share ever larger volumes of valuable data, enabling the application and development of AI beyond fundamental research.[1] Today, it can be found in smartphones or in self-driving cars. It is used across industries to optimise processes and has helped governments to combat the COVID-19 virus last year.[2]

Second, there isn't agreement on what falls into the bracket of 'intelligent'. Generally, dictionary definitions of intelligence rely on relating it to human intelligence and they are as yet unable to characterise in general what kinds of computational procedures should be called intelligence. Some, such as Dr Kate Crawford, senior principal researcher at Microsoft Research, even argue that AI is not intelligent at all.[3] Over time, as the way companies use AI changes and people become accustomed to previous advances, perhaps the idea of what intelligence means will evolve.

Third, AI can seldom be regarded as a stand-alone technology, and it does not have clear-cut boundaries. It ranges from software, such as voice assistants or facial recognition, to hardware-embedded systems, including robots or autonomous vehicles. Taking the example of self-driving cars, it becomes clear how AI software is embedded into non-AI technology, which makes it hard to disentangle.

[1] McKinsey (2017), *Artificial Intelligence – the next digital frontier?*.
[2] IBM (2020), *Artificial Intelligence (AI)*, Available at: https://www.ibm.com/cloud/learn/what-is-artificial-intelligence [Accessed August 2021].
[3] Crawford, K. (2021), *Atlas of AI - Power, Politics, and the Planetary Costs of Artificial Intelligence*, New Haven, US: Yale University Press.

We have identified three main internal barriers: financial factors, data challenges, and human traits and enterprise culture. These all act as limiting factors to demand for AI.

Amongst the nearly 10,000 replies from EU companies participating in the EU Commission's European enterprise survey, financial factors posed the biggest internal barrier to the adoption of AI technologies.[22]. Half of respondents stated that the procurement cost of the relevant technologies as well as the subsequent operational costs posed a challenge for them. Results for the UK are similar to the EU average. Two in five respondents to a survey by CDEI spanning nearly 1,000 firms already using AI and data-driven technologies (DDT) named lack of funds to purchase or develop further technologies as a barrier.[23] SMEs in the UK struggled particularly with the procurement costs of AI technologies, with a quarter of micro firms and 13% of small and medium-sized firms highlighting the cost barrier in a 2019 survey of 1,500 firms by Be the Business.[24]

A second financial factor inhibiting the adoption of AI across firms is the uncertain return on investment (ROI) and the measurement of AI induced benefits. While revenue increases or time saved could be easily quantified, an improved customer experience arising from the adoption of AI is difficult to measure accurately. Having surveyed 3,000 global CIOs in 2019, Gartner found that 42% did not fully understand the benefits and uses of AI in the workplace.[25] A study by ESI Thought Lab found that for many of the 1,200 firms surveyed across 15 countries, calculating the ROI on AI was still an art, not a science; 79% of surveyed firms that had reported negative or no ROI had no system in place to measure returns.[26] This lack of understanding and performance metrics could explain the widespread scepticism the MAPI Foundation found amongst 200 US manufacturing firms on achieving sufficient ROI from AI solutions. In their 2019 study, 40% of respondents cited this as a key barrier.[27] Consequently, an uncertain ROI depresses demand for AI.

The second main barrier to adoption of AI technologies cited by firms can be classified as 'data challenges'. Growth in the adoption of AI technologies across economies has been found to be inhibited by legacy infrastructure; existing information systems are often not structured to facilitate advanced analytics. Legacy infrastructure mainly poses a challenge for firms at the beginning of the AI adoption journey. The European enterprise survey found that 42% of companies not currently using AI technologies cited insufficient or incompatible existing IT infrastructure as a major barrier to AI adoption.[28] The findings are supported in the UK by evidence from the roughly 400 respondents to a survey by EY that existing infrastructure is the current biggest internal barrier to the improvement of data foundations and subsequent implementation of AI solutions, especially for large companies.[29]

[22] Definition of external and internal barriers differ slightly between European Commission study and this current work, some separate categories were grouped together, for example, categories 'lack of public or external funding', 'cost of adoption', and 'cost of adapting operational processes' have been combined into one barrier named financial factors.
[23] CDEI (2021), *UK Business Innovation Survey.*
[24] Be the Business (2019), *The UK's Technology Moment – why 2020 can be the year that changed our trajectory.*
[25] Gartner (2019), *3 Barriers to AI Adoption,* Available from: https://www.gartner.com/smarterwithgartner/3-barriers-to-ai-adoption/ [Accessed July 2021].
[26] ESI ThoughtLab (2021), *Driving ROI Through AI. AI best practices, investment plans, and performance metrics of 1,200 firms*.
[27] MAPI Foundation (2019), *The Manufacturing Evolution: How AI Will Transform Manufacturing & the Workforce of the Future,* Available at: https://static1.squarespace.com/static/58862301f7e0ab813935c244/t/5d48788e7b132300013f15b0/1565030557296/MAPI-ITIF-AI-workforce-report-F.pdf [Accessed July 2021].
[28] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[29] EY (2021), *Data foundations and AI adoption in the UK private and third sectors.*

Even if a firm is not struggling with legacy infrastructure, successful AI adoption relies on it having a well-functioning data ecosystem. Companies need to have reached sufficient data sophistication to be able to break down data silos, and to have the capability to aggregate, pre-analyse, and identify high-value data. This is because factors such as data completeness, relevancy, and bias will affect the output value and overall quality of an AI system. Firms in the European Union seem to have recognised the need to improve data processes before moving into the use of advanced technologies to leverage the data's potential. Only one fifth of respondents cited lack of internal quality data as a major obstacle in their implementation of AI technologies – with a greater share of non- AI technology adopters than AI adopters considering this a challenge.[30]

The barriers to AI adoption relating to data ecosystems vary by company size. According to findings from IBM's Global AI Adoption Index 2021, surveying 5,500 IT professionals, difficulty collecting data represents the largest hurdle for small firms. Conversely, the biggest barrier for large firms was related to increasing data complexity and data silos, which inhibit the transparent and efficient flow of information across the firm. [31] In the UK, access to quality data and data management remain a key concern amongst companies, according to the Business Innovation Survey. Half of respondents were concerned about the former and nearly three quarters stated fragmentation of data across different sources as a challenge in their internal processes. Given that a solid data ecosystem is a prerequisite for the adoption of (further) AI technologies, this represents a drag on AI adoption growth in the country.

Lastly, company culture and typical human traits can stand in the way of the adoption of new technologies. Few surveys attempt to capture these factors. As creatures of habit, humans can be reluctant to change their method of doing things once they have found a way they deem effective and efficient. Considering technology specifically, there is often a fear of human redundancy. The difficulty in understanding and predicting decisions made by computer algorithms can lead to a feeling of loss of control amongst the workforce and can generate a negative perception of new technologies.[32] For example, today AI is already capable of evaluating X-rays as well as radiologists can in research settings. If this technology is adopted by healthcare providers more broadly, the role of radiologists will have to transform.[33] These general human tendencies often translate into either failing to see the need for AI, or an incomplete understanding of technologies' advantages.

For these reasons, support for AI adoption amongst leadership staff is required to ensure a broad company stakeholder buy-in and to avoid unnecessary frictions.[34] Top management support ensures that sufficient organisational resources are employed in the adoption of new technologies and helps reduce organisational resistance.[35] In the UK, lack of management sponsorship of AI was cited as one of the least pressing barriers

[30] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[31] IBM Watson and Morning Consult (2021), *Global AI Adoption Index 2021*.
[32] Marr, B. (2019), *The 4 biggest barriers to AI adoption every business needs to tackle*, Forbes, Available at: https://www.forbes.com/sites/bernardmarr/2019/02/25/the-4-biggest-barriers-to-ai-adoption-every-business-needs-to-tackle/?sh=670f7b452731 [Accessed August 2021].
[33] Gartner (2019), *3 Barriers to AI Adoption,* Available from: https://www.gartner.com/smarterwithgartner/3-barriers-to-ai-adoption/ [Accessed July 2021].
[34] Forbes (2019), *The 4 Biggest Barriers To AI Adoption Every Business Needs To Tackle*, Available at: https://www.forbes.com/sites/bernardmarr/2019/02/25/the-4-biggest-barriers-to-ai-adoption-every-business-needs-to-tackle/?sh=3e5b4bb92731 [Accessed July 2021].
[35] Yoon, T. E., & George, J. F. (2013), *Why aren't organizations adopting virtual worlds?*, Computers in Human Behaviour, 29(3), 772–790. https://doi.org/10.1016/j.chb.2012.12.003.

by firms. Respondents had broadly accepted the need for the adoption of data driven technologies, which could reflect positively on AI adoption rates over time.[36]

2.2 External barriers

External barriers are hinderances to the adoption of AI that are outside a firm's immediate control. Amongst those most frequently cited in the literature surveyed for this study are labour supply constraints, the regulatory framework, and ethical considerations.

First, the most cited external barrier to the successful adoption of AI technologies was the lack of AI and data science skills amongst existing employees and a shortage of talent in the wider workforce in both EU and UK surveys.[37] These shortages constrain the supply of AI technologies. AI technologies require workers who are educated and trained not just to develop, but also to maintain and troubleshoot AI systems. In addition, it requires people without the technical ability, but who understand how and where the use of AI technologies could improve the business process. A skilled workforce generates trust in AI and will reduce the impact of some of the anxieties and organisational cultural influences mentioned above around the adoption of AI.[38] This will ultimately have an impact on demand for AI technologies, if AI systems are more widely trusted and accepted.

The three key relevant skills lacking amongst the EU workforce were programming, big data management, and machine learning or modelling skills. Needs for the first were more pronounced in the financial and insurance sector, where 59% of firms highlighted an undersupply. Manufacturing firms on the other hand were more likely to report machine learning or modelling skills as being in short supply.[39] [40]

Among existing staff, 55% of AI companies not adopting AI technologies in the EU reported lacking skills relevant to AI – for companies using AI this percentage was considerably less, 28%.[41]

With respect to the external workforce, there is no significant difference in AI adopting and non-adopting firms struggling to fill vacancies with people possessing the right skills. Both face the same job market, with nearly six out of ten firms in the EU highlighting this challenge in the European enterprise survey. However, small firms face an uphill battle competing for talent: they are often unable to offer the rewards needed to attract and retain skilled data scientists, being outbid by larger companies that often already heavily invest

[36] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[37] EY (2021), *Data foundations and AI adoption in the UK private and third sectors*.
[38] European Parliamentary Research Service (2020) *The ethics of artificial intelligence: Issues and initiatives*, Brussels: Scientific Foresight Unit, Available from: https://www.europarl.europa.eu/RegData/etudes/STUD/2020/634452/EPRS_STU(2020)634452_EN.pdf [Accessed September 2021].
[39] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[40] Ipsos Mori (2020) *Understanding the UK AI labour market: 2020*, Available at: https://www.gov.uk/government/publications/understanding-the-uk-ai-labour-market-2020 [Accessed October 2021].
[41] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.

in AI (such as Google, Facebook, Amazon, etc.).[42] This is problematic because small firms require skilled staff to leverage the potential of AI solutions. Currently, 42% of micro firms (<10 employees) reported finding complex algorithms to be difficult to understand and trust. Consequently, the relative advantage of firms who have already heavily adopted AI technologies is extended, and technology adoption differences become more entrenched.[43]

Second, regulatory uncertainty and costs have been quoted by firms across surveys as one of the key reasons why they progressed cautiously in the adoption of AI technologies. In spite of awareness of AI's benefits, for example in claims administration and underwriting in the case of the insurance industry, regulatory uncertainty ultimately acts as a drag on demand for AI technologies.[44]

Uncertainty with respect to the scope and implementation of privacy laws can constrain the adoption of AI for example in the healthcare and finance sectors, where there are strict rules regarding physical, network, and process security measures to ensure sufficient protection of personal data.[45] In the European enterprise survey, both for the EU on average and the UK, strict standards for data exchange relating to privacy laws were cited as a barrier to AI adoption by around one-third of firms. Significant differences in responses from AI adopters and firms planning to adopt AI technologies did not exist, albeit firms with more than 250 employees were more likely to cite privacy laws as a barrier. Compliance with data security and protection guidelines becomes more complicated with scale – the larger the firm, the more likely it reported data security compliance as a major hurdle in the adoption of AI technologies.[46]

Another obstacle in the adoption of AI for firms are uncertainties around the liability for damages that could be caused by the technologies. This is not universally relevant but depends on the business context each company operates in. For automakers and manufacturers as well as healthcare providers, however, it does pose a particular concern.[47] Amongst EU firms, an average of 27% of AI adopters cited this as a considerable barrier to their adoption of further AI technologies, while 38% of non-AI adopting firms were concerned about these liability aspects. In the UK, an average of 30% across firms at all stages of AI adoption mentioned liability as a key challenge.

Moreover, in its third edition of the State of AI in the Enterprise, Deloitte found that nearly 60% of its 2,700 surveyed firms across 9 countries that had adopted at least one AI technology worried about future regulatory directives. Their responses came in light of Canada's 'Directive on automated decision-making' and the EU's 'European strategy for data'. Firms did not oppose further regulation, but 62% feared that ineffective or regressive regulation would be implemented, that would hamper research and stifle innovation. Further, prospective AI companies might be deterred from starting given regulatory uncertainties, limiting the supply of AI technologies on the market. This is something for policymakers to be

[42] Metz, C. (2017), *Tech giants are paying huge salaries for scarce A.I. talent,* New York Times, Available at: https://www.nytimes.com/2017/10/22/technology/artificial-intelligence-experts-salaries.html [Accessed September 2021].
[43] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[44] ESI ThoughtLab (2021), *Driving ROI Through AI. AI best practices, investment plans, and performance metrics of 1,200 firms*.
[45] European Parliamentary Research Service (2020), *The impact of the General Data Protection Regulation (GDPR) on artificial intelligence*, Available at: https://www.europarl.europa.eu/RegData/etudes/STUD/2020/641530/EPRS_STU(2020)641530_EN.pdf [Accessed October 2021].
[46] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.
[47] *Ibid.*

aware of when devising strategies to increase AI adoption amongst firms and encourage the supply of AI technologies. [48]

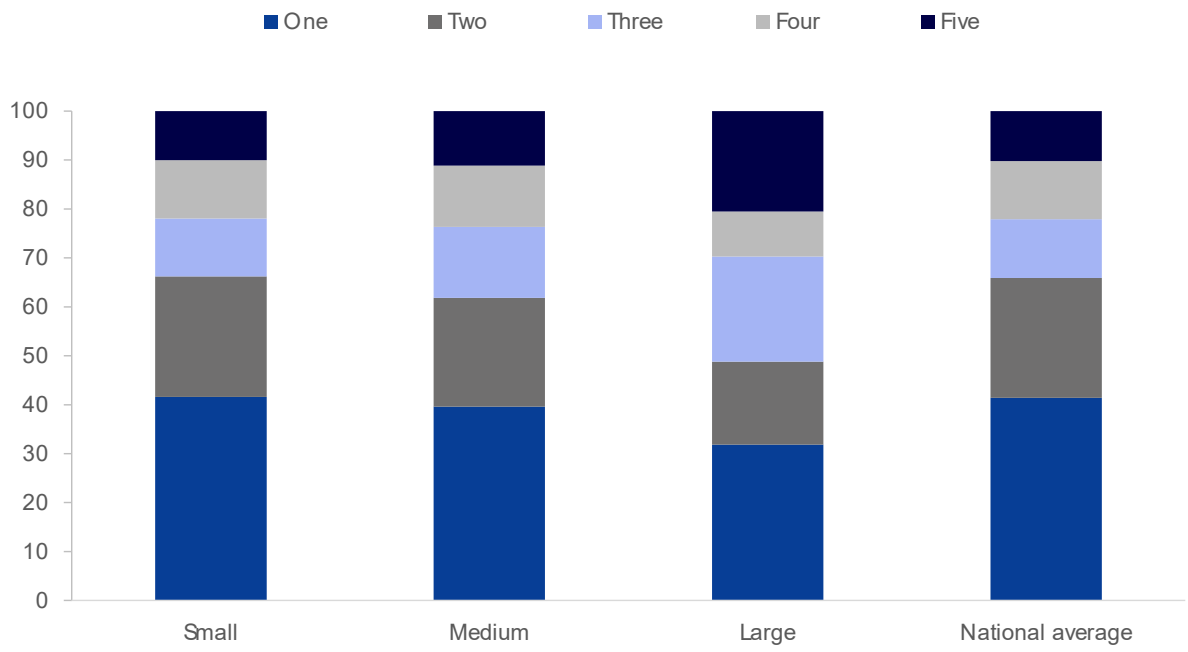
Lastly, 44% of respondents to ESI Thought Lab's survey ranked managing ethical issues of AI adoption as amongst their top three adoption obstacles. Scale and AI maturity increased the likelihood of firms identifying ethics as a major barrier. Concerns revolve around trained biases and algorithmic transparency: the real world is biased in many ways (naming just a few with gender, sexuality, ethnicity, religion), meaning that real-world data will also have these features. With this training data feeding into them, algorithms internalise biases and they become embedded into the technologies – exacerbating the problem of bias.[49][50] In addition, AI's ability to detect patterns in data may pose privacy risks; even when no direct access to personal data is provided, AI has the potential of allowing the re-identification of anonymised personal data in ways that were not foreseen before machine learning capabilities became widespread. Further, there are concerns around the transparency and accountability of algorithms themselves. There is no clear guidance as to which ethical guidelines are being encoded into them, how algorithms have reached their conclusions, and who effectively is responsible for algorithms' outputs.[51] The interdependencies between these issues and the questions regarding liability mentioned in the paragraph above add complexity and complicate the development of universal ethical guidelines.

Together, opacity and lack of explicability and accountability inhibit the creation of trust in AI technologies and thereby slow down demand for and adoption of these technologies amongst businesses. IBM's Global AI Adoption Index[52] for 2021 showed that 58% of respondents considered these factors their third biggest impediment to AI adoption, after lack of skilled staff and data challenges. In the UK, the Business Innovation Survey from 2021[53] found that half of respondents said they had processes in place to address bias and discrimination in datasets, However, around a fifth of respondents still considered they were lacking the in-house skills to ensure appropriate ethical governance, a skills deficit that was a hinderance to their adoption of (further) AI technologies.

[48] Deloitte (2020), *Thriving in the era of pervasive AI. Deloitte's State of AI in the Enterprise*. 3rd edition.
[49] Hao, K. (2019), *This is How AI Bias Really Happens -— and Why It's so Hard to Fix*. MIT Technology Review, 4 Feb 2019
[50] Angwin, J., Larson, J, Mattu, S., and Kirchner, L. (2016), *Machine Bias: There's software used across the country to predict future criminals. And it's biased against blacks*, ProPublica, 23 May 2016.
[51] McKinsey (2017), *Artificial Intelligence – the next digital frontier?*.
[52] IBM Watson and Morning Consult (2021), *Global AI Adoption Index 2021*.
[53] CDEI (2021), *UK Business Innovation Survey.*

four or more AI technologies to assist in their business activities. This translates to 3% and 8% respectively of all firms of that business size in the UK. (See Figure 3.1.)

Figure 3.1: Number of technologies adopted by business size, 2020 (per cent of adopting businesses)



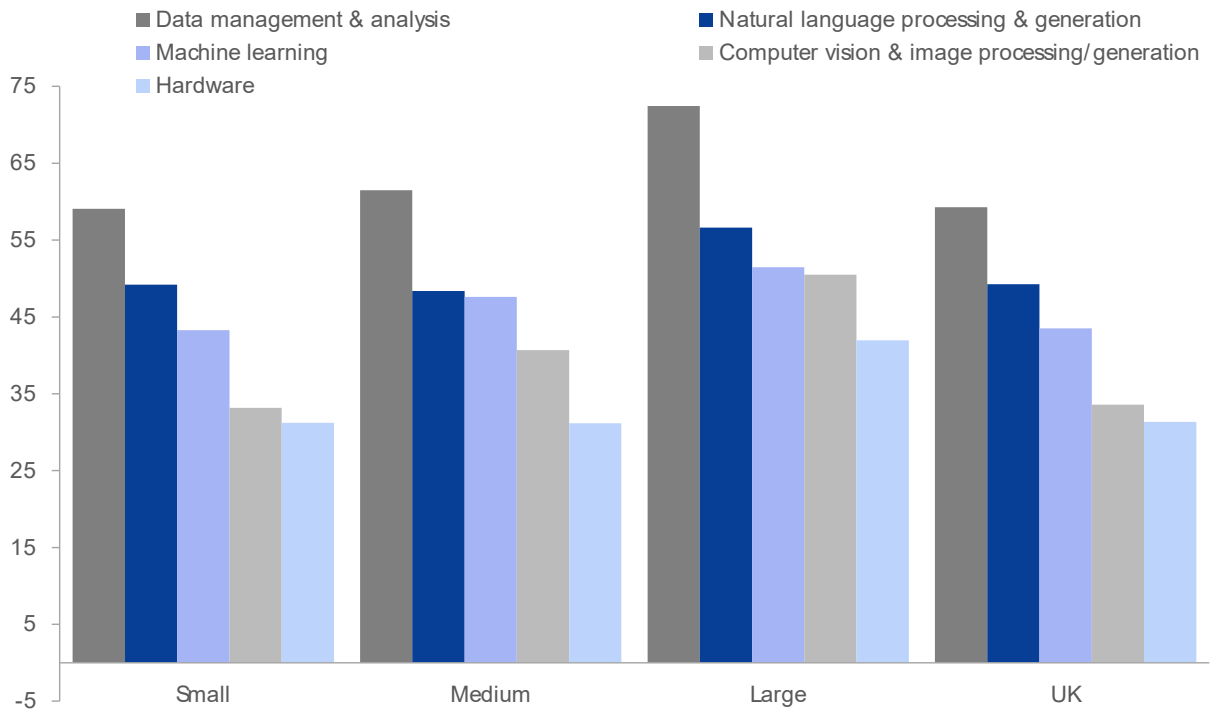
Notes: Sample size of AI adopting firms is 660.
Source: Capital Economics analysis of YouGov survey.

Data management and analysis is the most commonly adopted AI solution, with 60% of all AI adopting companies in the UK, or 256,000 businesses, using it in the past year. The second most prevalent AI solution adopted in our sample was natural language processing and generation, which 213,000 businesses have adopted. Typical use cases here could be in customer service functions, where chatbots and voice assistants streamline customer queries and direct them to the most relevant department or person. (See Figure 3.2)

This trend looks set to continue. Surveyed companies that do not currently use AI, but are planning to, responded most frequently that they were intending to adopt AI solutions for data management and analysis. This equates to 259,000 companies or 89% of current non-AI using businesses that communicated plans to use AI in the future. The adoption of natural language processing technology is the second most frequent response amongst non-AI using companies in the UK; 248,000, or 85% of non-AI using firms intending to adopt any AI in the future, plan on adopting the technology in the future.[64]

[64] Survey respondents could select multiple technologies they intended to adopt in the future.

Figure 3.2: Adoption by technology and business size, 2020 (per cent of UK businesses that have adopted AI)



Notes: Sample size of AI adopting firms is 660. Respondents could select multiple technologies.
Source: Capital Economics analysis of YouGov survey.

Adoption by sector

We can disaggregate results on adoption by business sector. However, the results should be treated with caution as small sample sizes in some sectors mean that estimates were made based on business size across the entire sample.

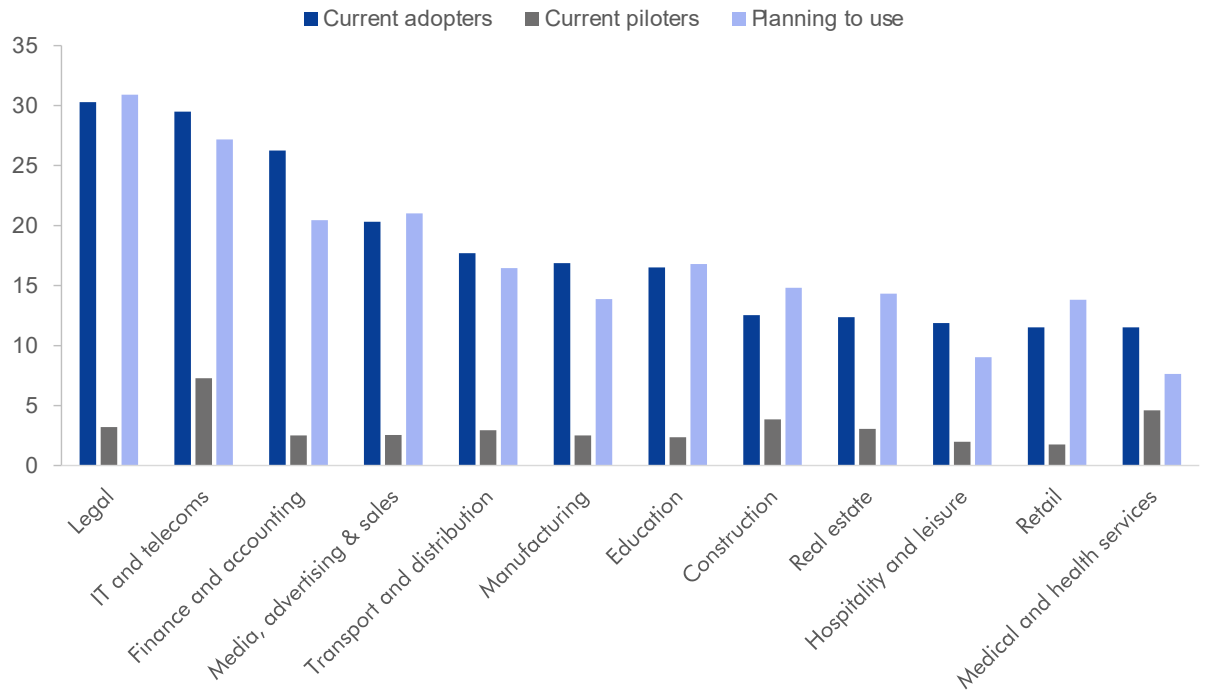
The sectors with the highest shares of businesses currently adopting at least one AI technology are legal and IT & telecoms; both record adoption rates of around 30%. In the legal sector, the uses of AI range from reviewing contracts and legal research to generating forecasts of litigation outcomes.[65] The next highest sectors in terms of adoption rate are finance and accounting as well as the media, marketing, and sales industry.[66] Among other things, AI is used in the latter industry to process data and customer profiles to tailor messages to each client. According to our survey, AI technologies are currently being used least in retail and health services, where around 12% of businesses have adopted at least one AI technology. (See Figure 3.3.)

[65] Emerj (2021), *AI in Law and Legal Practice – A comprehensive view of 35 current applications*, Available at: https://emerj.com/ai-sector-overviews/ai-in-law-legal-practice-current-applications/ [Accessed September 2021].
[66] YouGov sector: Media/marketing/advertising/PR & sales.

These findings are supported by previous work done on AI adoption. In its global survey of 2,400 companies on the State of AI, McKinsey reported the highest likelihood of AI adoption in high-tech and telecom sectors. UK evidence from the 2021 *Business Innovation Survey* equally highlighted that the incidence of AI users was highest in the digital and communications sectors, and lowest in healthcare.[67]

The four sectors with the highest adoption rates (legal, IT & telecoms, finance and accounting, and the media, advertising and sales industry) also have the highest incidence of non-AI users that plan to adopt at least one AI solution in the future. Additional sectors that might see sizeable increases in AI adoption rates in the near to medium term based on their survey responses are transport and distribution, and education. Nearly one fifth of transport and distribution companies are currently employing AI in some capacity, while 16.5% of current non-AI adopters are planning to do so in the future, equating to 14,500 businesses. For the education sector, the adoption rate in 2020 is 17% (or 5,500 firms), with a further 4,500 (or 17% of current non-adopting companies) planning to do so. (See Figure 3.3.)

Figure 3.3: Share of businesses adopting by sector, 2020 (per cent)



Notes: Sample size for adopting and piloting is 2,008; Sample size for planning to adopt is1,349; Excludes 'Other' category.
Source: Capital Economics analysis of YouGov survey.

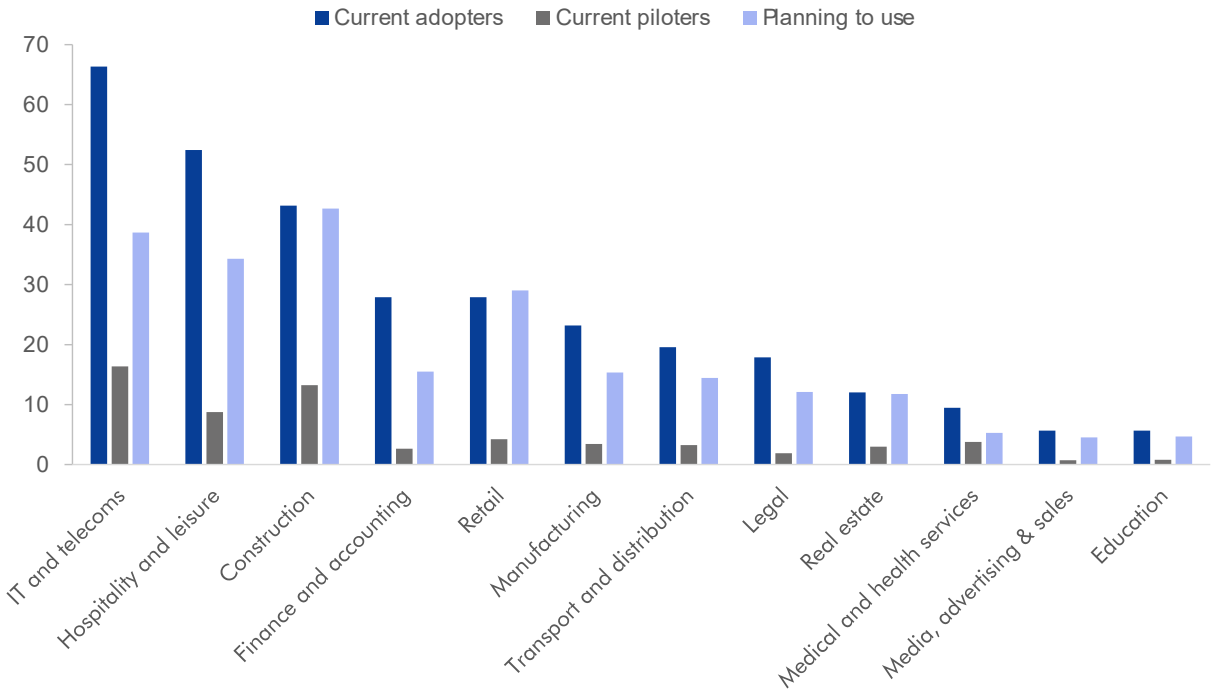
Accounting for the size of sectors, the majority of AI adopters in absolute terms are working in IT & telecoms and hospitality & leisure, with 66,500 and 52,500 firms currently using AI respectively. In comparison, the legal sector, which has the highest adoption rate, has nearly 18,000 firms currently using AI. (See Figure 3.4.)

[67] CDEI (2021), *UK Business Innovation Survey*.

Conversely, the highest absolute number of firms not deploying any AI currently is in hospitality and leisure, with 380,000 non-users. This is followed by the construction and retail sectors in which 288,000 and 210,000 businesses respectively are currently not using any AI. Measured in absolute numbers, there is a lot of potential to increase the number of firms adopting AI in these sectors.

Two per cent of businesses across the United Kingdom are currently piloting at least one AI technology. As with adoption, there is variation between sectors. IT & telecoms is the leading sector in terms of piloting AI, with over 16,000 firms doing so, or 7.3% of all businesses in the sector. Although the health services sector has the lowest incidence of AI adopters, it has the second highest share of companies currently piloting at least one AI technology; one in twenty of businesses in the sector currently do so. This result could be driven by the COVID-19 pandemic, which has accelerated the spread of AI adoption in the sector as AI solutions were developed to combat the challenges posed by the pandemic, such as optimising hospital capacity.

Figure 3.4: Number of businesses adopting by sector, 2020 (thousands)



Notes: Sample size for adopting and piloting is 2,008; Sample size for planning to adopt is1,349; Excludes 'Other' category.
Source: Capital Economics analysis of YouGov survey.

3.2 Adoption rate scenarios

To estimate the potential path of AI adoption over the next twenty years we have developed three scenarios for the adoption rate by business size and sector.

Overall adoption in the UK

The scenarios are driven by results from the survey of businesses. Respondents were asked specifically about whether they plan to adopt in the next year and these results are used as the projections in 2021 for all scenarios. The overall adoption rate increases from 15.1% in 2020 to 15.5% in 2021.

Over time, the rate of adoption will be affected by whether firms can overcome barriers to adoption or whether the government can remove or reduce some of these obstacles. The scenarios reflect this. Between 2021 and 2025, the AI adoption rate across the UK economy increases by between five (downside) and ten (upside) percentage points from its current level.

Data from the European Commission's survey of businesses conducted in 2019 is used to determine the extent to which current barriers to adoption prevent businesses that have said they plan to adopt AI in the future from doing so by 2025. In the downside scenario, we assume that the most frequently cited barrier is not overcome by that percentage of businesses. This barrier is the difficulty in hiring new staff in most sectors and translates to an average of 55% of firms that are planning to adopt being unable to do so by 2025. In the upside scenario, we use the barrier which the smallest share of firms considers an obstacle to AI adoption and assume that all but these firms will overcome any constraints and adopt AI by 2025. In most sectors, this barrier is a lack of external funding or concerns about liability for damages caused by AI in most sectors. An average of 22% of firms consider it to be an obstacle to their adoption. In the central scenario the mid-point between the upside and downside is used (38.5%).

In the central scenario, AI adoption grows at an annual rate of 10% until 2025, translating to 267,000 more businesses adopting an AI technology and thereby increasing the share of businesses adopting from 15.1 to 22.7%. In the downside scenario, adoption increases by 8% annually, so that 64,000 fewer businesses have adopted AI by 2025 than in the central case, and the overall share of businesses adopting is 20.6% by that point. Meanwhile, in the upside scenario in which more barriers to adoption are overcome, 762,000 businesses have adopted AI by 2025, compared to 699,000 in the central scenario. The share of businesses adopting is 24.8% in 2025 in this scenario, with annual adoption growth of 12%.

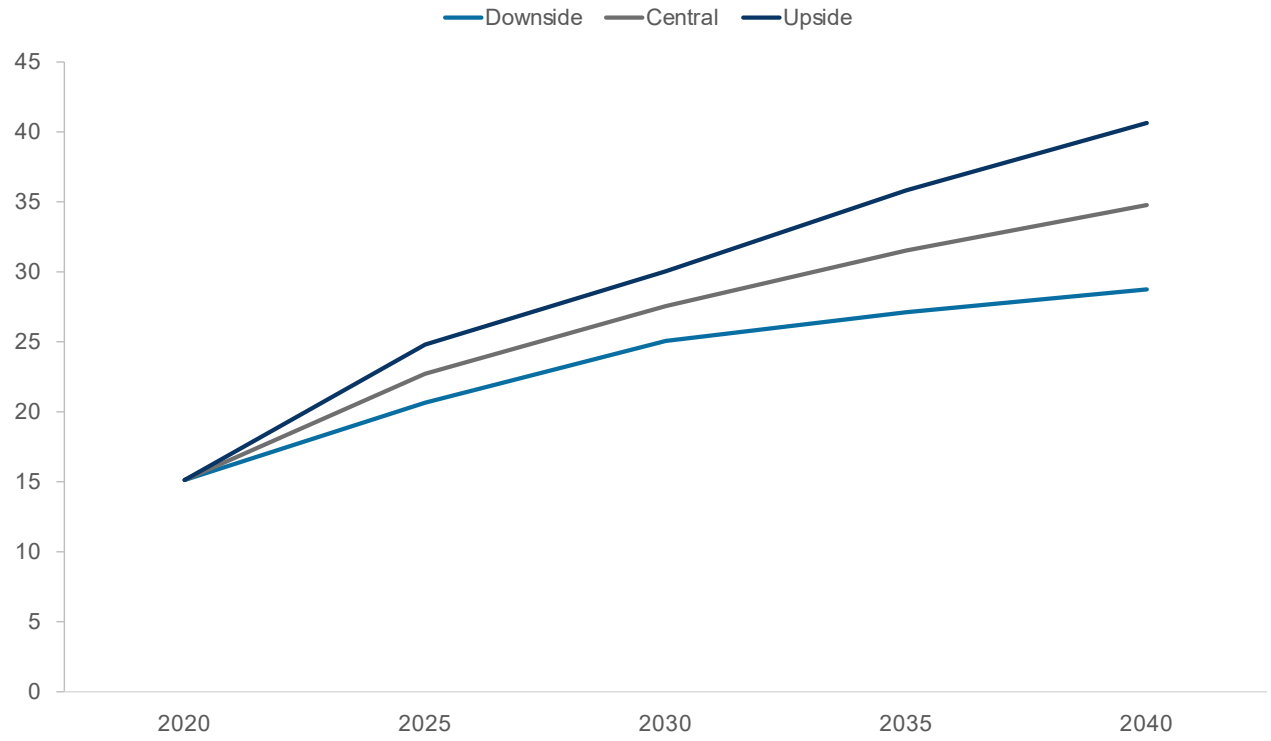
Further ahead, the number of businesses adopting by 2030 is determined directly by the share of businesses that responded to the survey that they were either piloting AI or planned to adopt it. In the central scenario, it is assumed that all these businesses do adopt AI by 2030. This equates to a total of 912,000 businesses, or 27.5% of all UK businesses.[68]

In the upside and downside scenarios, it is assumed that the equivalent of 120% and 80% of these businesses adopt AI by 2030 respectively. Although it is difficult to accurately assess these values, it is plausible that a certain number of businesses fail in their adoption of AI after piloting. This could for example be because they do not see a sufficient return on their investment, or because they encountered disruptions when switching from an existing to an AI system.[69] On the other side of the spectrum, some businesses previously hesitant in adopting AI, may change their mind and implement AI solutions as they see others reaping benefits.

[68] It has been assumed that the total UK business population grows at an annual rate of 1.5% for small and medium-sized firms, and 0.4% for large firms between 2020 and 2040. For further detail, see Methodology section A.3, page 58.
[69] Be the Business (2019), *The UK's Technology Moment – why 2020 can be the year that changed our trajectory.*

In the longer term, we assume that varying shares of businesses adopt AI in the period between 2030 and 2040 who in 2020 indicated no plans to do so - businesses are unlikely to have foresight more than a decade in advance, and AI technologies will become better understood, easier to implement and cheaper over time. This assumption is informed by academic models on the diffusion of innovation, which suggest there are a considerable share of entities that adopt a 'wait and see' approach before adopting an innovative new technology.[70] This results in the adoption rates in the three scenarios fanning out further. Our modelling suggests that between 1.1 million and 1.6 million, or 18.8% to 40.6%, of UK businesses could have adopted AI technologies by 2040.

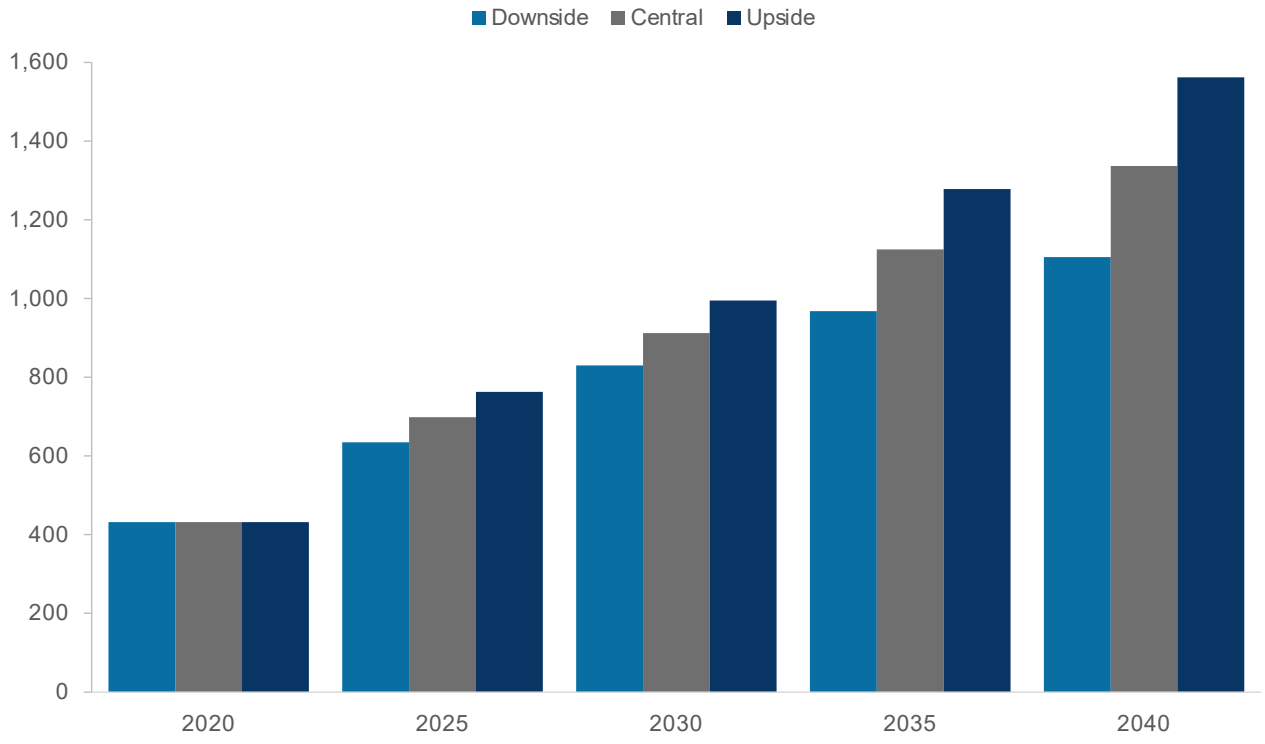
Figure 3.5: Share of businesses adopting by scenario, 2020-2040 (per cent)



Source: Capital Economics analysis of YouGov survey.

[70] Dearing, J.W. and Cox, J. G. (2018), *Diffusion of Innovations Theory, Principles, And Practice*, Health Affairs, Vol. 37 (No. 02), pp. 183-190.

Figure 3.6: Number of businesses adopting by scenario, 2020-2040 (thousands)



Source: Capital Economics analysis of YouGov survey.

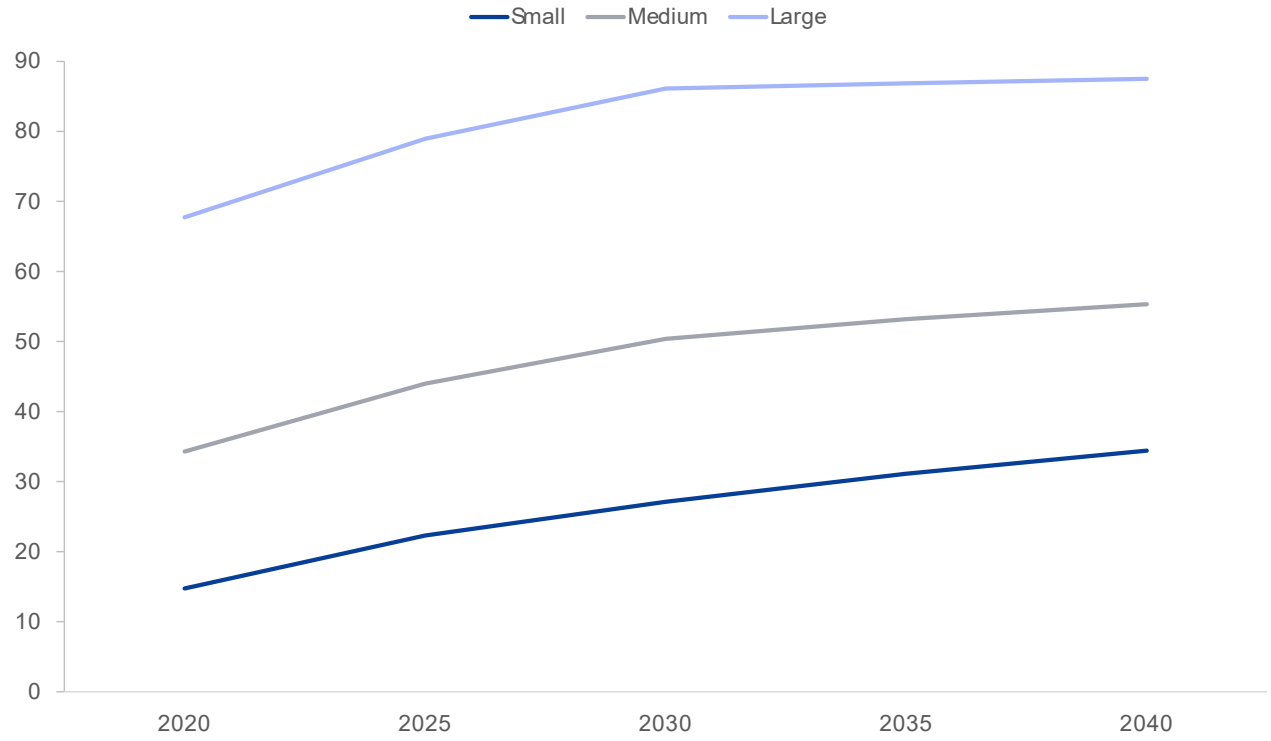
Adoption by size

Large firms remain the most likely to adopt AI in all scenarios. With an adoption rate of 68% in 2020, nearly twice that of medium companies, AI adoption amongst large companies reaches 86% by the end of this decade in the central scenario before flattening out. By 2040, between 6,900 (downside) and 7,600 (upside) large companies will have adopted at least one AI technology.

Small firms could reach the 2020 adoption rate of medium firms (34%) by 2040, with a total of 1.3 million small businesses adopting at least one AI technology in the central scenario. Meanwhile, the adoption rate for medium sized companies increases from 34% in 2020 to 55% in 2040 in the central scenario.

Across all scenarios, adoption rates by 2040 for small businesses range between 28 and 40%, for medium firms between 50 to 61 %, and for large firms between 83 to 92 %.

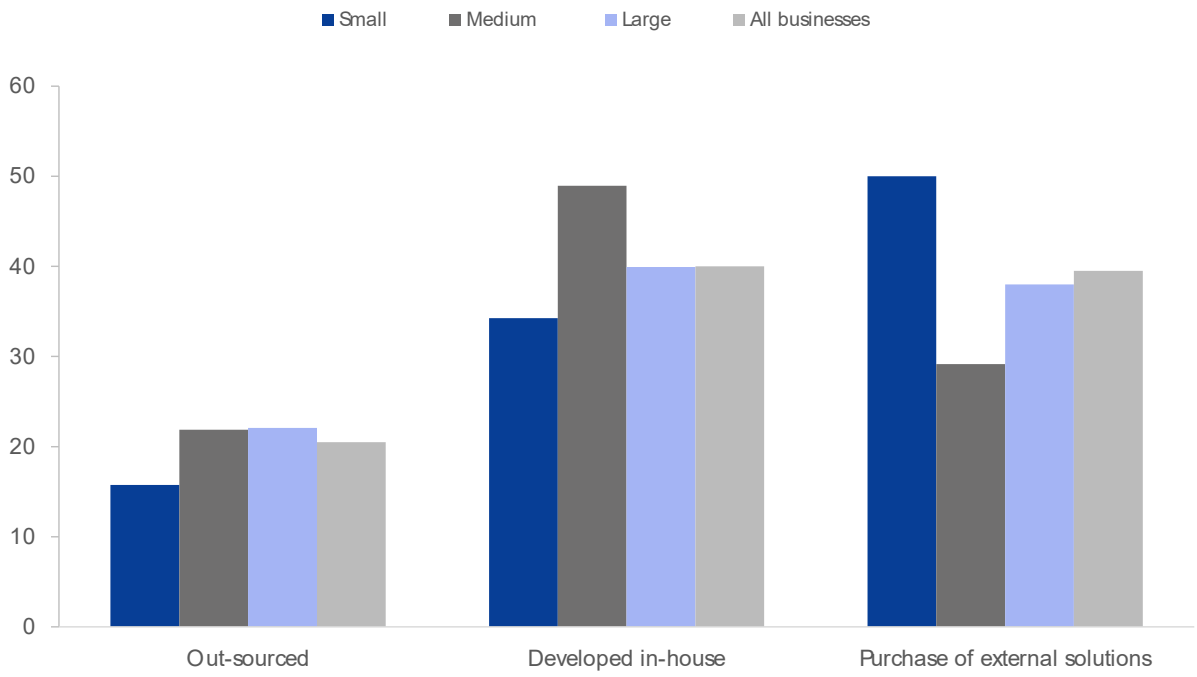
Figure 3.7: Share of businesses adopting by size, central scenario 2020-2040 (per cent)



Source: Capital Economics analysis of YouGov survey.

Medium sized firms were the most likely to develop AI solutions in-house. Around 49% of these firms did this compared to 40% of large firms. This is also reflected in the expenditure figures discussed further below in this section, which show medium sized companies have a higher spend on labour related to AI relative to their turnover. Although we don't have information on the reasons for this from the survey, it may be as a result of high growth tech-based companies which are more focused on achieving growth through deploying AI backed processes. (See Table 4.1.)

Figure 4.1: Adoption rates by sourcing type, 2020 (per cent of adopting UK businesses)



Notes: Sample size of AI adopting firms is 660.
Source: Capital Economics analysis of YouGov survey.

Evidence from other countries suggests a higher share of businesses purchasing 'off the shelf' solutions. For example, in a pan-European survey of businesses, nearly six in ten (59%) rather than 40% of firms responded that they had sourced their AI technologies externally through purchase of software and/or ready-to-use systems. [72] Furthermore, the share of firms who developed AI solutions in-house compared to sourcing externally did not vary significantly by business size. Much of the difference with the results from our survey is likely to be explained by the fact that these are not exclusive options and the European Commission survey allowed firms to pick more than one option. Businesses who said that they mainly develop AI in-house may also have purchased some software externally, but this would not be captured in our numbers.

[72] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.

Overall expenditure on AI

Our survey suggests that, in 2020, the estimated 432,000 companies in the UK who have already adopted AI, spent a total of £16.7 billion on AI technologies and £46.0 billion on labour associated with development, operation or maintenance of those technologies. The expenditure across the UK last year equates to an average labour spend of £106,700 per company. The estimate of spending on technologies includes both new investment and investment in updating and maintaining existing capital. Meanwhile, the labour cost estimate is likely to include a range of workers that have some involvement with AI but are not necessarily focused on it for the entirety of their role. Within spending estimates there will be some large contributing companies that are high tech and entirely AI focused. However, there are also many companies that incorporate some form of AI to improve operations across a broad range of industries and activities.

Trying to benchmark these spending figures is difficult because of the lack of available AI expenditure data and different studies' divergent scope of what is considered AI. According to the International Data Corporation, global expenditure on AI technologies only totalled $50.1 billion in 2020.[73] This would suggest that our estimate of £16.7 billion for the UK only is at the high end, but we do not have information on their sample and it is possible that they have employed a different definition of AI, have a smaller sample size per country or do not have a representative sample by business size and sector.

Meanwhile, comparing to other technologies our estimate looks reasonable. In real terms, our estimate of spending on AI technologies is equivalent to total spending on software by UK companies in 1999, or 19% of expenditure on hardware, software, and R&D in 2019.[74] Furthermore, AI technologies spending is a fraction of the total supply chain spending of UK businesses (around 1%), which totalled £1,738 billion in 2020. In addition, combined total expenditure on AI technologies and labour represents 9% of turnover of adopting businesses.[75]

Expenditure by size

As with adoption rates, expenditure on AI technologies and labour related to AI shows considerable variation by business size.

On average, small firms spent £9,400, medium firms spent £380,000 and large firms spent £1.6 million on AI technologies in the last year, equating to 1.6, 4.0, and 2.4% of their turnover respectively. Consequently, medium sized firms are spending more of their turnover on AI than large or small companies. This is consistent with the fact that a higher share of medium sized firms who adopt AI develop it in-house. Large companies accounted for nearly half of total expenditure on AI technologies in the UK in 2020 (£8.2 billion), having spent nearly twice the amount medium-sized companies did (£4.6 billion). Small companies comprised 23% of total AI technologies spending in 2020 (£3.9 billion).

[73] IDC (2020), *Worldwide Spending on Artificial Intelligence Is Expected to Double in Four Years*, 25 August 2020, Available at: https://www.idc.com/getdoc.jsp?containerId=prUS46794720 [Accessed July 2021].

[74] ONS (2020), *Annual gross fixed capital formation by industry and asset*, Software, Available at: https://www.ons.gov.uk/economy/grossdomesticproductgdp/datasets/annualgrossfixedcapitalformationbyindustryandasset [Accessed September 2021].

[75] ONS (2020), *Supply and Use Tables,* Available at: https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/inputoutputsupplyandusetables [Accessed September 2020].

Finance and Accounting	1.1	2.9	4.0
Hospitality and leisure	1.6	4.5	6.2
Legal	0.3	0.9	1.2
IT and telecoms	1.7	4.7	6.3
Media/marketing/advertising/ PR & sales	0.2	0.4	0.6
Medical & human health services	0.8	2.4	3.2
Education	0.2	0.8	1.1
Transport and distribution	0.8	2.3	3.1
Real estate	0.4	1.0	1.3
Other	4.7	12.5	17.2

4.2 Spending scenarios

To estimate the potential trajectory of AI expenditure over the next twenty years we employed the same three scenarios as in chapter 3 for the expenditure on AI technologies by business size and sector, including a central, upside and downside scenario.

Overall expenditure in the UK

In 2020, the 430,000 AI adopting firms spent a combined £16.7 billion on AI technologies and £46.0 billion on labour associated with AI. Technology expenditure includes investment in new AI solutions as well as the replacement and maintenance cost of existing AI technologies.

For technologies spending, we separate out new investment from spending on the update and maintenance of existing assets. Of the £16.7 billion spent in 2020, we estimate that £3.8 billion was new investment with the remainder comprising update and maintenance spend. An estimate of depreciation is used to calculate this expenditure, which is based on a four year life-cycle for software assets.[76] (See Appendix A.3 for more detail.)

We use survey responses to a question about businesses' anticipated increase in expenditure to project new investment forward over the next five years and total investment from previous years to calculate update and maintenance investment. The modelling also accounts for the additional businesses that adopt AI during this period as estimated in section 3.2. In the central scenario, spending on AI technologies increases by £13.5 billion to £30.3 billion between 2020 and 2025, at a compound annual growth rate of 12.6%.

These figures seem reasonable given other estimates of the rate of spending growth. Deloitte's *State of AI in the Enterprise* report suggested that firms intended to spend 10% to 20% more on AI in 2019.[77] Meanwhile,

[76] NIESR (2017), *Academic review of asset lives in the UK,* IESR Discussion Paper No. 474 , Available at: https://www.niesr.ac.uk/sites/default/files/publications/DP474.pdf [Accessed September 2021].
[77] Deloitte (2020), *Thriving in the era of pervasive AI. Deloitte's State of AI in the Enterprise*. 3rd edition.

IDC's forecast of global AI technologies spending suggests that spending on AI will double over the next four years, equivalent to an annual rate of 22%.[78]

Considering the downside and upside scenarios, AI technologies spend could increase to between £27.2 billion and £35.6 billion by 2025, at annual growth rates of roughly 10 and 16% respectively.

For the longer-term projections, for which we do not have survey data, there are three key factors to consider: the increase in number of firms using AI, the increase in intensity of use by a given firm and the change in the price of technologies. In order to capture these in our scenarios, we use long term projections for automation and employment to create a volume index, take the annual change in this index to represent the flow rather than stock, and then convert this into nominal terms using a price deflator. (See Appendix A.3.)

A study by McKinsey provides estimates of maximum potential automation by 2050 in each sector, as well as a range of scenarios for the pace of adoption.[79] In their study, they also consider the development of new technologies – we exclude this and focus only on the expenditure on current AI technologies. In addition, we adjust the pace of adoption by sector based on the adoption rates from our modelling. (See Appendix A.3.)

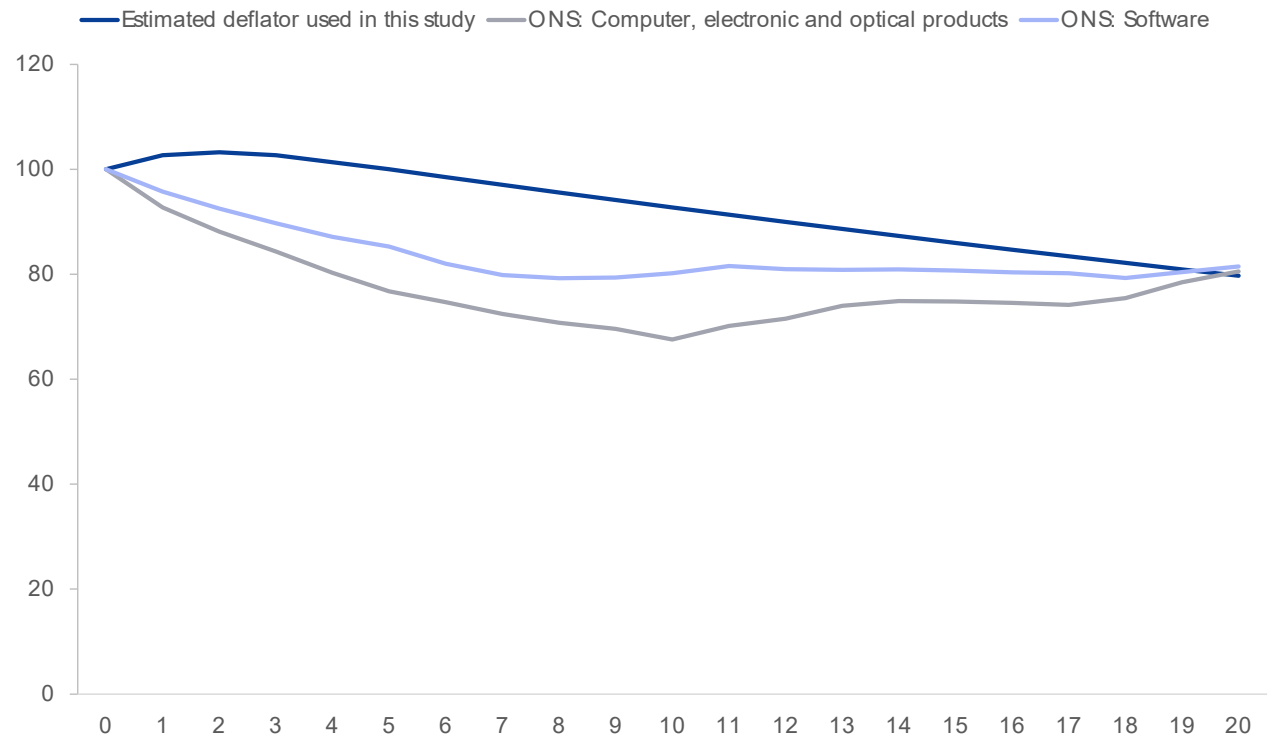
In our central scenario, the percentage of work hours automated reaches around half of its potential maximum by 2040, with some variation between sectors. Total spending on AI technologies increases to £83.5 billion by 2040 at a compound annual growth rate of 8.4%. The average spend of AI adopting firms increases from £38,800 to £62,400 over the period. As a percentage of turnover, spending on AI technologies remains approximately constant between 2020 and 2040, at around 2.4% (See Figure 4.3.)

The rate of growth slows later in the forecast period as the price of technologies falls over time. To estimate the fall in the price of current AI technologies we considered the scale of price falls seen in other similar technologies. The price of software and computers and other electronic products dropped by between 20% and 35% over ten-year periods (from 1997). Subsequently, prices tended upwards, likely due to new and better technologies coming onto the market, such as smart phones and tablets. Our modelling does not account for new AI technologies, and therefore we have assumed a 30% drop in prices over the twenty year period. Recent supply chain disruptions have been taken into account and result in increases in the price index until 2023. (See Figure 4.2.)

[78] IDC (2020), Worldwide Spending on Artificial Intelligence Is Expected to Double in Four Years, 25 August 2020, Available at: https://www.idc.com/getdoc.jsp?containerId=prUS46794720 [Accessed July 2021].

[79] McKinsey Global Institute (2017), *A future that works: Automation, Employment, and Productivity*, Available at: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary [Accessed September 2021].

Figure 4.2: Price index of varying technologies (Index, Year 0 = 100)



Notes: Start point is 2020 for the deflator of this study. For the ONS deflators for computer, electronic, and optical products as well as the deflator on software, the start year is 1997.

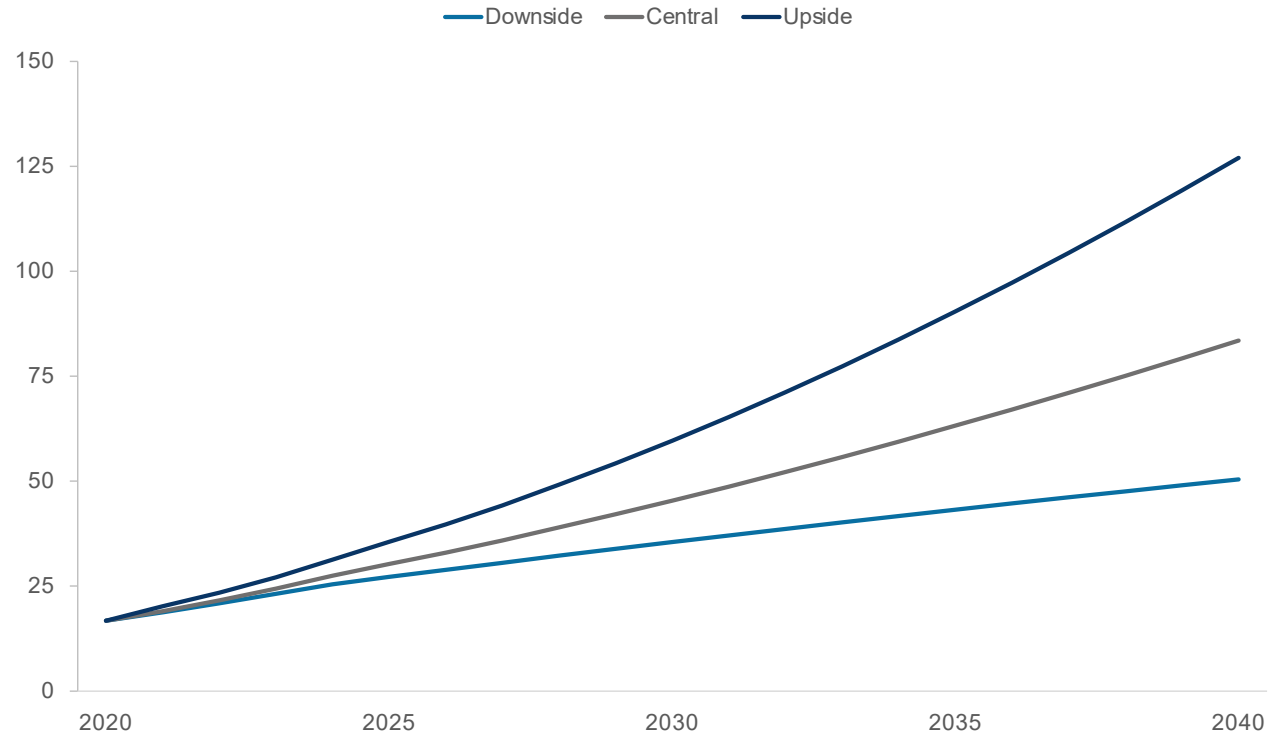
Source: ONS.[80]

In the downside scenario, with automation reaching around one fifth of its potential, total spending on AI technologies reaches £50.4 billion by 2040. This corresponds to an annual growth rate of 5.7%. Between 2020 and 2040, in this scenario, average expenditure of adopting firms on technologies still rises by around £7,000 to £45,600. Spending accounts for 1.8% of turnover of adopting firms in 2040, down from 2.4% in 2020. While individual business expenditure decreases as a share of turnover, partly driven by the fall in prices, overall spending continues to increase. (See Figure 4.3.)

In the upside scenario, the percentage of work hours automated reaches over 90% of its potential maximum on average. Consequently, average expenditure on technologies rises to £81,300 per adopting company over the period. Total spending equates to £127 billion in 2040, growing at a rate of 10.7% annually. As a result, expenditure on technologies as a share of turnover of adopting firms is 3.2% in 2040, an increase by around 0.8 percentage points from its 2020 value.

[80] ONS (2021), *Investment in intangible assets in the UK*, Available at: https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/experimentalestimatesofinvestmentinintangibleassetsintheuk2015/2018 [Accessed September 2021].

Figure 4.3: Expenditure on technology by scenario, 2020-2040 (£ billion)



Source: Capital Economics analysis of YouGov survey.

Our labour cost scenarios are based on the ratio of AI related labour to AI technologies spend by business size.[81] Analysing data on software investment and employment in software related occupations as a comparator, suggests an increase in the ratio of labour spend to technologies spend over time. The rate of growth of software related employment outstripped the rate of growth in investment between 2004 and 2019.[82][83]

To generate conservative estimates, we assume that the ratio of labour spending related to AI to spending on AI technologies remains constant over time. We also adjust prices for increases in wages over time.

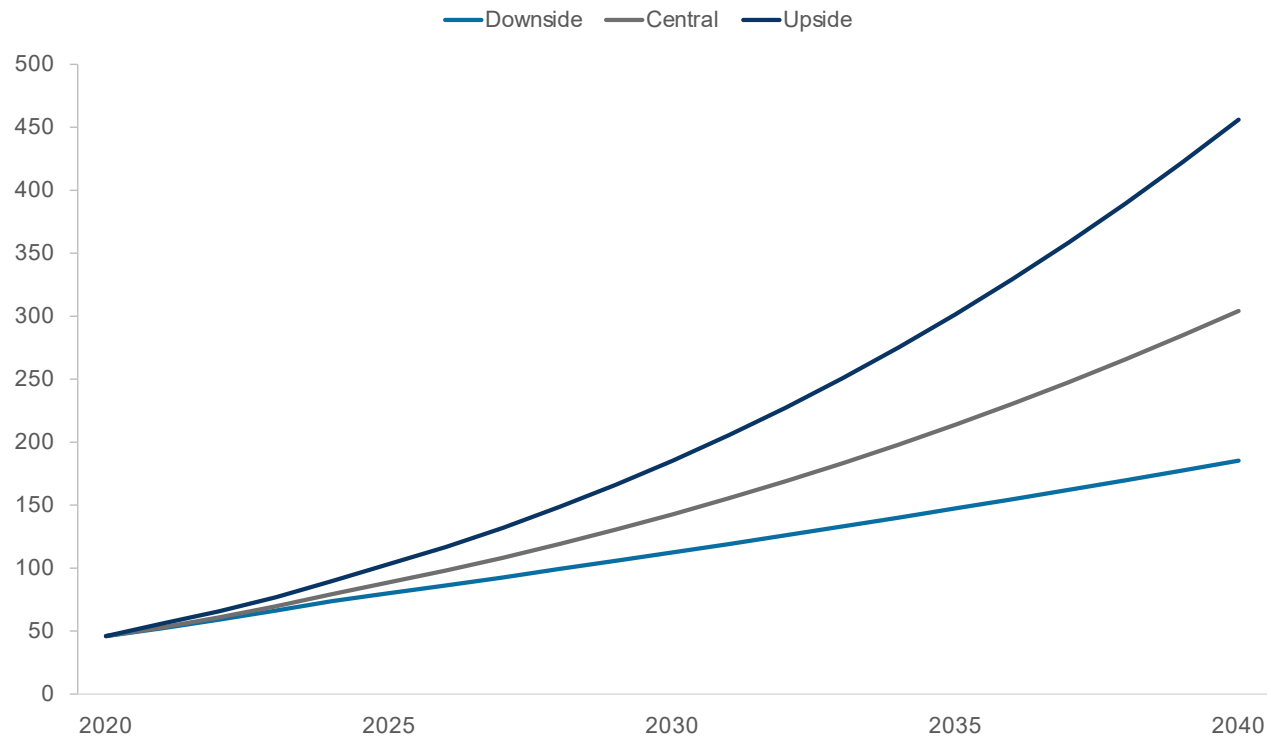
In our central scenario, labour costs rise from £46.0 billion in 2020 to £304.2 billion in 2040 at a compound annual growth rate of 9.9%, or to £216 billion at a compound annual rate of 8.0% in real terms. (See Figure 4.4.) By 2040, spending on labour costs related to the development, operation and maintenance of AI technologies represents 36% of adopting firms' total labour costs. It is important to note that these labour costs do not take into account any displacement effects of AI technologies adoption on labour. Given a lack of previous work in this area, it is difficult to benchmark the scale of these numbers to other estimates. However, the broad scale seems reasonable. As a comparison, assuming average total cost of an employee

[81] The ratio for small firms is 2.6, 4.3 for medium-sized firms, and 1.9 for large companies.
[82] ONS (2021), *Annual Population Survey,* Accessed from Nomis (selected occupations).
[83] Between 2009 and 2019, employment in selected occupations grew by 3.5% and investment by 3.2%.

of £50,000, the total spend on occupations closely related to software in the UK was £74.8 billion in 2020, meaning AI related labour could account for half of these.[84]

The estimates of spending on labour related to the development, operation and maintenance of AI range from £185.2 billion (£130.5 billion in real terms) in the downside scenario to £456.0 billion (£329.0 billion in real terms) in the upside scenario. This equates to an annual growth rate between 7.2% and 12.1% (5.3% and 10.3% in real terms), or a range of 26.5% to 45.9% of AI adopting companies' labour costs.

Figure 4.4: Expenditure on labour by scenario, 2020-2040 (£ billion)

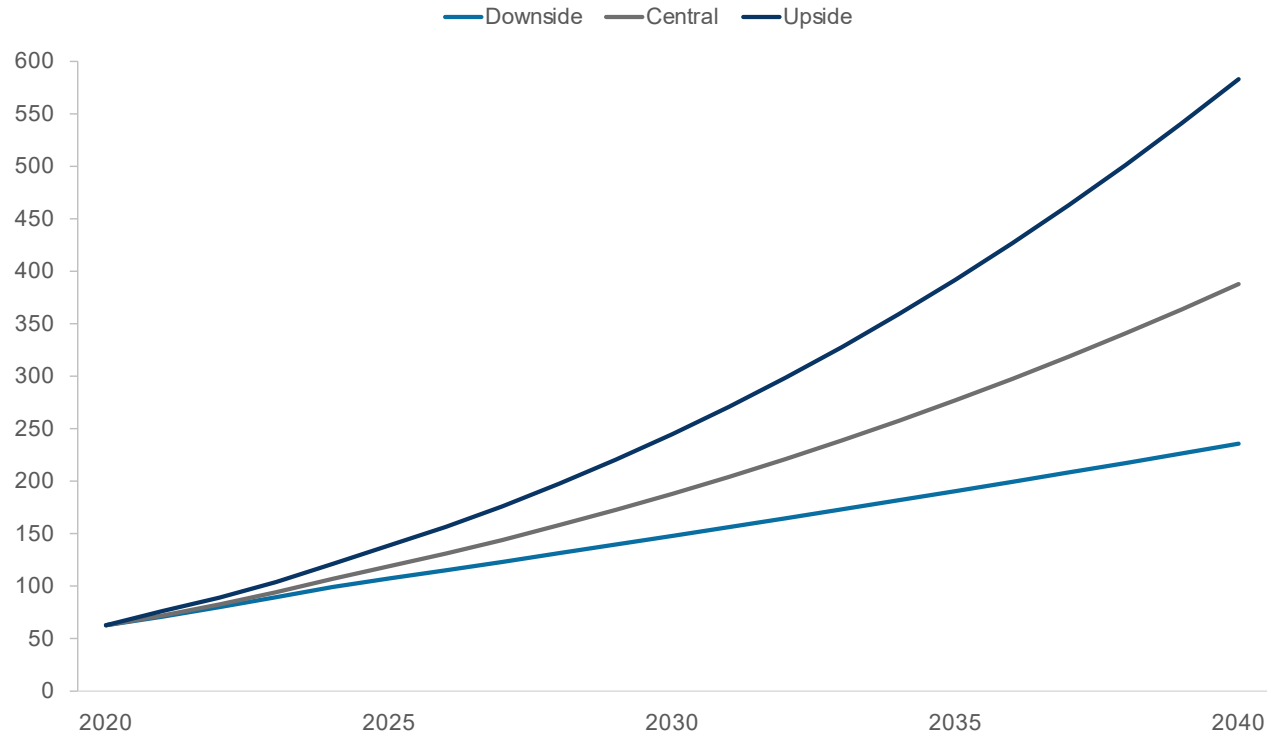


Source: Capital Economics analysis of YouGov survey.

Overall, spending on AI technologies and labour is projected to increase from £62.8 billion in 2020 to £387.7 billion in 2040 (£299.6 billion in real terms) at an annual growth rate of 9.5% in the central scenario. Growth is faster at the beginning of the period and then flattens off. Spending per adopting business grows from an average of £145,400 to £290,000 over the period. The net worth of the UK's AI supply sector was estimated at £15.6 billion in 2020 according to DataCity. If spending by businesses increases in line with our central scenario, there is considerable scope for growth in the value of the UK supply sector in the coming years.[85]

[84] ONS (2021), *Annual Population Survey,* Accessed from Nomis (selected occupations).
[85] DataCity (2020), *UK Artificial Intelligence analysis 2020,* Available at: https://thedatacity.com/insight/uk-artificial-intelligence-analysis-2020/ [Accessed September 2021].

Figure 4.5: Total expenditure on labour and technology by scenario, 2020-2040 (£ billion)



Source: Capital Economics analysis of YouGov survey.

Expenditure by size

Expenditure on AI technologies and labour related to AI shows considerable variation by business size. In the central scenario, we assume business' expenditure on AI grows by an annual rate of 8%, 10%, and 13% for small, medium, and large-sized businesses respectively between 2020 and 2025. These growth rates represent the average annualised five year growth rate for each business size from our survey.

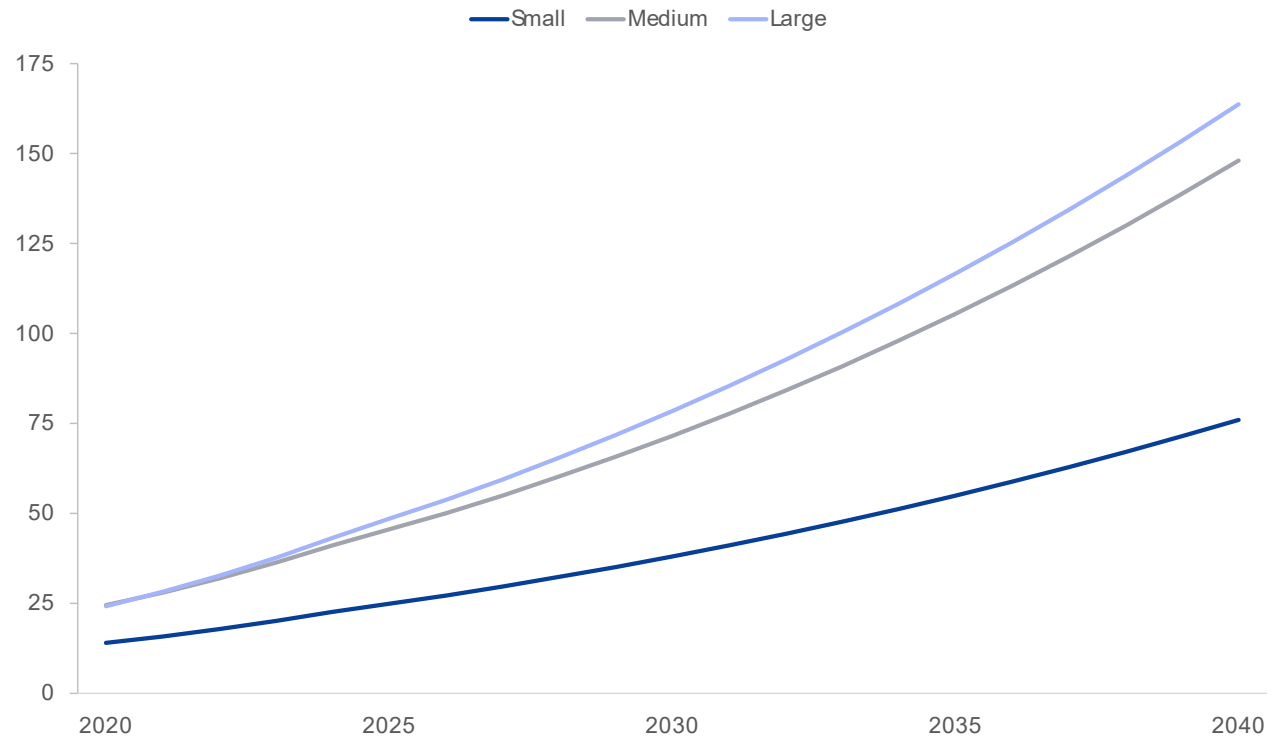
As such, large companies could increase their expenditure on AI labour and technologies from £24.2 billion in 2020 to a total of £48.5 billion by 2025 in the central scenario. In this scenario, medium-sized businesses will spend around £45.6 billion on AI solutions by 2025, with small business' expenditure around 40% below this figure, standing at £24.9 billion.

For the upside and downside scenarios, the growth rates assumed for 2021 and 2021 to 2025 differ. In the upside scenario, we took the average reported spending increase rate for each business size from our survey results for 2021 and assumed these do come to pass. Large companies reported the highest anticipated spending increase on AI technologies and labour, of nearly 50% in 2021. This compares to small and medium business' average intended expenditure increase of around 35%. Between 2021 and 2025 in the upside scenario, we assume that spending grows 20% faster than in the central scenario. Consequently, large companies' expenditure on AI solutions grows at an annual rate of 19.5% until 2025, with the total annual expenditure equalling £58.9 billion by 2025. Small firms would increase spending by 14.9%annually to £28.0 billion, and medium sized firms' expenditure would grow at 16.1% to £51.7 billion in this scenario.

In the downside scenario, spending in 2021 is assumed to grow at a third of the rate applied in the central scenario, and at half the central scenario's rate between 2021 and 2025. As such, AI spending of small firms is £2.0 billion below that of the central scenario by 2025 – or £4.1 billion and £5.7 billion for medium and large-sized companies respectively.

Overall, annual spending on AI technologies and labour will likely range between £47.9 and £108.5 billion for small companies by 2040, between £91.8 and £213.7 billion for medium-sized companies, and £95.9 and £260.8 billion for large companies, depending on the scenario. In the central scenario, expenditure will have grown at an annual rate of 8.8% for small, 9.4% for medium, and 10.0% for large businesses between 2020 and 2040. These equate to total AI spending of £76.0 billion for small, £148.0 billion for medium, and £161.7 for large businesses in 2040.

Figure 4.6: Labour and technology expenditure by size, central scenario 2020-2040 (£ billion)



Source: Capital Economics analysis of YouGov survey.

- The sectors set for the largest increase in adoption rates by 2025 and by 2040 according to our central scenario based on survey results are IT and telecommunications (+29 percentage points by 2040), and legal (+28.8 percentage points by 2040) as well as media, marketing and sales (+24.8 percentage points by 2040).

- Total expenditure on labour related to the development, operation or maintenance of AI technologies is approximately 2½ times that of expenditure on AI technologies themselves; skills will be needed to sustain the increase in spend over time.

- With the right conditions, total AI expenditure could grow between 11% and 17% annually over the next five years.

- There is a wide range of potential outcomes for spending on AI technologies and labour, depending on progress to overall potential in the adoption and intensity of AI use, ranging from £236 billion by 2040 in the downside scenario to £583 billion by 2040 in the upside scenario.

Contribution to the literature

This report adds to the literature on the scale and nature of AI use in the UK. It supplements existing evidence on adoption with a large survey of over 2,000 businesses focused specifically on the UK, while providing breakdowns by business size, sector and technology type. Estimates of expenditure on AI by UK businesses are sparse, and this study provides new estimates with a breakdown by business size and by spending on technologies and labour. In addition, it includes three scenarios for the trajectory of AI spending over the next 20 years which is based on modelling using survey results, as well as a range of official statistics and other publications. These provide indicative estimates of the broad scale of increase that can be expected depending on the ability of firms and government to overcome barriers to adoption that currently exist. There are limitations to this study. There are a range of assumptions that underpin the calculations, which should all be treated as indicative estimates. (See Section A.4.)

There is more work that can be done on AI in the UK that would be useful additions to the literature and increase understanding of the subject area, including:

- Continuing to improve data collection on adoption and expenditure on AI technologies in the UK under a single definition of AI, and increasing access to this data

- Increased literature on policies that reduce the barriers to AI use by businesses

- An assessment of the net impact of AI adoption on employment and business expenditure

- An assessment of the economic impacts of the increased adoption of AI through productivity improvements

- Analysis on the economic impacts of the increased use of AI products by consumers
- Analysis of AI adoption and expenditure amongst UK public organisations

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APPENDIX - METHODOLOGY

This appendix sets out the methodology and key assumptions used in the modelling of AI adoption and spending in the UK.

A.1 Survey background

To gather data on AI adoption and spending to inform the modelling in this study a survey of private businesses was conducted in conjunction with YouGov.

The following four survey questions were asked to businesses:

1. **Does your business use any of the following Artificial Intelligence technologies or do you intend to do so?** (Technologies = machine learning, natural language processing and generation, computer vision/image processing and generation, data management and analysis, hardware, robotic process automation)
   [please tick one option for each technology]

   a. Currently piloting
   b. Used for over 3 years
   c. Used for 1-3 years
   d. Not used but planning to adopt in the next year
   e. Not used but planning to adopt further into the future
   f. Not used and no plans to adopt

2. **How did your business adopt the majority of the technologies you ticked in question one?**
   [Please tick one]

   a. Developed in-house (fully, or by adapting existing software)
   b. Through purchase of external software or ready-to-use systems
   c. Out-sourced the development of AI applications to external providers

3. **How much has your business spent on artificial intelligence technologies and the labour related to these technologies?**
   [Please tick one in each column and estimate the total cost for all technologies identified in question one]

	Technology costs of AI over **past three years**	Labour costs relating to the development, operation, or maintenance of AI technologies **in the past twelve months**
< £10,000		
£10,000 – £50,000		
£50,000 – £100,000		
£100,000 – £500,000		
£500,000 - £1 million		
£1 – 10 million		
£10 – 20 million		
> £20 million		

4. **How much do you anticipate your total expenditure on the Artificial Intelligence technologies that you identified in question one will increase in the future?**
[Please tick one in each column]

	Next year	Next 5 years
N/A		
<10%		
10-25%		
25-50%		
50-75%		
75-100%		
100-150%		
>150%		

The total survey sample was 2,019 private businesses, including 1,127 small businesses (55.8%), 291 medium businesses (14.4%) and 601 large businesses (29.8%). Following standard categorisations of business size used in official statistics, businesses employing less than 50 employees were classified as small, those employing between 50 and 249 workers as medium, and firms with over 250 workers as large. Respondents spanned all regions of Great Britain and all private sectors. Businesses in Northern Ireland have thus not been surveyed. For the purposes of this study, which is concerned with AI adoption in the United Kingdom, it is assumed that behaviour of businesses in Northern Ireland reflects the behaviour of businesses in Great Britain, as derived from survey responses. After removing spurious responses, the identification process of which included an analysis of expenditure responses relative to firm size (in terms of turnover), the sample reduced to 2,008 quality responses. The 11 companies' responses removed from the sample were micro and small firms that had answered they had spent over £10 million on AI in the past three years.

In this study, AI is defined as highlighted in section 1.1. Survey participants were asked about their usage or planned usage of the following six technologies: robotic process automation (RPA), machine learning, natural language processing and generation, data management and analysis, computer vision and image processing, and hardware related to AI. Although information on robotic process automation is gathered, this is not included in our AI totals because it does not constitute AI as defined in this study. Instead, a respondent is classified as an AI adopter, if the business uses at least one of the remaining five technologies. In the survey,

respondents were asked about RPA as a way to ascertain that we capture valid responses. The inclusion of the RPA category helps respondents to not mistakenly attribute the use of this non-AI technology to the machine learning bucket, which is the broadest of the five. Expenditure responses from companies using RPA and AI have been adjusted to remove the effect of RPA spending. As an example, for a company who used two AI technologies and RPA, we allocated two thirds of their expenditure to AI technologies and discarded the remaining third in our analysis.

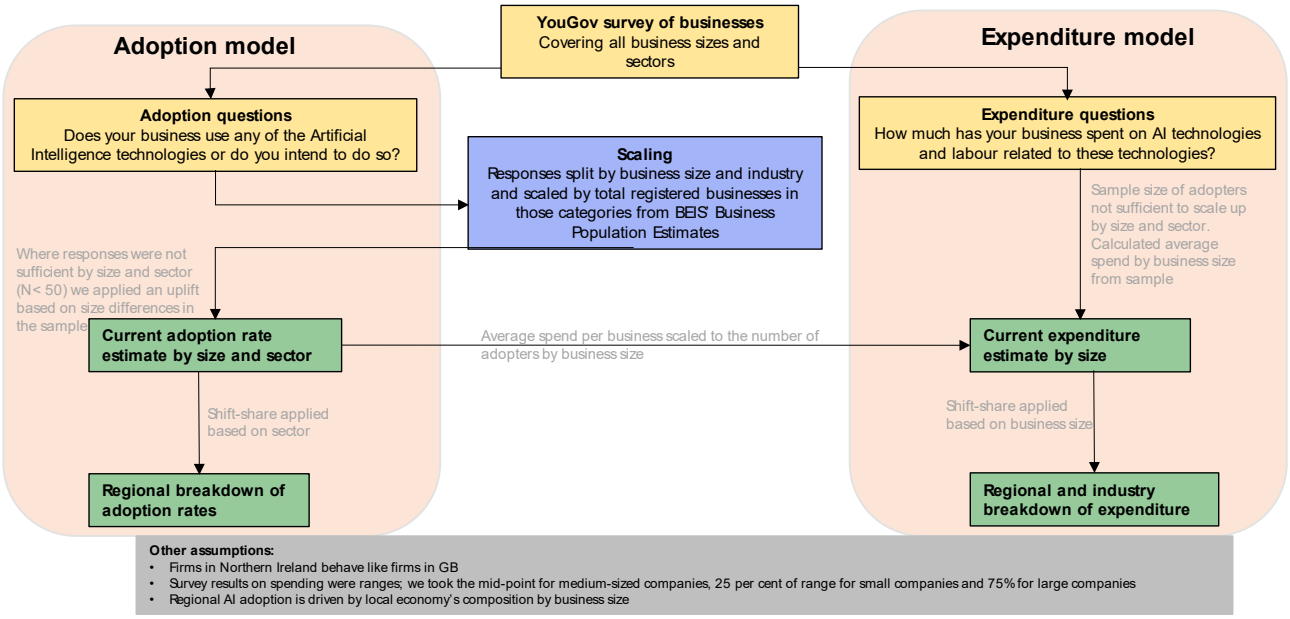
In the survey, businesses were asked to self-identify the sector in which they operate. This study's model is based on the YouGov sector breakdown which includes thirteen sectors.[86] However, as these sectors do not correspond exactly to the Office for National Statistics' Standard Industrial Classification (SIC) code breakdown, for scaling up responses to the UK business population sixteen SIC broad industry groups were mapped to these thirteen YouGov sectors. Where the SIC sector was broader than the corresponding YouGov sector, the SIC sector was split using four-digit Business Register and Employment Survey (BRES) employment data.

[86] Manufacturing, construction, retail, finance and accounting, hospitality and leisure, legal, IT and telecommunications, media/ marketing/ advertising/ PR and sales, medical and health services, education, transportation and distribution, real estate, other.

Modelling current adoption of and expenditure on AI

The survey was used to model the adoption and expenditure on AI technologies in 2020. The overall approach taken was to scale the survey results by sector and business size. In cases where the sample size wasn't sufficient to do this, other approaches were taken. (See Figure A.1.)

Figure A.1: Overview of modelling 2020 adoption and spend



Note(s): Yellow = survey results; green = calculation; blue = data input; grey= assumption

Adoption

Objective: Estimation of the current number of businesses adopting, piloting, or planning to adopt AI technologies in the UK.

Scaling survey responses to UK estimates: to estimate the current number of private businesses in the UK that have either (i) adopted; (ii) are piloting; or (iii) haven't adopted AI, the survey responses were distributed proportionally to the total UK business population by size and in each sector. For example, the number of small companies in the finance industry. Using the same approach, the number of businesses that are piloting an AI technology but not currently using one were estimated, as well as the number of businesses that are not currently using AI but plan to do so in the future.

The scaling up of responses was undertaken using data from the Department for Business, Energy & Industrial Strategy's (BEIS) Business Population Estimates (BPE).[87] Only registered private businesses were considered, to ensure holding companies and other micro businesses that are unlikely to adopt AI are not taken into

[87] BEIS (2020), Business Population estimates for the UK and regions, Available at: https://www.gov.uk/government/collections/business-population-estimates [Accessed August 2021].

account. Respondents who answered 'Don't know' to any of the four survey questions have been distributed proportionately to survey results.

Results on the number of businesses that have already adopted AI, those currently piloting, and those planning to adopt at least one AI technology in the future are broken down by size and sector. Given the three size bands and thirteen sectors, there are 39 categories.

Where the sample size in any given sector by size breakdown was less than 50 the average difference in adoption rates for small, medium, or large businesses across the entire sample were applied to size-bands within the sector that did have more than 50 responses. For two sectors, where no size-band had enough responses, total sample averages for adoption, piloting, and future adoption rates were used; these sectors are Transportation & Distribution and Real Estate.

For example, the survey contained responses of 36 medium-sized construction businesses. This was below the 50 response threshold required for robust results. For this reason, we took the adoption rate of small construction firms, 12.4%, and multiplied it by factor 2.4 to arrive at an estimated adoption rate for medium-sized firms. This factor was calculated by looking at how many more medium-sized firms have adopted any AI technology relative to small businesses across the entire sample.

Expenditure

Objective: Estimation of the expenditure on AI technologies and AI related labour of the number of businesses having already adopted AI technologies.

The estimation of current expenditure on AI was broken down by labour and technologies spend. Labour includes the expenditure on labour related to the operation, maintenance, or development of AI technology solutions. The survey asked for an estimate of spending on both separately, based on ranges (see tables in section A.1). These ranges have been converted into values based on the size of company responding. The midpoint of each range was used for medium firms, with small and large firms' values at the quarter and three-quarter point respectively. For example, a medium-sized firm that reported expenditure in the range of £1 million to £10 million would be noted as having spent £5 million. For a small company expenditure would be £2.5 million, and £7.5 million for a large business. Taking into consideration that companies might have acquired AI technologies more than a year ago, and to account for anomalies that may have resulted from the COVID-19 pandemic in 2020, respondents were asked about their technology expenditure in the last three years, which was then annualised for the modelling process.

Preliminary analysis showed that there were considerable differences in average spend by business size. Consequently, for modelling current expenditure a more granular size breakdown was used to separate out micro businesses (less than 9 employees). The weighted average of labour and technology expenditure by each business size was calculated across the sample and subsequently multiplied by the number of businesses of each size having adopted AI – as found in the adoption model detailed above.

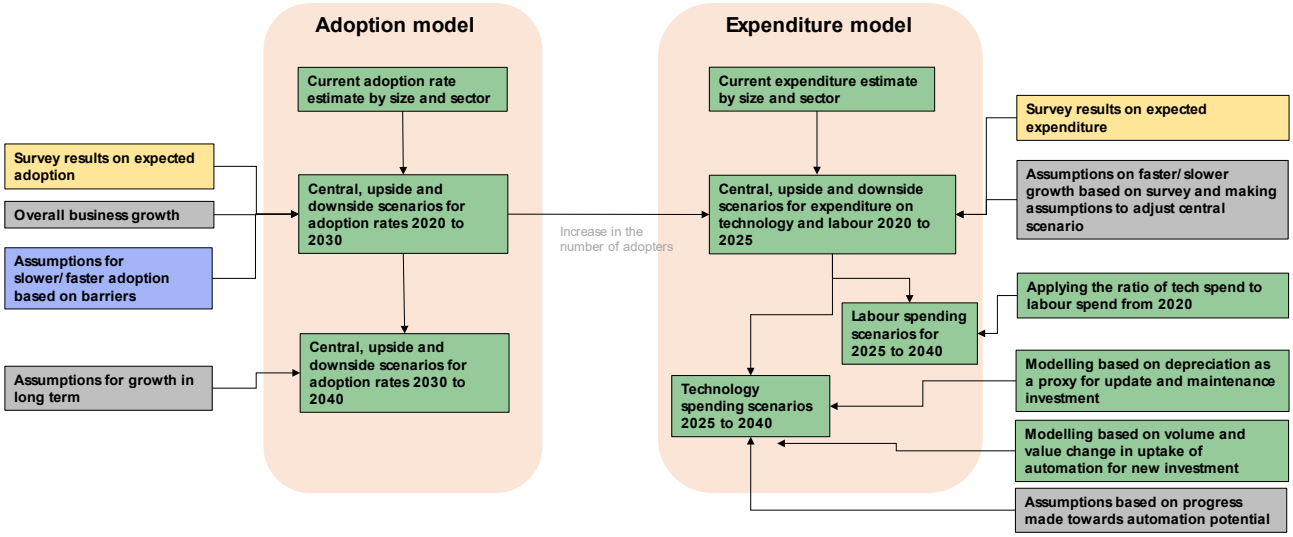
The sample of adopting businesses was not sufficient to obtain reliable average spend estimates by sector, therefore spend estimates are based on business size. The spend by sector is then calculated by applying the average spend by business size to the total number of UK businesses of each size having adopted AI in each sector – as found in the adoption model detailed above.

A.2 Adoption and expenditure scenario modelling

To provide estimates of the broad scale of business investment in AI over the next twenty years we undertook scenario analysis, with a central, upside and downside projection. Figures are provided by sector and business size. Given that we have more robust information about likely growth in the near term, both adoption and expenditure models are split into two approaches for the near term and the medium/long term. The expenditure model distinguishes between labour related to AI and AI technologies expenditure. (See Figure A.2.)

The scenarios are based on the definition of AI illustrated in 1.1. For the purposes of this study, machine learning, natural language processing, computer vision, data management, and hardware are considered AI technologies. There are three implicit assumptions that underpin the scenario modelling. First, it is assumed that the definition of AI remains constant over the modelling horizons, i.e. no emerging technologies that do not exist in 2020 are taken into account. Second, the quality of the five AI technologies remains constant over time. Finally, the barriers to the adoption of these technologies also remain constant.

Figure A.2: Overview of modelling scenarios for 2020 to 2040



Note(s): Yellow = survey, green= model input, light blue= data input, grey = assumption.

Adoption scenario model

Objective: Estimation of the number of businesses adopting AI technologies over the period of 2020 to 2040 under three scenarios.

The number of AI adopting businesses by sector and size in 2020 from the adoption model are used as the starting point for the projections.

In all scenarios the overall growth in the number of businesses has been accounted for. The number of businesses grows between 2020 and 2040 at the same rate as the compound annual growth exhibited during

the period of 2000 and 2020. This growth rate has been calculated using BEIS Business Population Estimates figures for UK private businesses and is broken down by business size. (See Figure A.3).

For the first-year projection, 2021, the rate of uptake as indicated in the survey results which directly asked businesses whether they planned to adopt AI in the next year is taken.

For the period from 2021 to 2025, the projections differ reflecting the ability for firms and government to overcome or remove barriers to adoption. The European Commission's study containing a survey of firms that included detailed information on business' views on barriers to adoption was used to quantify this. [88] The top six barriers highlighted in the sample of 10,000 companies across Europe include internal barriers such as the cost of adoption and difficulties in hiring new staff, as well as external barriers. The latter encompass a lack of public/ external funding, the need for new laws or regulation, concerns about liability for damage caused by AI, and strict standards for data exchange. In the downside scenarios it has been assumed that out of the six barriers, the one with the highest share of companies considering it an obstacle, will be insurmountable for these companies. The remainder of companies will overcome this and any other obstacles and adopt AI. For the upside scenario, the barrier that the smallest share of firms considers to be an obstacle to AI adoption is taken, and it is assumed that all but these firms planning to adopt AI will overcome any constraints and adopt AI by 2025. The central scenario represents the midpoint between the two. See table A.2 below for the assumptions for percentage of firms already piloting or having indicated plans to adopt AI technologies, actually adopting by 2025 used for each sector. For example, amongst manufacturing companies in the EC survey, 58.6% considered hiring new staff the biggest barrier. For our downside scenario, we have hence assumed that the inverse, 41.4% of firms piloting or planning to adopt AI technologies will overcome this barrier, with the remaining 58.6% unable to do so.

Table A.2: Assumptions on the percentage of piloting or planning to adopt firms adopting AI by 2025, per cent

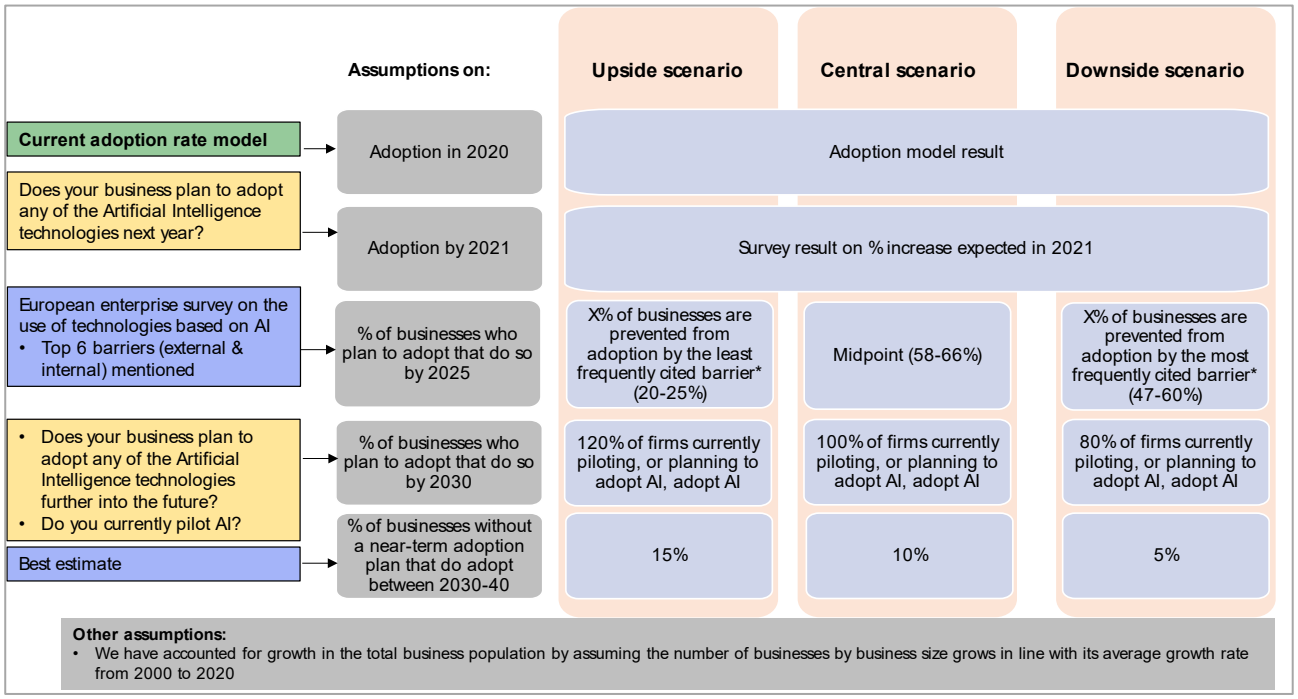
Scenarios, % of firms adopting by 2025:	Downside	Central	Upside
Manufacturing	41.4	58.7	75.9
Construction	46.1	61.3	76.5
Retail	45.5	60.3	75.0
Finance & Accounting	48.0	63.8	79.6
Hospitality & Leisure	43.1	60.5	77.9
Education	45.9	62.8	79.7
Legal	44.5	62.1	79.8
IT & Telecoms	41.4	60.0	78.6
Media/marketing/ advertising/ PR & sales	44.5	62.1	79.8
Medical & health services	40.1	58.4	76.8
Transport & distribution	44.1	60.1	76.1
Real estate	53.0	65.7	78.5
Other	44.5	62.1	79.8

[88] European Commission (2019), *European enterprise survey on the use of technologies based on artificial intelligence*, Luxembourg: Publications Office of the European Union, doi:10.2759/759368.

Source(s): European enterprise survey on the use of technologies based on artificial intelligence[89]

In the central scenario, it is assumed that by 2030 all companies that indicated in the survey that either they are piloting or that they plan to adopt AI do so by 2030. For the downside scenario, it is assumed that only 80% of those that are currently piloting or plan to adopt do so by 2030. In the upside, some firms that don't currently have any plans to adopt do end up adopting by 2030, so we have assumed 120% of the firms that are piloting or plan to adopt actually do adopt AI by 2030.

Figure A.3: Assumptions for adoption scenarios



Note(s): Yellow = survey, green= model input, light blue= data input, grey = assumption.

Expenditure scenario model

Objective: Estimation of the expenditure on AI technologies and related labour by AI adopting companies over the period of 2020 to 2040 under three scenarios.

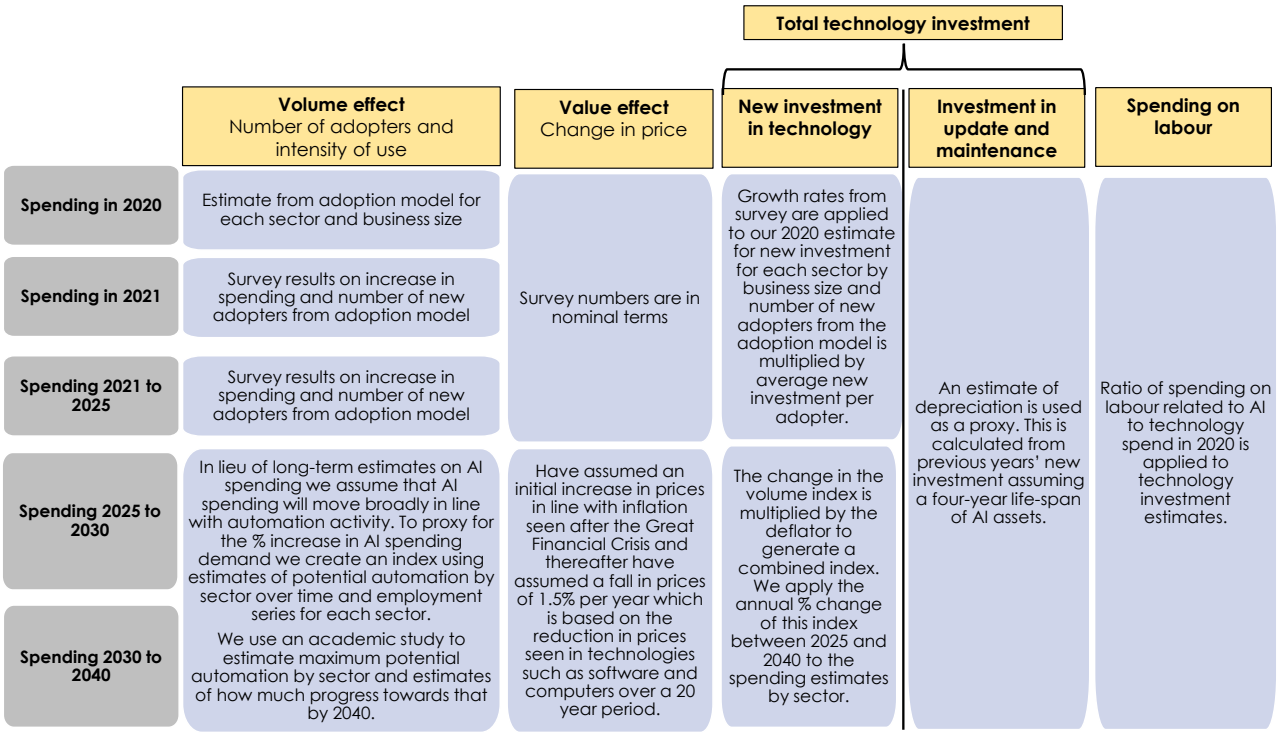
The projections for AI spending are based on a combination of the results from the survey of UK businesses and the adoption rate modelling in the near term. In the medium/long term proxies for the volume and value changes in AI activity are used to produce scenarios on AI technologies spending and the ratio of spending on labour to technologies is used for the labour spending scenarios. The approach taken reflects the need to account for the increase in intensity of spending by individual firms as well as the number of businesses that use AI. In addition, it accounts for the changing price of technologies over time. (See Figure A.4.)

[89] *ibid.*

The spending figures presented are gross figures. For example, the spending on labour relating to AI does not account for any jobs lost as a result of the increase in automation and AI spending. This paper does not attempt to measure the net impact on labour spending. Other literature estimates that the net impact of automation on jobs could range from a net gain of 12 million jobs by 2025 to a net loss of 58 million jobs globally.[90]

All figures are presented in current prices and therefore include the impact of changing technology costs over time.

Figure A.4: Overview of expenditure scenarios modelling



Source: Capital Economics

The approach taken splits spending on technology into new investments in AI technology and investment in the update and maintenance of existing AI technologies. To split the 2020 spending figure between these two we projected the total technology investment spend backwards by four years in order to estimate the depreciation costs in 2020. (See Figure A.4.) To project the 2020 figure backwards we assumed the same annual rate of growth as expected in the next five years in the central scenario to apply to the period 2016 to 2020.

[90] World Economic Forum (2020), *The Future of Jobs Report,* Available from: http://www3.weforum.org/docs/WEF_Future_of_Jobs_2020.pdf [Accessed September 2021].

New investment in technology

For 2021, survey respondents were asked directly about their intended increase in spending. They were also asked about their expected increase in spending over the next five years. The sample sizes for the spending questions were significantly smaller than that for adoption because it was only asked to those that currently use AI. As such, results were split by business size only and the same growth rates were applied to all sectors for a given business size.

The average increase in spend for 2021 from the survey responses was over 30% for all business sizes compared to an annual average growth rate of between eight and 13% over the next five years. As such, for 2021 we apply the survey estimates in the upside scenario only. In the central scenario we apply the average annual growth rate over the next five years and in the downside scenario we assume the increase in spending is one third of that in the central scenario.

For 2021 to 2025, the average annual growth rates for small, medium and large businesses were applied in the central scenario. In the upside scenario the growth rate was 20% higher and in the downside scenario the growth rates were half of those applied in the central scenario. Businesses will not necessarily have accurate figures for the next five years and the scenarios reflect that uncertainty. Applying the growth rates for the scenarios is more of an art than a science. However, we have looked at the difference in growth rates in investment in related assets over time in the United States, where there are more data available, which provides a guide to the sort of scale that is possible for different technologies. Investment in intellectual property products from software publishers grew around 20% more than investment in intellectual property products related to computer systems design and related services over the five year period leading up to 2020. Meanwhile, investment in own account software grew at half the latter's rate.[91]

In addition to the growth in spending of businesses already using AI, the average spend per business is assumed for the new adopters in each scenario from the adoption rate model.

For the period 2025 to 2040, the assumptions in each scenario were broadly based on estimates of the potential increase in automation activity from McKinsey's '*A future that works: Automation, Employment, and Productivity'* study that was based on work by Arntz, Gregory, and Zierhan from 2016 as well as an earlier paper by Frey and Osborne from 2013.[92][93][94] In this study they presented a range of projections for the increase in automation as measured by the percentage time spent on current work activities; this encompasses new businesses using AI and companies using more AI. Although we don't have the underlying data, we use approximate estimates from the graph to form the outlook for automation in our central, downside and upside scenarios. We don't include the increase in potential automation over time as our calculations are based on current technologies.

[91] Bureau of Economic Analysis (2020), *Investment in Private Nonresidential Fixed Assets*, Available at: https://apps.bea.gov/itable/index_fa.cfm [Accessed September 2021].

[92] McKinsey Global Institute (2017), *A future that works: Automation, Employment, and Productivity*, Available at: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary [Accessed September 2021].

[93] 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.

[94] Frey, C.B. and M.A. Osborne (2013), The Future of Employment: How Susceptible are Jobs to Computerization?, University of Oxford.

The key assumption is that AI spending will grow broadly in line with automation activity. We also made an assumption about the current rate of automation, for which we have assumed 3%, which was informed by the McKinsey study and PWC estimates. A volume series was created by multiplying estimates of the share of time spent on work activities that is automated in each sector between 2020 and 2040 by employment in those sectors. Employment was assumed to grow at an average 1.7% across sectors – its compound annual growth rate between 2000 and 2020.[95] The estimates of time spent on work activities that is automated took into account:

- The maximum potential automation with current technologies in each sector[96]
- The total level of adoption by 2040 in three scenarios[97]
- Sector variation in speed of uptake using results from the modelling on adoption rates of AI by 2040.

The annual change in the volume series is then deflated to account for the changing technology costs over time. For the decrease in technology costs, it is assumed that the price of AI will fall by 30% over the 20 years - this is based on historic falls in prices seen in other technologies. Current shortages in semiconductors and supply chain bottlenecks are captured in an initial increase in the price of technology until 2025, with technology prices decreasing from 2026 onwards. The temporary increase reflects the increase in the ONS' experimental deflators for Computer, electronic and optical products as well as Software for the period just after the financial crisis.[98] (See Table A.3.) The growth rates of the change in automated employment adjusted for falling technology prices for each sector are applied to the 2025 estimates of spending up until 2040.

Note that numbers between 2025 and 2040 have been smoothed to remove a jump in 2026 as the calculations move away from being based on survey results and to estimates of the volume and price changes by 2040.

Table A.3: Deflator series for technology cost reduction 2020-40

Year	Index
2020	100.0
2021	102.7
2022	103.2
2023	102.7
2024	101.3
2025	100.0

[95] Office for National Statistics (2021), *JOBS05: Workforce jobs by region and industry,* Available at: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/datasets/workforcejobsbyregionandindustryjobs05 [Accessed September 2021].

[96] McKinsey Global Institute (2017), *A future that works: Automation, Employment, and Productivity*, Available at: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary [Accessed September 2021].

[97] McKinsey Global Institute (2017), *A future that works: Automation, Employment, and Productivity*, Available at: https://www.mckinsey.com/~/media/mckinsey/featured%20insights/Digital%20Disruption/Harnessing%20automation%20for%20a%20future%20that%20works/MGI-A-future-that-works-Executive-summary [Accessed September 2021].

[98] ONS (2021), *Investment in intangible assets in the UK*, Available at: https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/articles/experimentalestimatesofinvestmentinintangibleassetsintheuk2015/2018 [Accessed September 2021].

2026	98.5
2027	97.0
2028	95.6
2029	94.1
2030	92.7
2031	91.3
2032	90.0
2033	88.6
2034	87.3
2035	86.0
2036	84.7
2037	83.4
2038	82.2
2039	80.9
2040	79.7

Source(s): ONS.

Update and maintenance investment in technology

To estimate the spending by businesses on updating and maintaining AI assets (software) estimates of depreciation were used to reflect the capital that needs to be replaced. A lifespan of four years was applied, based on a study by the National Institute of Economic and Social Research which suggested software has a lifespan of three to five years.[99] A linear depreciation has been assumed so the estimate for update and maintenance in a given year is calculated by summing the total investment over the past four years and dividing by four.

Spending on labour related to AI

Projections for labour spend are based on the ratio between spending on AI related labour and AI technology in the 2020 estimates, broken down by business size. This ratio is applied to technology spend in each of the three scenarios and the figures are inflated to reflect increasing wages. Growth in labour costs was assumed to grow at 3% throughout the period based on the compound annual growth rate of the labour cost index between 2000 and 2019.[100]

A.3 Limitations

This study adds new data and modelling to the literature on the use of artificial intelligence by providing estimates of the current and future adoption and expenditure of private businesses in the UK. There are several limitations to the analysis that should be acknowledged, and the findings should be viewed in the context of the limitations of the study:

[99] NIESR (2017), *Academic review of asset lives in the UK*, IESR Discussion Paper No. 474 , Available at: https://www.niesr.ac.uk/sites/default/files/publications/DP474.pdf [Accessed September 2021].
[100] Eurostat (2021), Labour cost index by NACE Rev. 2 activity, dataset: LC_LCI_R2_A [Accessed September 2021].

- Given the nature of the modelling employed and assumptions made the estimates presented are indicative of the broad scale of activity rather than precise figures.

- There is a higher level of confidence in the numbers for 2020 and between 2021 and 2025 as these have a stronger grounding in the survey data collected and uncertainty around the economic environment inevitably rises the longer the time horizon.

- The estimates are based on current AI technologies as defined in chapter 1. They do not account for new technologies that would increase the ability to automate current work activities, nor changes that would reduce the skills barrier for AI technologies operation.

- The modelling does not account for potential economic crises or downturns.

- The figures for expenditure are gross numbers; they do not account for any reduced spending on labour or capital as a result of using AI technologies.

- The sectoral and regional numbers are less robust than the totals and disaggregation by business size. Regional estimates are driven by the proportion of different business sizes in those economies. For adoption estimates, sectoral numbers are based on the survey but supplemented by assumptions using business sizes where sample sizes were insufficient. For expenditure estimates, the sectoral estimates are driven by the proportion of different business sizes in each sector.