

Demographics and technology

A new frontier of
investment opportunities
at the crossroads of
population change and
technological innovation

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Ageing economies face a stark choice: do nothing and decline or transform and continue to grow. Fortunately, automation and AI can go a long way to counterbalance the shrinkage of the labour force, and the timing of their evolution is opportune.

Executive summary

Demographic change is transforming our societies and economies. Its steady creep is gathering pace and force, demanding that countries adapt and innovate if they are to cope with the deep, structural shifts that their populations are just starting to experience. While the drivers of population change are multiple and uneven, one constant holds true: by 2050 the world's leading economies are all expected to experience a significant increase in dependency, or the ratio between those not working and working. Unlike other economic forecasts that are estimated with a significant level of uncertainty, the probability that projected demographic changes will take place is very high. In addition, there is not much a country can do to materially alter its demographic course, especially in the span of a couple of decades.

Ageing economies face a stark choice: do nothing and decline or transform and continue to grow. Fortunately, automation and artificial intelligence (AI) can go a long way to counterbalance the shrinkage of the labour force, and the timing of their evolution is opportune. Governments and companies have thus a viable path to growth going forward. Our study focuses on examining the interplay of demographics and technology with the aim of identifying the potential growth drivers and investment opportunities of the future.

The interplay between demographic pressures and technological advancements is expected to reshape the global economic landscape, presenting both challenges and opportunities for governments, businesses and individuals to navigate. From an investing perspective, it will reshape the investment opportunities across countries and industries, generating new winners and losers.

The sequencing of automation typically adheres to a pattern in ageing economies. First comes the deployment of *substitution robots*, which directly take the place of workers who are becoming scarce or expensive to employ. Then comes the use of *productivity robots*, which improve hourly output. In an ageing society, both types of robots have a role to play.

Substitution robots simply sustain production levels with fewer workers, whereas productivity robots have the potential to increase output and generate competitive advantages. Yet worker-replacement robots can be implemented swiftly, while productivity-enhancing systems necessitate additional investments in training, data systems and organisational redesign, which typically take years to yield returns.

The economies that successfully navigate both automation phases are likely to counteract labour shortages with productivity gains, whereas those that remain only in the substitution phase may run the risk of eventual declining competitiveness. The economic policies and company-level investment choices regarding this technological transformation should provide valuable insights into how well individual countries, industries and companies are likely to navigate the crossroads of technological capabilities and demographic challenges ahead.

For all countries undergoing demographic transitions, the key to the successful adoption of productivity-enhancing technologies fundamentally lies in developing the infrastructure and technology diffusion capabilities required to turn automation and AI into productivity-improving engines.

In the context of industrial automation, advancements in robotics and AI are enabling machines to perform an expanding range of tasks. We estimate that AI will achieve peak productivity gains in the 2030s, well in time to counteract some of the most significant demographic challenges faced by ageing economies.

The timing of AI adoption in each country, in relation to its demographic pressures, can significantly alter its productivity outlook. Countries may face temporary declines in productivity during the early stages of AI adoption, corresponding to the lower part of the AI J-curve, before achieving significant gains.

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For ageing economies, this poses a dual timing challenge: the demographic headwinds potentially occurring alongside AI's disruptive phase. Strategic planning and well-timed investment decisions could help the affected economies and sectors navigate the trough of their AI diffusion process, enabling them to subsequently emerge with enhanced automation capabilities and better productivity and growth potential. It is effectively an exercise and a venture in turning the developing demographic challenges into a durable competitive advantage.

The economic impact of automation relies not only on cost savings but also on demand patterns. If ageing populations' consumption patterns favour sectors that can be automated and deliver efficiency gains, this would have a broader positive effect on the country's productivity and growth dynamics. If, on the other hand, ageing populations' consumption preferences favour sectors that cannot be automated, the economic outlook for the corresponding economies could be bleak. Understanding how consumption patterns evolve as populations age is crucial for identifying investment opportunities for the years to come.

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Our analysis examines the shifts in consumption patterns that occur as populations age across various geographies and combines its findings with the potential productivity gains bound to occur through automation and AI. Our novel approach allows us to identify the investment opportunities that are likely to be attractive given the structural transformation of economies due to demographics and technology. Our results suggest that some of the most compelling investment opportunities may well be found in sectors that are conducive to AI, cater to the ageing population and operate in economies with sufficient technology-enabling infrastructure.

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Introduction

Demographic change is reshaping the world we live in. The population structures of countries across the globe are changing, and the pace of change will only increase in the coming decades, forcing societies and economies to adapt. These adaptations will, in turn, influence the scope and trajectory of technological innovation, with consequential implications for investors.

In the coming 25 years, leading advanced economies are all projected to experience a decline in the working-age share of their populations due to falling fertility rates (births per woman) and ageing societies. This could very well result in challenges such as labour shortages, reduced productivity and increased dependency ratios – or the ratio between those not working and working.

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China's situation is particularly arresting. It is projected to be the country most affected by ageing, with the population expected to halve by the end of this century due to its sustained low fertility rate. What's more, China's elderly dependency ratio is projected to surpass 100% by 2080, meaning there will be more people aged over 65 than those aged 15 to 65. Other countries, led by Canada, are set to see their populations rise through 2050 thanks to immigration, assuming past immigration trends continue.

Technology can counterbalance the economic consequences of these demographic changes. Indeed, as labour becomes scarcer and more expensive in ageing societies, businesses have greater incentives to invest in technologies that can substitute human labour and/or enhance productivity. This innovation dynamic is particularly relevant in the context of industrial automation, where advancements in robotics and AI are enabling machines to perform an expanding range of tasks and render existing labour more productive.

The experiences of Germany and Japan show how this dynamic is already playing out in different ways in different countries. Germany's rapidly ageing population requires immediate worker replacement, whereas Japan's earlier demographic shift has enabled a more mature emphasis on enhancing productivity.

These respective experiences follow what has become a predictable pattern, seen in multiple countries experiencing demographic change: first comes substitution of labour by robots, which directly take the place of workers who are becoming scarce or expensive to employ. Later come productivity robots, which improve hourly output by increasing speed, maintaining quality or minimising waste. They complement the workforce rather than replace it.

This two-phase pattern provides a guide for investors. Countries undergoing demographic transitions should anticipate initial waves of automation focusing on labour-intensive sectors, followed by investment in productivity-enhancing technologies. As both developed and developing economies age, policymakers must consider how to support the transition to automation, ensuring that investments in new technologies mitigate labour shortages rather than induce labour market disruptions.

Policymakers must consider how to support the transition to automation.

The key to success will not lie in merely deploying the most robots, but in developing the organisational capabilities that turn individual machines into significant efficiency improvements. As AI takes automation beyond manufacturing to cognitive tasks, grasping these sequential patterns will be essential for navigating the broader economic transformation and investment opportunities on the horizon.

What is more, we believe that rather than leading to stagnation, demographic shifts coupled with automation technologies may serve as a catalyst for productivity growth. A declining working-age population raises the cost of routine labour, prompting an initial wave of automation aimed at replacing workers. But once the most pressing bottlenecks are resolved, a subsequent, longer wave of investment focused on efficiency gains emerges, increasing value per hour worked.

Wider economic ramifications can also be expected to stem from demographic change. At a macro level, automation could boost gross domestic product (GDP), thereby curbing debt levels. At a more micro level, consumption patterns can be expected to change as the relative size of different age groups morphs. The “silver economy” catering to seniors is already booming, while technology-driven increases in the affordability of some goods and services will appeal to younger age groups.

These demographic changes and economic developments should create distinct investment opportunities, especially in sectors and countries that stand to benefit from shifting consumption patterns and can leverage technological efficiencies to meet evolving demographic needs.

Understanding these interconnected trends will be crucial for navigating the investment landscape in the years to come, as they represent fundamental shifts in the drivers of global economic growth and consumption demand.

This paper aims to dissect the demographic challenges facing leading economies and to examine the effects of technology on economic production. We then put these two analyses together to evaluate their implications for the investment opportunities of the future.

Our analysis is broken down as follows:

- Section 1 presents the demographic challenges facing leading economies using some key metrics to assess their outlooks and population characteristics.
- Section 2 reviews the key takeaways from leading literature on technology and demographics.
- Section 3 explains past technological revolutions and how new technologies are diffused into the wider economy, eventually having such cascading effects that they can even reshape markets.
- Section 4 looks at how automation may affect different sectors in different geographies.
- Section 5 estimates changes in consumption patterns due to demographic developments and quantifies the impact of automation and AI deployment on productivity, consumption and debt sustainability.
- Section 6 discusses the investment implications of our analysis, identifying the sectors and countries that are likely to benefit from evolving demographics and the development of automation and AI.
- Section 7 concludes with some final thoughts.

1. Demographics: facts, figures and perspectives

The demographic challenges facing the world's leading economies are unfolding at different rates in different countries but with one constant: by 2050 they are all projected to experience a significant increase in the elderly dependency ratio – or the population over 65 to the population aged 15-65 – regardless of whether their total populations increase or decrease. This sweeping change can be expected to strain economies and societies and force governments and businesses to adapt, creating new winners and losers.

Demographic change is likely to affect most people in modern societies in one way or another, whether through retirement financing, urban planning, healthcare, etc. This section explains past demographic trends, projections for the decades ahead and the drivers of population change in different leading economies. In Section 6, we combine these findings with economic growth theory to identify countries and sectors that stand to benefit from these demographic changes.

1.1 DEMOGRAPHICS DATA

This study uses data from the 2024 update of the World Population Prospects (WPP) database, which is the most recent one available.

TABLE 1 presents the demographic metrics we compute to describe the demographic pressures that 11 industrial countries will face:

1. Population change between 2024 and 2050
2. Elderly dependency ratio (ratio of population aged 65+ to 15-65)
3. Working-age share (proportion of the population aged 15-65)
4. Life expectancy at birth
5. Prospective old-age threshold (age at which remaining life expectancy is 15 years)

In terms of population change, Italy, Spain, Germany, Japan and China will experience declines, while Canada, the US, the UK, Switzerland, Benelux and France are expected to see their populations increase through 2050. The world population will grow until the mid-2080s to a peak of 10.3 billion, before starting to slowly decline to 10.2 billion by 2100. These forecasts are based on the medium fertility projections from the United Nations (2024b).

It is important to note that these projections assume that current immigration policies continue. However, increasing social and political resistance to immigration in

TABLE 1
Demographic statistics for select countries

COUNTRY	POPULATION CHANGE	ELDERLY DEPENDENCY RATIO		WORKING-AGE SHARE		LIFE EXPECTANCY AT BIRTH		PROSPECTIVE OLD-AGE THRESHOLD	
	2024–2050	2024	2050	2024	2050	2024	2050	2024	2050
Switzerland	+5%	30.8%	53.3%	66.2%	58%	84.1	87.3	73	75
United Kingdom	+9.5%	30.8%	40.9%	64.4%	61.4%	81.4	85.1	72	74
Benelux	+3.5%	31.8%	45.2%	65.4%	60.5%	82.3	85.9	72	74
France	+2.6%	36.1%	48.5%	62.6%	57.9%	83.5	86.6	74	76
Germany	-7.4%	36.9%	53.5%	64.3%	57.9%	81.5	85.2	71	74
Italy	-12.4%	38.8%	70.4%	64.8%	53.5%	83.9	87.2	73	75
Spain	-6%	32.1%	68.8%	67.2%	53.7%	83.8	87.1	73	75
Japan	-15%	50.7%	73.1%	60%	52.5%	84.9	88.4	74	77
China	-10.9%	21.2%	52.3%	70.3%	60.7%	78	83.4	69	73
Canada	+15.2%	30.4%	42.1%	66.4%	62.1%	82.7	86.2	73	75
United States	+10.4%	27.7%	37.9%	66%	62.1%	79.5	83.2	72	74

Sources: UN World Population Prospects 2024, Pictet Research Institute

Notes: The elderly dependency ratio is the ratio of the 65+ population to the 15–65 population. The working-age share is the share of the 15–65 population to the total population. The prospective old-age threshold is defined by Kotschy and Bloom (2023) as the age at which remaining life expectancy is 15 years. Analysis based on medium WPP forecasts.

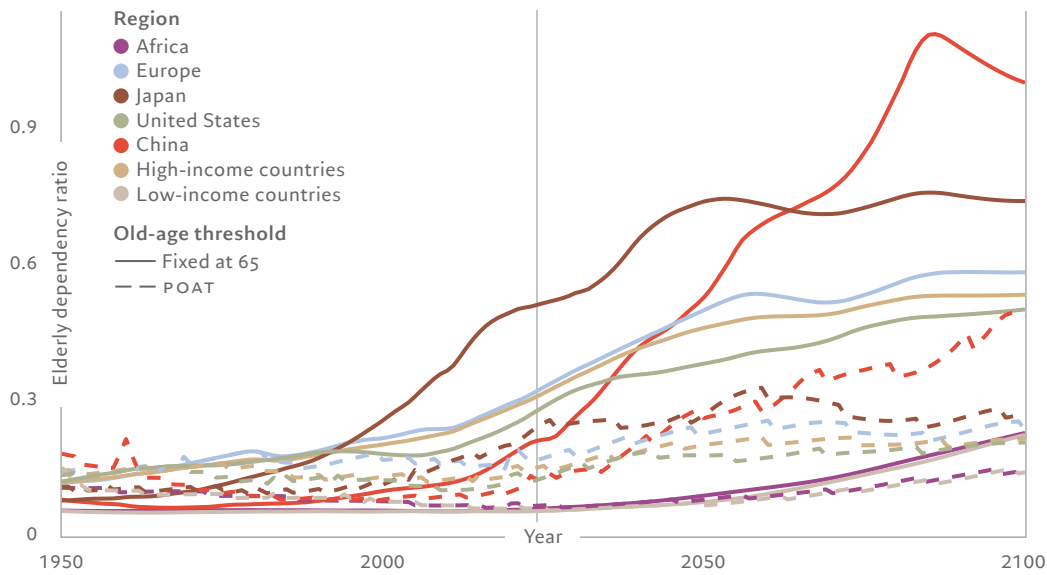
many developed countries introduces significant uncertainty into these forecasts, particularly in countries such as the US, UK and Canada, where projected population growth relies heavily on sustained immigration inflows. If immigration policies become more restrictive due to political pressures, the actual population trajectories of these countries may be less favourable than current projections indicate.

Equally important as the growth or decline of a population is its age structure as reflected in the elderly dependency ratio. The older a population is, the larger its dependency. The US and UK are expected to suffer only mildly from ageing, while Italy, Spain and Germany will see their dependency ratios increase substantially. Japan is and will remain the oldest, most dependent country through 2050. China's dependency is expected to increase exponentially, from 21% to 52% by 2050 and to over 100% in the 2080s.

This ageing is also reflected in the declining share of the working-age population in all countries, with the largest drops in Spain, Italy and China. The US and UK are the countries likely to experience the smallest declines in the working-age population, assuming immigration trends remain unchanged.

The last four columns of TABLE 1 pertain to life expectancy: life expectancy at birth and the prospective-old age threshold (POAT). The latter, introduced by Kotschy and Bloom (2023), is defined as the age at which individuals in a population have 15 years of remaining life expectancy.

FIGURE 1
Elderly dependency ratio over time



Sources: UN World Population Prospects 2024, Pictet Research Institute

Notes: The elderly dependency ratio is the ratio of the old population to the working-age population (aged 15 to the old-age threshold). The old-age threshold is either fixed at 65 or based on the POAT (varying over time). Post-2024 projections are based on the medium fertility scenario of WPP 2024.

This age reflects the challenges posed by ageing populations, such as how to finance longer retirements, particularly in countries with pay-as-you-go pension systems.

At the same time, increasing longevity and better health suggest that people could work longer before retiring. However, this is not universally applicable. Physically demanding jobs take a significant toll on workers' bodies, leading to earlier physical decline and making later retirement unfeasible for many. Furthermore, raising the retirement age is often politically sensitive and a difficult policy to implement.

The idea of linking retirement age to life expectancy is gaining traction in some countries (BBC News, 2025; CNBC, 2025). Denmark has had such a policy in place since 2006 and recently raised its retirement age from 67 to 70, to be gradually phased in by 2040. Italy is considering a similar policy based on life expectancy.

Dependency ratios

FIGURE 1 illustrates the elderly dependency ratio of selected countries and regions, using either a fixed old-age threshold of 65 (solid lines) or a dynamic threshold based on the POAT, which varies over time (dashed lines). The figure highlights the importance of the old-age threshold, showing that raising the retirement age can help mitigate the effects of ageing populations. In China, it could considerably reduce dependency by 2100.

1.2 AGE PYRAMIDS

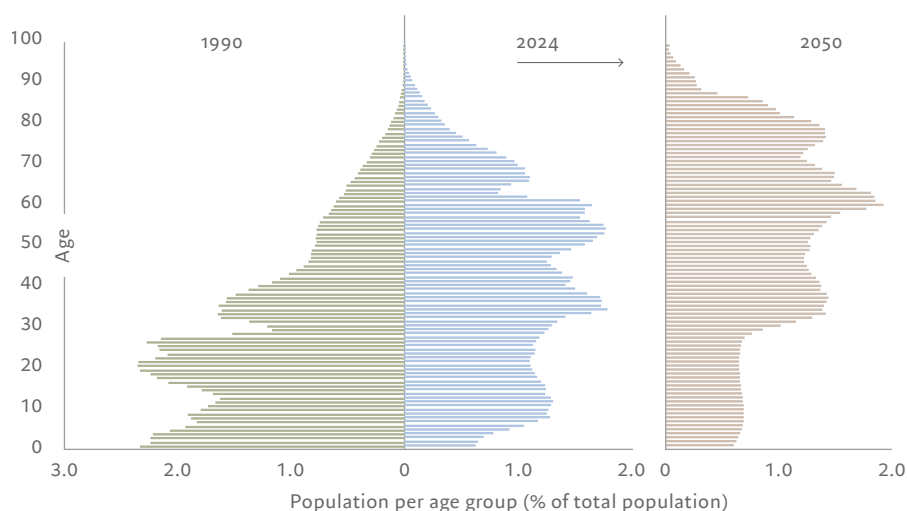
Demographic change can also be seen in shifting age pyramids, which visually represent the age distribution of a population at a given point in time. The figures below show snapshots of the total population in 1990, 2024 and 2050. In this way, we have a visual of the demographic changes that have been under way and those that are expected to take place in the next 25 years.

The pyramid of a population that is not ageing would be shaped like a triangle with a large base and a narrow apex. An ageing population would be the opposite. Any irregularities in this “typical” shape are likely to be the result of events or policies that affected the age structure, as seen below. To save space, the pyramids show 1990 on one side and 2024 on the other. The 2050 projections are displayed only as the right-hand side part of a half pyramid.

FIGURE 2
Japan age pyramids



FIGURE 3
China age pyramids



Sources: UN World Population Prospects 2024, Pictet Research Institute

FIGURE 4
Germany age pyramids

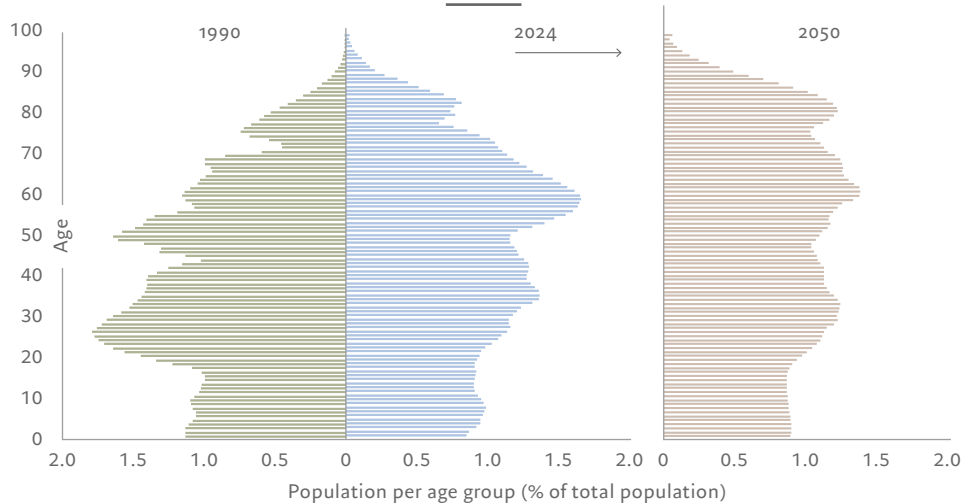


FIGURE 5
United States age pyramids



Sources: UN World Population Prospects 2024, Pictet Research Institute

Japan was the first country to experience significant ageing. FIGURE 2 captures this process with the base of the pyramid narrowing and parts towards the top widening.

FIGURE 3 shows a similar pattern in China, with its pronounced peaks and troughs reflecting the impact of various government fertility policies to curb or encourage population growth. Over the past decade, China's fertility rate has declined significantly, as evidenced by the narrowing base of the pyramids in both 2024 and 2050. This trend underscores the challenges China faces in managing its demographic future.

FIGURES 4 and 5 display the recognisable effects of WWI and WWII in Germany and the Baby Boomer generation in the US. The US population is younger than Germany's, as seen by its egg-shaped pyramids compared to Germany's thinning pyramid base. The two countries are not expected to age to the same extent as Japan and China.

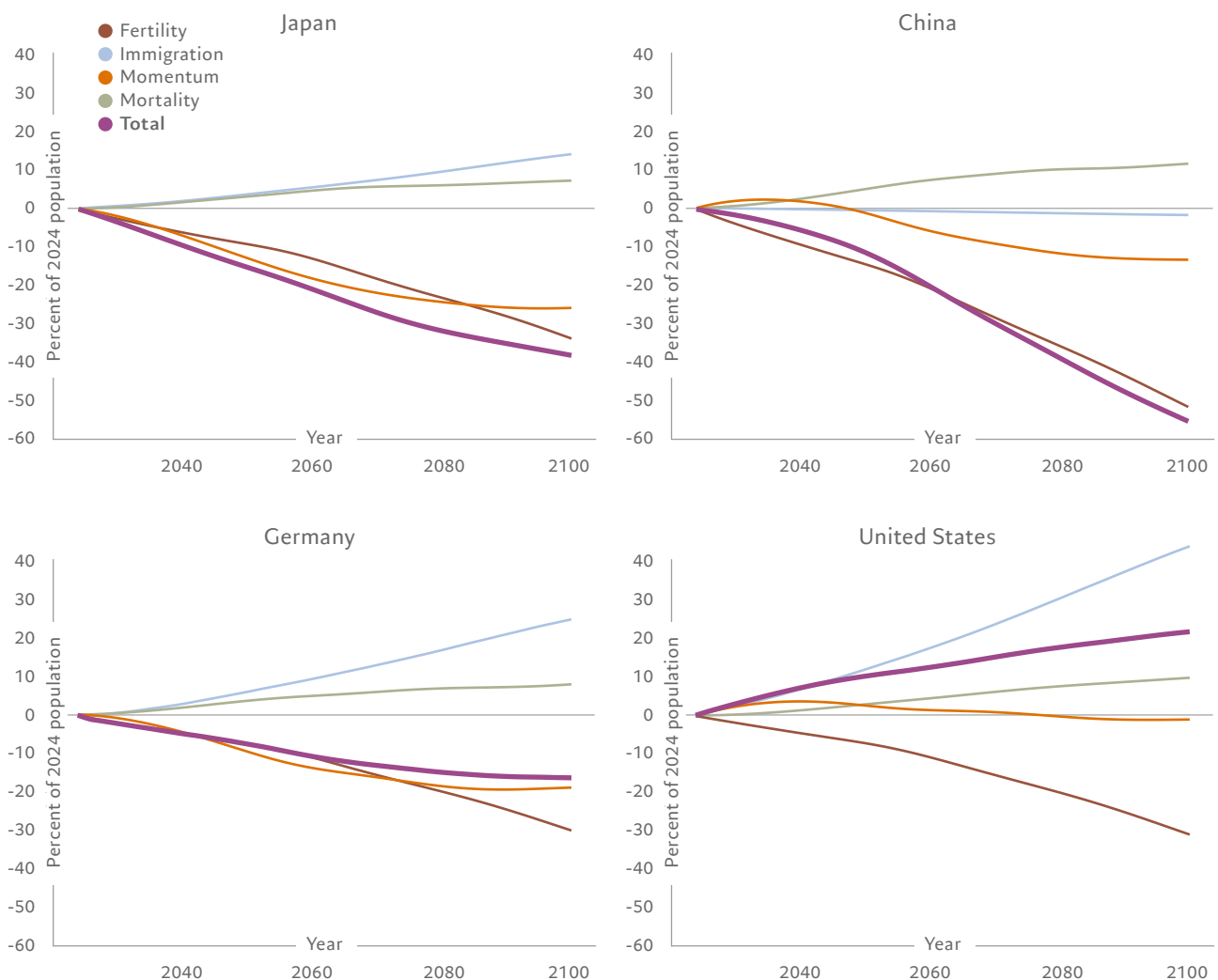
1.3 FACTORS DRIVING POPULATION CHANGE

The dynamics behind population change are not homogenous across countries or over time. Following the methodology of the United Nations (2024a), we isolate four factors that influence population change over time:

- Fertility
- Immigration
- Momentum
- Mortality

Momentum describes how the current population age structure will affect future trends. A very old population will have a negative momentum factor, and a very young population a positive one. FIGURE 6 shows a breakdown of the populations of Japan, China, Germany and the US by each of these factors.

FIGURE 6
Factors contributing to population change



Sources: UN World Population Prospects 2024, Pictet Research Institute

Notes: Contribution of each of the four factors of population change as a percentage of the 2024 population. The bold line represents the sum of the four factors, which is the total expected change over time for the medium fertility forecasts.

Japan has the most negative momentum factor, which is consistent with it having started ageing before the other countries. The impacts of immigration and mortality are positive, but not enough to prevent the population from declining due to its current age structure and the low fertility rate. Combining these effects, the United Nations (2024b) forecasts that the Japanese population will fall by almost 40% by the end of the century.

China's population is expected to fall in excess of 50% by 2100.

While this is a big drop which will have consequences at various levels, China's population is expected to fall even more, or in excess of 50% by 2100. The drivers of this decline in China are different than those in Japan. In particular, China has a less negative population momentum than Japan as its population started ageing later. However, immigration in China is almost zero whereas it is positive in Japan. Nevertheless, in both cases, the populations of Japan and China are expected to see sharp declines by the end of the 21st century.

The US is the only country in FIGURE 6 whose population is expected to keep growing through the century, due largely to the sizeable impact of immigration. While the US and Germany are similarly impacted by changes in fertility rates, the impact of immigration in the US is almost twice as high as that in Germany as a percentage of the total population. As mentioned earlier, these projections may change if there are significant alterations to US immigration policy in the future. At the same time, the momentum factor in the US remains relatively stable, while in Germany, it is becoming increasingly negative.

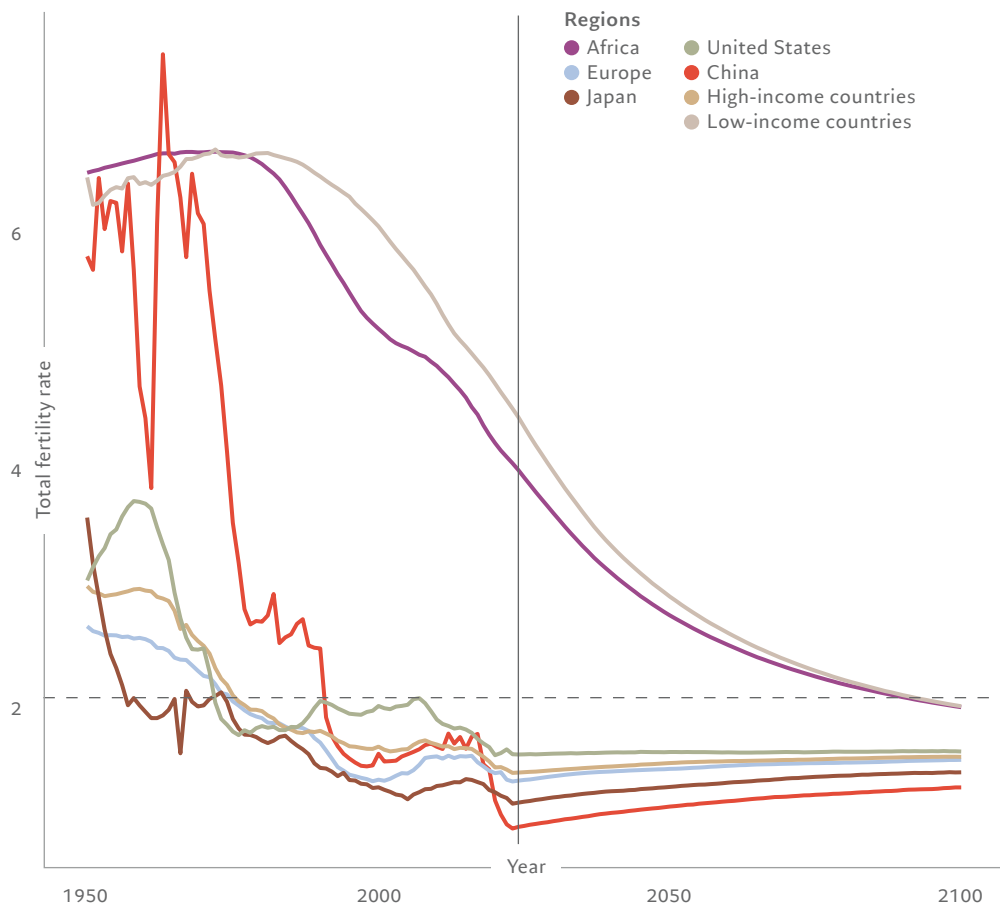
Mortality does not vary significantly across the four countries due to their levels of development.

1.4 TOTAL FERTILITY RATE

FIGURE 7 shows that fertility rates have been declining everywhere since 1950, including in low-income countries and Africa. The largest and sharpest decline is seen in China, where fertility hovered around 6 prior to 1970, then sharply fell to 2.7, before dropping below the replacement level from the 1990s onward.¹ Japan was the first country to experience important fertility declines in the 1950s. Fertility in Europe has been declining consistently since 1950 (except for a small rebound in the early 2000s).

¹ The sharp peak and trough in China around 1960 are due to the Great Chinese Famine that severely hit China between 1959 and 1961.

FIGURE 7
Total fertility rate over time



Sources: UN World Population Prospects 2024, Pictet Research Institute

Notes: Total fertility rate (TFR) refers to the average number of live births per woman in her lifetime. For simplicity, we use “fertility” to refer to TFR in the rest of the paper. The dotted line at 2.1 refers to the minimum TFR needed to maintain the size of the population.

Low-income countries and Africa are also seeing decreasing fertility rates, although they still have much higher levels than the other (more economically developed) countries. The forecasts through the end of the century show modest increases in fertility in developed countries, but still far from reaching the replacement level of 2.1.

The above projections are all but certain to materialise given the nature of population changes and the inability of social policies to have a materially positive impact on fertility rates. Therefore, countries are bound to face a stark choice: either do nothing and decline in population and economic activity or invest in innovation and technological transformation and continue to grow.

2. The intersection of technology and demographics

As global ageing trends have led to concerns about future economic stagnation, they have also sparked a debate on the benefits that technology and automation can bring to economic activity. Hansen (1939) introduced the concept of secular stagnation on the idea that an ageing population leads to excess savings, reduced investments and slower economic growth. Similarly, Gordon (2017) identified demographic change as a key “headwind” to productivity and labour force participation. In contrast, Acemoglu and Restrepo (2017) challenge these theories, revealing that ageing does not necessarily correlate with declining GDP per capita. Instead, the countries hit hardest by ageing are the ones leading the automation adoption process, suggesting that technological adaptation is a critical factor in offsetting the economic pressures of demographic shifts.

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Using data from the International Federation of Robotics (IFR), Acemoglu and Restrepo (2017) demonstrate that between the early 1990s and 2015, countries experiencing faster demographic ageing – as measured by the growth in the ratio of individuals aged 50 and older to those aged 20-49 – adopted industrial robots at significantly higher rates. For example, Germany, Japan and South Korea, which are among the most rapidly ageing societies, are leaders in robot adoption. Even within the OECD, a strong correlation exists between ageing and robot adoption.

The link between ageing and automation is not merely coincidental; it is underpinned by the principles of directed technological change, as discussed in Acemoglu and Restrepo (2022). As labour becomes scarcer and more expensive in ageing societies, companies have stronger incentives to invest in technologies that can replace workers. This dynamic is particularly relevant in the context of industrial automation, where advancements in robotics and AI are enabling machines to perform an expanding range of tasks.

Acemoglu and Restrepo's (2022) model shows that labour scarcity can drive innovation in automation technologies, leading to productivity gains that offset the negative effects of demographic change. In this framework, the adoption of automation is not only a response to current labour shortages but also a forward-looking strategy to address anticipated demographic trends. Importantly, Acemoglu and Restrepo (2022) highlight that the economic impact of automation depends on the relative abundance of capital. In capital-abundant economies, where the cost of capital is low, the adoption of automation technologies is more likely to lead to productivity gains and increased output. Abeliatsky and Prettnner (2023) propose an alternative model to tackle the same question and reach similar conclusions. Empirical evidence shows that countries with greater capital availability and higher levels of ageing have been more successful in integrating automation into their economies. For example, Germany's leadership in both robot production and adoption reflects its ability to leverage technological innovation to counteract demographic pressures. This is particularly true in industries with high automation potential, such as motor vehicles, electronics and chemicals, where robots are increasingly performing tasks that were once labour-intensive.

The interplay between demographic pressures and technological advancements is likely to reshape investment opportunities and generate new winners and losers.

Our study contributes to the above literature by providing a new empirical analysis on the intersection of demographics and technology across geographies, taking into account changes in consumption patterns that occur as populations age and uncovering the investment opportunities of the future.

The interplay between demographic pressures and technological advancements is likely to reshape the global economic landscape, presenting both challenges and opportunities for governments, businesses and individuals to navigate. From an investing perspective, it is likely to reshape investment opportunities and generate new winners and losers.

3. How technologies are diffused: lessons from past technological waves

To analyse the effects that the current automation and AI technologies may have in reshaping the economic and investment landscape of the future, it is important to understand how previous general-purpose technologies (GPTs) were diffused and what those experiences may imply for robotics and AI. Historical trends in technology adoption offer valuable insights to determine where robotics and AI are in their diffusion cycles and when we can anticipate their maximum economic impact.

The global economic order has consistently been shaped by a few general-purpose technologies that are so transformative in scope and have such cascading effects that they fundamentally reshape markets, competencies and even demographic patterns. From electricity and the internet to industrial robotics and today's AI platforms, these general-purpose technologies differ markedly but all share a common trajectory: each begins as an elusive frontier technology before institutional alignment, cost structures and skill acquisition converge to enable diffusion across sectors and borders, ultimately becoming the foundational infrastructure of production (Comin & Mestieri, 2014; Stokey, 2021). Companies and governments adopt general-purpose technologies for diverse, sometimes conflicting objectives such as cost optimisation, strategic autonomy or social inclusion. Yet, once diffusion reaches critical mass, the technology unifies these diverse motives into a cohesive growth trajectory.

3.1 WHAT LEADS TO MASS DIFFUSION OF A TECHNOLOGY?

Three interconnected factors influence whether a general-purpose technology achieves its transformative potential.

- **Market scale** generates enough demand to counterbalance significant fixed adoption costs, effectively turning early experimentation into standard practice (Keller, 2004).
- **Human capital externalities** serve as strong catalysts, as younger, more educated demographic groups exhibit a greater ability to learn and adapt, which reduces the typically prolonged timeline associated with late adoption (Comin & Mestieri, 2014).
- Lastly, **fiscal capacity** – indicative of underlying prosperity and demographic vitality – enables public sector intervention through investments in essential infrastructure and risk-sharing mechanisms that systematically reduce entry barriers (Stokey, 2021).

When these three conditions align, technological diffusion accelerates rapidly, leading to significant productivity gains. Conversely, absent one of the above factors, technologies with transformative potential may remain confined to isolated areas, resulting in minimal productivity gains short of expectations and reinforcing what the literature refers to as the modern productivity paradox – a decline in productivity despite the rapid progress in a technology (Brynjolfsson et al., 2021).

The narrative of each technological wave is less about sudden creative destruction and more about the gradual coordination of multiple stakeholders.

The narrative of each technological wave is less about sudden creative destruction (the process in which new innovations replace and make obsolete older innovations) and more about the gradual coordination of multiple stakeholders – engineers, capital providers, regulatory authorities and end-users – whose economic incentives progressively converge around shared adoption frameworks:

- The electric dynamo initially illuminated urban transport networks before expanding to dispersed agricultural operations.
- Packet-switched communication protocols emerged from military research infrastructure and later became the backbone of modern digital payment systems.
- Industrial robotics first gained momentum within Japan's demographically constrained motor vehicle manufacturing sector before spreading across mid-tier European production facilities.
- Today, the deployment of AI is concentrated among well-capitalised multinational corporations while spreading to critical applications in public health diagnostics and smallholder agricultural risk management.

This pattern repeats with remarkable consistency across decades and technological domains, offering a roadmap for understanding how today's emerging technologies might be diffused.

3.2 WAVE I – ELECTRIFICATION: TURNING SPARKS INTO GROWTH

When Thomas Edison's Pearl Street Station lit up a square mile of lower Manhattan in 1882, the underlying dynamo technology had already existed for 50 years. The transformative breakthrough resided not in the initial technological discovery but in the systematic diffusion process – expanding progressively from urban districts to various industrial sectors and ultimately reaching wide-ranging rural regions.

Metropolitan areas with high-density residential blocks, commercial entertainment venues and street-railway infrastructure created sufficient demand to justify substantial capital requirements for power generation infrastructure and dedicated transmission networks. By 1890, New York, Chicago and Philadelphia together accounted for over half of America's installed electrical capacity, despite accommodating merely one-tenth of the national population (Stokey, 2021). The initial adopters were not individual households but large commercial operators – tramway companies and textile manufacturing facilities – whose operational scale enabled them to recover the costs of specialised investments while seeking lower fuel expenditures and improved machinery performance.

Timing disconnect – where
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Engineers trained at newly established polytechnic institutions began redesigning manufacturing configurations centred around individual motors at each machine on a production line to eliminate cumbersome overhead line-shaft systems. Although this freed production processes from single, synchronised drive mechanisms, measurable productivity gains remained limited until the 1910s (Comin & Mestieri, 2014). This timing disconnect – where initial investments temporarily depress measured efficiency before generating substantial productivity gains – would become a defining feature of all subsequent technological waves.

Most rural areas remained without electricity until the 1936 Rural Electrification Act extended grids via cooperative financing, raising farm electrification from 7% to 90% by 1950 and narrowing urban-rural productivity gaps (Lewis & Severnini, 2020; Stokey, 2021).

The international diffusion trajectory exhibited similar characteristics with notable variations. Europe's industrial clusters achieved swift adoption rates, while large, sparsely populated colonial regions faced extended delays until post-independence states secured the necessary fiscal resources. Where governments utilised tariff sovereignty or concessional financing to support electrical grid infrastructure – such as Sweden's hydropower coordination programmes or India's Five-Year Plans – electrical penetration accelerated dramatically, reducing regional income disparities (Keller, 2004).

3.3 WAVE II – THE INTERNET/ICT REVOLUTION: FROM RESEARCH BACKBONE TO MOBILE MARKETPLACE

When the first data packet travelled across an experimental computer network in 1969, the scientists behind it envisioned little beyond efficient computational resource sharing. Fast forward five decades, nearly five billion individuals now own networked devices, with Internet Protocol as essential and seamlessly integrated into our lives as electricity. The profound economic impact of the internet arose not from its technical prowess but from how quickly and widely it was able to spread thanks to existing factors. In the case of the internet diffusion was enhanced by self-reinforcing network effects, where more users attract more users.

**The profound economic impact
of the internet arose not from its
technical prowess but from how quickly
and widely it was able to spread thanks
to self-reinforcing network effects, where
more users attract more users.**

Throughout the 1970s and 1980s, communication and internet protocols were primarily utilised by defence contractors and research universities. The first communities to adopt the technology tended to be young, highly educated and international. These traits proved consequential for diffusion dynamics. Tacit knowledge transfer occurred rapidly through graduate educational settings and open-source communication networks; successive cohorts transformed their newly acquired technical competencies into practical applications, systematically lowering entry barriers for future adopters. By the time Tim Berners-Lee launched the inaugural World Wide Web server in 1991, the underlying code architecture had already achieved maturity.

Deregulation in the form of the Telecommunications Act of 1996 and urban subscriber density drove consumer adoption, lifting US internet use from 52% of adults in 2000 to 95% by 2023 (Pew Research Center, 2024).

Initial investments in information and communication technology (ICT) triggered a productivity paradox as companies restructured; by 2000, integration of point-of-sale systems, databases and online interfaces had doubled US total factor productivity (TFP) growth (Brynjolfsson et al., 2019).

Advanced economies rapidly replicated the US trajectory, while low- and middle-income nations faced prolonged delays due to inadequate fixed-line infrastructure. The breakthrough emerged from wireless transmission technologies, such as the global system for mobile communications (GSM). These standards enabled voice-oriented base stations to be upgraded through software for packet data transmission, dramatically reducing deployment costs. Mobile broadband now accounts for some 75% of new connections, lifting world internet penetration from 16% in 2005 to 68% in 2024 (ITU, 2024).

3.4 WAVES III AND IV – FROM HISTORICAL PATTERN TO FORWARD GUIDE: PROJECTING THE FRAMEWORK ONTO ROBOTICS AND AI

The parallel development narratives of electrical and internet technologies reveal a systematic choreography characterising the diffusion processes of the major general-purpose technologies examined in this study. FIGURE 8 encapsulates this framework into three sequential phases: *Development & Early Adoption*, *Market Scaling & Augmentation*, and *System Integration & Transformation*. Each phase enables distinct productivity enhancement mechanisms that have remained remarkably consistent across technological domains and over time.

This systematic progression creates what economists call the productivity J-curve, where initial technology investments temporarily depress measured efficiency as organisations absorb substantial learning costs, before accelerating rapidly during later phases (Brynjolfsson et al., 2021).

FIGURE 9 illustrates this pattern across all major technological waves, showing how productivity trajectories follow remarkably similar paths despite vast differences in technological architecture and historical context.²

Industrial robotics has progressed through various developmental phases and is currently transitioning from *Market Scaling & Augmentation* to *System Integration & Transformation*. The technology began its early development phase in the 1980s and 1990s with applications in automotive welding. It then achieved market scaling through collaborative robotic systems and is now nearing full system integration with just-in-time production systems.

² The trajectories presented here reflect our analytical synthesis of findings from key studies: electricity diffusion patterns from Atkeson and Kehoe (2007) and Devine (1983); internet productivity impacts from Brynjolfsson and Hitt (2003) and Jorgenson and Stiroh (2000); robotics deployment effects from Acemoglu and Restrepo (2020) and IFR data; and AI productivity estimates from Acemoglu (2025), Autor (2024) and McKinsey (2023) for the optimistic scenario. Although no single study offers complete trajectory data across all phases, the fundamental J-curve pattern consistently emerges, enabling us to construct representative diffusion paths that capture the essential dynamics observed across technological waves. The range of AI productivity trajectories is defined by Acemoglu (2025) for the conservative automation scenario and is extrapolated from Autor (2024)'s complementarity thesis, adjusted in relation to historical productivity surges observed during the diffusion of the internet.

FIGURE 8
The three-phase technology diffusion framework

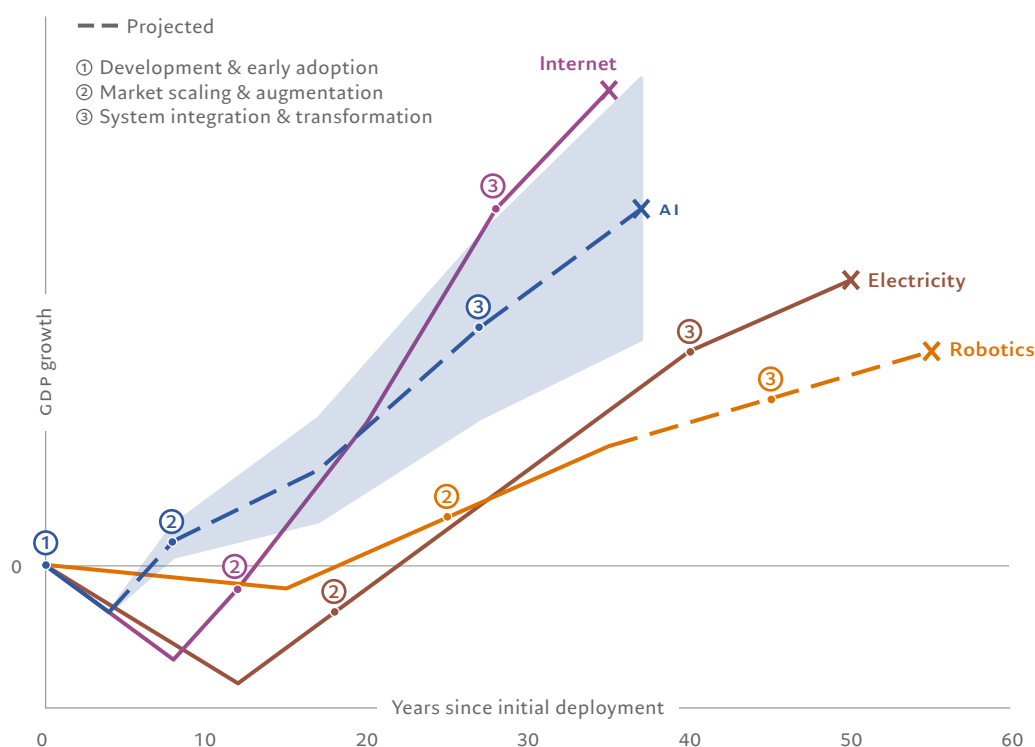
● Complete
● In progress
● Waiting line

The recurring three-stage technology diffusion ladder for GPTs

	1 DEVELOPMENT & EARLY ADOPTION	2 MARKET SCALING & AUGMENTATION	3 SYSTEM INTEGRATION & TRANSFORMATION
Key characteristics	- High costs, specialised users - Proof-of-concept implementations	- Network effects multiply value - Regional ecosystems form	- Seamless coordination across systems - Complete economic transformation
Electricity 1880-1950	Urban lighting	Mass consumer adoption and industrial clusters	Rural electricity expansion
ICT/Internet 1980-2010	Connecting research institutions	Platform grants (e.g., Google, Amazon)	Remote work and mobile payments
Industrial robotics 1980-present	Automotive welding robots	Collaborative robots in manufacturing	Just-in-time production systems
AI/Machine learning 2015-present	Route optimisation and predictive analytics	Medical diagnosis assistance	Predictive coordination systems

Sources: Acemoglu (2021, 2025), Acemoglu & Restrepo (2018), Brynjolfsson et al. (2021), Calvino & Fontanelli (2023), Comin & Mestieri (2014), Keller (2004), Lipcsey (2024), Stokey (2021), UNCTAD (2023), Pictet Research Institute

FIGURE 9
The productivity J-curve across general-purpose technologies



Source: Pictet Research Institute

Note: Based on empirical synthesis from Acemoglu (2025), Acemoglu & Restrepo (2020), Atkeson & Kehoe (2007), Autor (2024), Brynjolfsson et al. (2021), Brynjolfsson & Hitt (2003), Devine (1983), IFR (2024b), Jorgenson & Stiroh (2000), McKinsey (2023).

AI is currently finishing phase 1 and entering the early stages of phase 2. After completing its foundational development phase with applications in route optimisation and predictive analytics, AI is now starting to scale through human-AI collaborative systems in medical diagnostics and other sectors. The technology has not yet advanced to phase 3, *System Integration & Transformation*, where predictive coordination systems will facilitate a complete economic transformation.

In robotics, scaling has accelerated due to the formation of regional ecosystems around key manufacturing facilities. Robot deployment densities in Japan, South Korea and China now exceed 40 per 1,000 workers, nearly quadrupling the global average (IFR, 2024a). Productivity improvements have followed the established trajectory shown in FIGURE 9, with cross-country manufacturing data indicating that increased robot density contributes approximately 0.4% to annual GDP growth (see Table 2 in Graetz & Michaels, 2018).³ Notably, robotics seems to have avoided the significant J-curve dip experienced by electricity and the internet thanks to the knowledge and experience gained from previous waves. This framework offers a structured method for identifying where various technologies are within their productivity cycles and determining when coordination benefits – and therefore the biggest growth opportunities – may arise.

Unlike previous technologies, the productivity dip associated with AI arises from significant intangible investments in data infrastructure, organisational restructuring and workforce retraining, which temporarily outweigh measurable returns. Companies are currently incurring substantial costs while facing integration challenges and learning curves. This has resulted in a brief but intense disruption period where cognitive work processes are being redesigned more quickly than workers may be able to adapt to, leading to temporary potential productivity declines despite considerable technological advancements. However, the recovery phase is expected to be of similar steepness as that of robotics, due to AI's network effects and the knowledge and experience accumulated during the disruption period and the diffusion of previous related technologies.

AI is currently entering the early scaling phase. The infrastructure required for the augmentation phase has only emerged in the last decade: affordable cloud computing capacity, extensive datasets classified for use by AI (labelled datasets) and computational capacity (GPU-accelerated training architectures). As companies initially adopted AI for specific cost-reduction applications, the benefits of its usage are still localised. Fewer than 7% of non-ICT enterprises report scaled AI implementation across 11 countries; within manufacturing sectors, this figure drops below 4% (Calvino & Fontanelli, 2023).

³ The referenced research measures TFP growth, which we translate into GDP growth impacts based on our empirical relationship where a 1% increase in TFP growth corresponds to a 0.8% increase in GDP growth. This conversion assumes that gains in TFP are proportionally aligned with GDP growth. The 0.8 multiplier is derived from an ordinary least squares (OLS) estimation using a cross-country panel regression involving 69 developed and emerging economies from 1993 to 2023, similar to Graetz and Michaels (2018). This relationship is underpinned by standard growth accounting theory as outlined by Solow (1956), which breaks down GDP growth into contributions from labour, capital and TFP.

Contributing factors reflect historical trends: shortages of machine-learning engineering talent, liability uncertainties in safety-critical operations and substantial intangible investments in data curation and organisational restructuring. However, signs of wider usage are emerging. In radiology applications, human-AI collaborative systems are enhancing diagnostic accuracy; distribution centres employing vision-guided technologies are achieving double-digit increases in picking speed; conversational agents are managing routine banking inquiries, allowing human staff to concentrate on exception-management tasks.

The convergence timeline indicates considerable opportunities ahead, albeit with crucial timing considerations. FIGURE 9 shows that AI is currently in the early phases of its J-curve trajectory, having completed its foundational phase and just beginning to scale. But the scaling process may not be the same in all economies or happen at the same time across sectors and geographies.

FIGURE 9 depicts the expected AI J-curve based on the experiences of the previous general-purpose technologies. Individual outcomes by industry and country may vary, but many advanced economies are likely to be going through the lowest point of AI's productivity J-curve in the next five to ten years. The challenge for those economies will be to manage the structural unemployment that AI applications may cause with the demographic issues the economies will be facing at the same time. The transition to a smaller workforce and more automated production processes will depend on strategic planning, workforce retraining and the pace of AI diffusion.

Although the eventual productivity path of AI is unknown, we can provide a range of possible outcomes based on existing research. Acemoglu (2025) estimates that current AI task-automation trajectories could enhance US GDP growth by 0.4% over the next decade.⁴ In contrast, Autor (2024) argues that AI's distinct ability to support human expertise rather than just replace it could result in significantly greater productivity gains than previous general-purpose technologies. Unlike earlier technologies that automated routine tasks, AI can enhance expert decision-making and broaden the application of human skills to a larger workforce. This complementary effect indicates that the potential trajectory of AI's productivity could be much steeper than current estimates based on automation alone suggest.

Building on Autor's (2024) framework and drawing parallels with the surge in productivity during the internet's J-curve, our upper bound projection suggests that AI could lead to productivity gains in the range of 1.0% to 1.5% – similar to those of robotics.⁵ We use Acemoglu's (2025) more conservative projections as a potential lower bound.

⁴ See footnote 3.

⁵ Aghion and Bunel (2024) confirm these estimates independently.

4. Automation diffusion: economy-level and sector insights

Industrial robots have evolved from being mere curiosities in factories to essential components of leading economies. The statistics are compelling: South Korea operates 101 robots per 1,000 employees – over six times the global manufacturing average of 16 (IFR, 2024b). Singapore follows with 77, while China, Germany and Japan each utilise more than 40 per 1,000 workers. With 541,000 new robots installed worldwide in 2023 and costs reduced to one-fifth of 1990 levels (Graetz & Michaels, 2018), this technology has clearly surpassed the early adoption phase.

Robots can serve up to two economic purposes:

- **Substitution robots** directly take the place of workers who are becoming scarce or expensive to employ.
- **Productivity robots** improve hourly output by increasing speed, maintaining quality or minimising waste. They complement the workforce rather than replace it.

Recognising this distinction clarifies why ageing economies tend to follow a predictable sequence: substitution comes first, followed by productivity enhancement. Initially, substitution robots address immediate labour shortages. An example might be robotic arms lifting heavy pallets or performing repetitive assembly tasks. Subsequently, productivity robots enhance the value of each worker. This could be precision welding systems that eliminate defects or AI-driven quality control that identifies errors that humans might overlook.

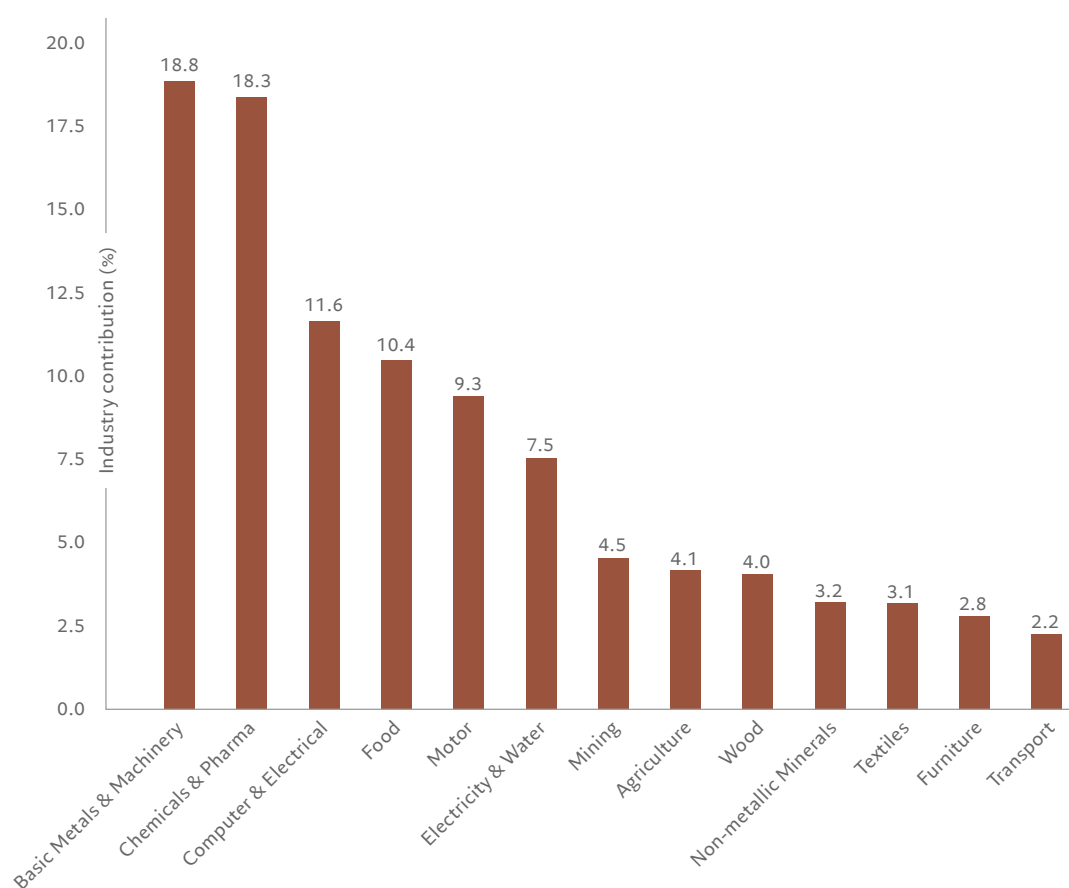
How ageing economies navigate this transition is crucial to their economic prospects. Substitution robots simply sustain production levels with fewer workers, whereas productivity robots have the potential to increase output and generate competitive advantages. Yet worker replacement robots can be implemented swiftly, while productivity-enhancing systems need additional investments in training, data systems and organisational redesign, which typically take years to yield returns (Acemoglu & Restrepo, 2022). Those economies that successfully navigate both phases can counteract labour shortages with productivity gains, whereas those that remain in the substitution phase run a real risk of declining competitiveness as costs increase without corresponding improvements in efficiency.

4.1 ROBOTIC DIFFUSION PATTERNS ACROSS ECONOMIES AND SECTORS

Our analysis in the rest of this study draws on a specially constructed dataset that merges detailed information on robot activities with demographic data from around the globe. Central to this is the IFR database, which tracks the annual number of robots installed by specific applications – such as arc welding, packaging or machine tending – across 75 countries accounting for over 90% of global robots.

FIGURE 10 illustrates the contribution of various industries to total industrial and agricultural GDP across four major regions – the EU, Japan, China and the US – averaged over the period 2008-2022. We can then examine which of these industries are more conducive to automation and therefore estimate the potential impact that automation and AI may have on productivity once fully diffused.

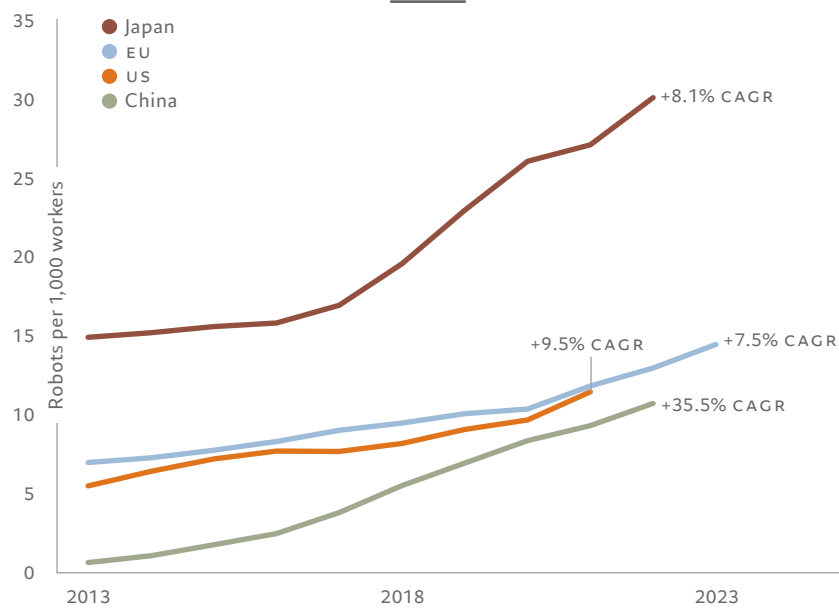
FIGURE 10
Industry breakdown of industrial and agricultural
GDP across major economies
(Japan, US, EU, China; 2008-2022 average)



Sources: National Bureau of Statistics (China), Statistics Bureau of Japan, Ministry of Economy, Trade and Industry (Japan), U.S. Bureau of Economic Analysis, U.S. Census Bureau, UNIDO, World Bank

Note: Yearly industry output has been adjusted for inflation to be able to calculate a cumulative contribution.

FIGURE 11
Automation intensity in the Basic Metals & Machinery industry across major economies (2013-2023)



CAGR = compounded annual growth rate
Sources: International Federation of Robotics, Pictet Research Institute

The significance of Basic Metals & Machinery in global industrial output coincides with the sector's widespread adoption of automation given its standardised production processes and focus on precision manufacturing. With the sector accounting for nearly one-fifth of industrial GDP, the pace of further adoption of automation through robotics and AI could significantly influence future productivity gains.

FIGURE 11 illustrates the different paces of automation intensity in the Basic Metals & Machinery industry in Japan, EU, US and China and is consistent with the idea that the J-curves of automation and AI may differ across countries and regions.⁶

- **Japan** leads the automation process in the sector as an early adopter that continues to fine-tune the usage of robots in the production process.
- **China** demonstrates a steady upward trajectory of automation adoption increasing from 1 to nearly 10 robots per 1,000 workers in just a decade.

The US and the EU show similar automation growth but given the better demographics of the US relative to the EU, we can view the pace of adoption in the US as being proactive in anticipation of its future needs. In fact, the adoption of robots in the US is likely the result of the country's position as a technology leader and its focus on industries that inherently demand productivity-enhancing automation, such as precision manufacturing and high-tech sectors.

⁶ Automation intensity, measured by the number of robots per 1,000 workers, is a popular benchmark for productivity potential across countries. The IFR defines industrial robots as "automatically controlled, reprogrammable multipurpose manipulators," highlighting their versatility. However, a single advanced robot can replace multiple simpler machines without changing the workforce, resulting in lower automation intensity but potentially higher productivity. Despite this limitation, research findings defend automation intensity as a metric and show corroborating evidence that the proxy correlates with productivity enhancement (see Acemoglu & Restrepo, 2018; Graetz & Michaels, 2018). The metric's usefulness is preserved by assuming that strong industrial countries will eventually adopt similar advanced robot technologies. Under this assumption, each robot represents roughly equivalent productive capacity, making cross-country comparisons attainable.

The use of robotics in Japan, the EU, the US and China is further examined below, where we explicitly distinguish between robots aimed at substituting labour and those aimed at enhancing productivity.

4.2 ROBOTS FOR PRODUCTIVITY ENHANCEMENT VS LABOUR SUBSTITUTION

The data on robot usage show that most robots currently in use are designed to enhance productivity rather than replace workers, including in the US, where the demographic pressures are less severe than in the other geographies examined.

Our measurement approach is intentionally conservative. Using the IFR database, we only account for the direct economic impact of robots currently in operation, disregarding broader effects such as improvements in supplier networks or overall quality gains that may permeate the economy. As a result, our estimates may understate the true economic benefits of robots used in the production process.

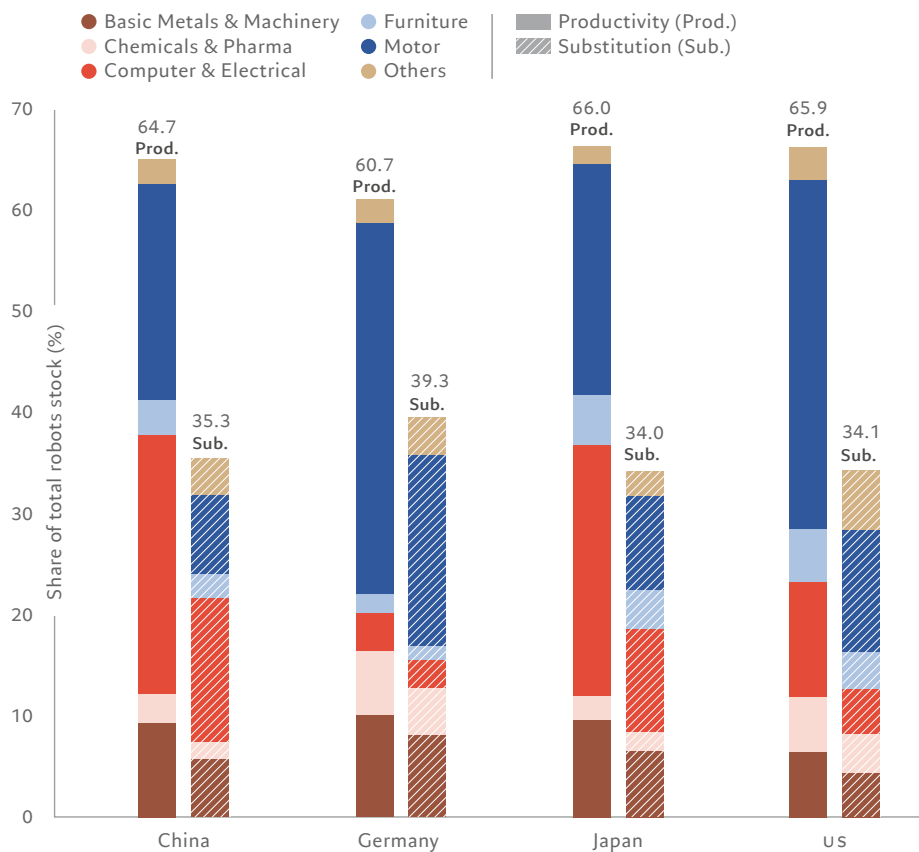
Worker replacement robots can be implemented swiftly, while productivity-enhancing systems need additional investments in training, data systems and organisational redesign, which typically take years to yield returns.

Using expert interviews and guidelines provided in Graetz and Michaels (2018) and IFR (2024b) we develop a classification methodology that assigns (fractional) usage of robots to whether they mainly substitute for labour (e.g., moving heavy pallets) or enhance productivity (e.g., laser welding). We classify each robot application based on its primary function. Our approach also allows for hybrid uses of robots that result in both substitution of some labour and enhancement of productivity in the remainder employed. We further develop a mapping system that translates robot applications into industry categories.

FIGURE 12 shows the breakdown of robot usage between productivity-enhancing and labour-substituting and by sector. In Japan, the US and China, approximately two thirds of robots are focused on enhancing productivity rather than eliminating jobs. Germany is a laggard in that process, with 60.7% of robots aimed at enhancing productivity and 39.3% still substituting labour. This implies there is room for increased productivity gains in Germany if the country advances in its automation process towards levels found in Japan, the US and China.⁷ Across all four countries, the productivity-enhancing use of robots

is deployed primarily in the Motor industry, while in China and Japan productivity gains are also gained through the use of robots in the Computer & Electrical sector. The evidence from FIGURE 12 is consistent with that provided in Graetz and Michaels (2018), who show that robot usage has contributed approximately 0.36% annually to labour productivity growth, with two thirds of this increase resulting from overall efficiency improvements rather than workforce reductions.

FIGURE 12
Productivity vs. substitution – robot applications
by sector, usage and country (2023)



Sources: IFR, Pictet Research Institute

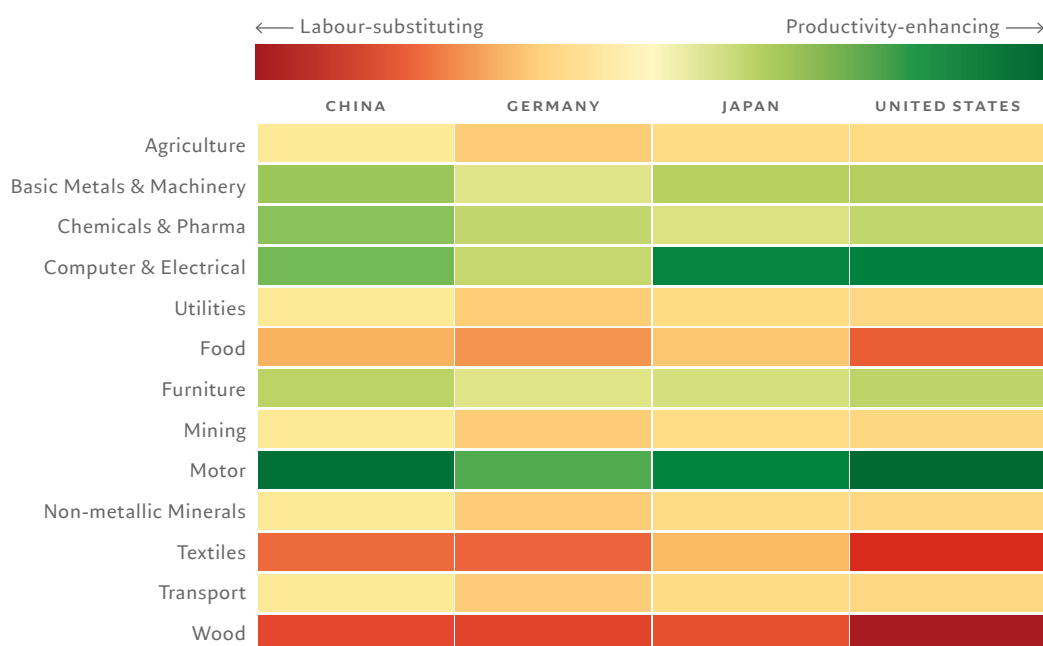
Note: Shaded bars denote labour-substitution use of robots while solid bars depict productivity-enhancing use of robots.

4.3 SECTOR DIFFERENCES IN AUTOMATION

Country-level patterns mask important sector differences. FIGURE 13 depicts the extent to which automation has been adopted to substitute labour or to enhance productivity across different industries and countries, presented as a heatmap analysis. This depiction highlights three distinct automation patterns that are consistent across nations, while still taking into account the specific demographic and economic conditions of each country.

⁷ The results remain consistent whether derived from the IFR robot application data or from our industry-based mapping. Conversely, India, which is not part of further analyses, exhibits the highest focus on productivity at 74.2%. This aligns with India's younger workforce. Companies are not facing challenges in sourcing workers, so they primarily utilise robots to enhance quality and efficiency rather than to fill labour shortages.

FIGURE 13
Share of productivity-enhancing vs. labour-substituting
industrial robots by country and industry (2023)



Sources: IFR, Pictet Research Institute

Technology-intensive sectors, such as Motor and Computer & Electrical, use robots mainly for precise welding and assembly, where human error can lead to significant defects. They have a strong focus on productivity enhancements underscoring the complementarity between labour and technology, regardless of demographic developments.

Labour-intensive sectors, such as Textiles, Wood and Food, show considerable variation across countries and typically favour substitution applications. Robots in these industries do heavy lifting and repetitive tasks, addressing pressures from ageing workforces. Countries facing labour shortages have a greater tendency towards automation, even in traditionally manual sectors.

Hybrid sectors, including Chemicals and Pharmaceuticals or Basic Metals & Machinery, use varying levels of automation. The reasons may be country-specific or related to the segment within the industry they are concentrated on.

The above taxonomy suggests that while there may be room for further automation and productivity gains across most industries, the biggest incremental productivity gains may be made with the use of automation in hybrid industries that have underinvested in technology. As a rule, the more precise the work and the higher the cost of errors, the higher the incentive for companies to invest in automation to control costs and remain competitive. In addition, the demographic factor adds further emphasis on automation by inducing companies to use the ever scarcer labour resources more productively.

4.4 AUTOMATION DISPARITIES ACROSS COUNTRIES: LESSONS FROM JAPAN

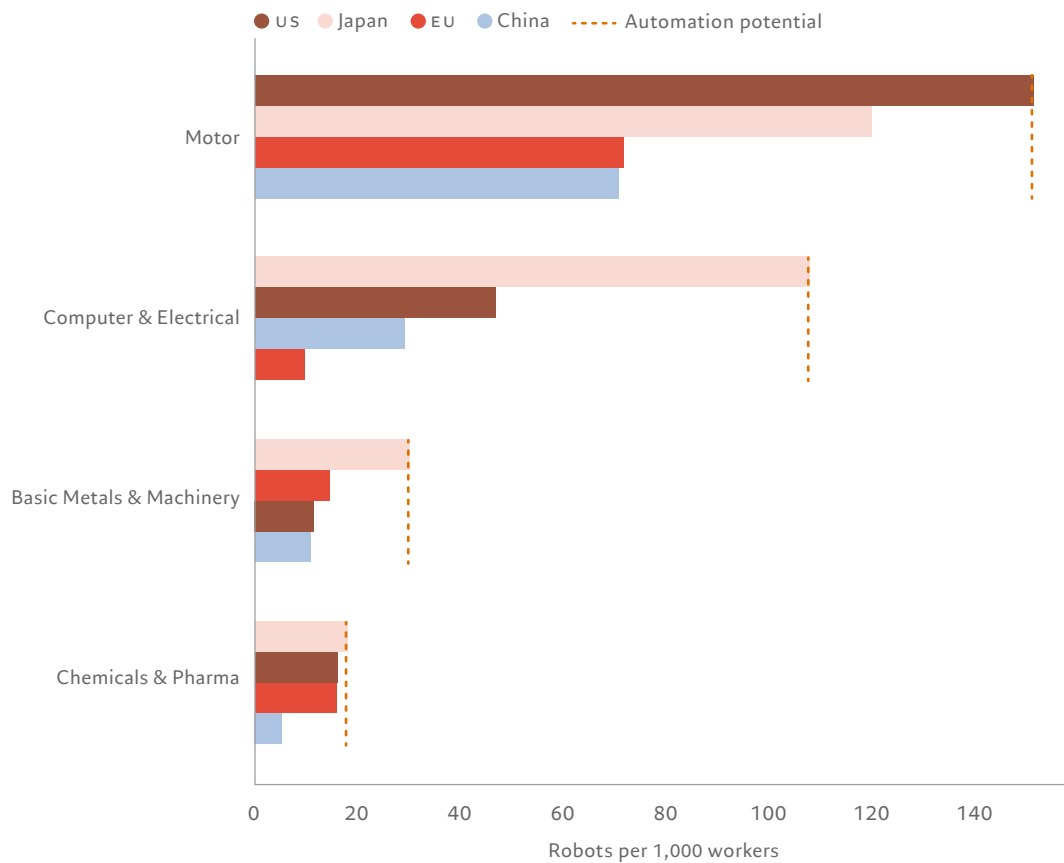
Japan's earlier struggle with deteriorating demographics led it to embrace automation from the late 1990s, when labour shortages in the Furniture and Transportation sectors became acute, as Kushida (2024) discusses. Companies needed machines to fill positions they were unable to staff. By 2010, most straightforward substitutions had been automated. Japan then transitioned to a second phase: complex electronics manufacturing, where collaborative robots and AI-powered vision systems assist ageing workers in enhancing their performance rather than replacing them entirely.

While Japan has continued to automate, reaching 100% of its potential in sectors such as Computer & Electrical, other countries are still in earlier stages of automating their production. Using the highest level of automation already achieved in Japan, US, Germany and China for the four most automation-conductive industries – Motor, Computer & Electrical, Basic Metals & Machinery and Chemicals & Pharma – FIGURE 14 illustrates the potential for automation in the four countries. It is instructive to look at these industries as not only the most conducive to automation, but also as the three largest contributors to global GDP, with the Motor industry being the fifth, as seen in FIGURE 10.

Japan's earlier struggle with deteriorating demographics led it to embrace automation from the late 1990s.

The highest levels of automation are found in Japan, except in the Motor industry, where the US leads the way. Clearly, the automation potential is still significant in the Motor, Computer & Electrical and Basic Metals & Machinery industries. This implies that these industries could achieve significant productivity gains and cost savings going forward as automation becomes more widely diffused, especially in the EU and China, with still significant room for improvement in the US, especially in Computer & Electrical and Basic Metals & Machinery.

FIGURE 14
Automation potential by industry and country (2022)



Sources: IFR, Pictet Research Institute

The position of the EU in FIGURE 14 across three of the four industries reveals the effects of the underinvestment in technology in Europe and the potential for productivity gains that may lie ahead if automation is widely adopted. Even though China relies heavily on manufacturing and has made considerable technological advancements, FIGURE 14 shows considerable room for further automation across the four industries examined, suggesting that productivity in China could be further enhanced through automation despite the negative demographic trajectory of the country.

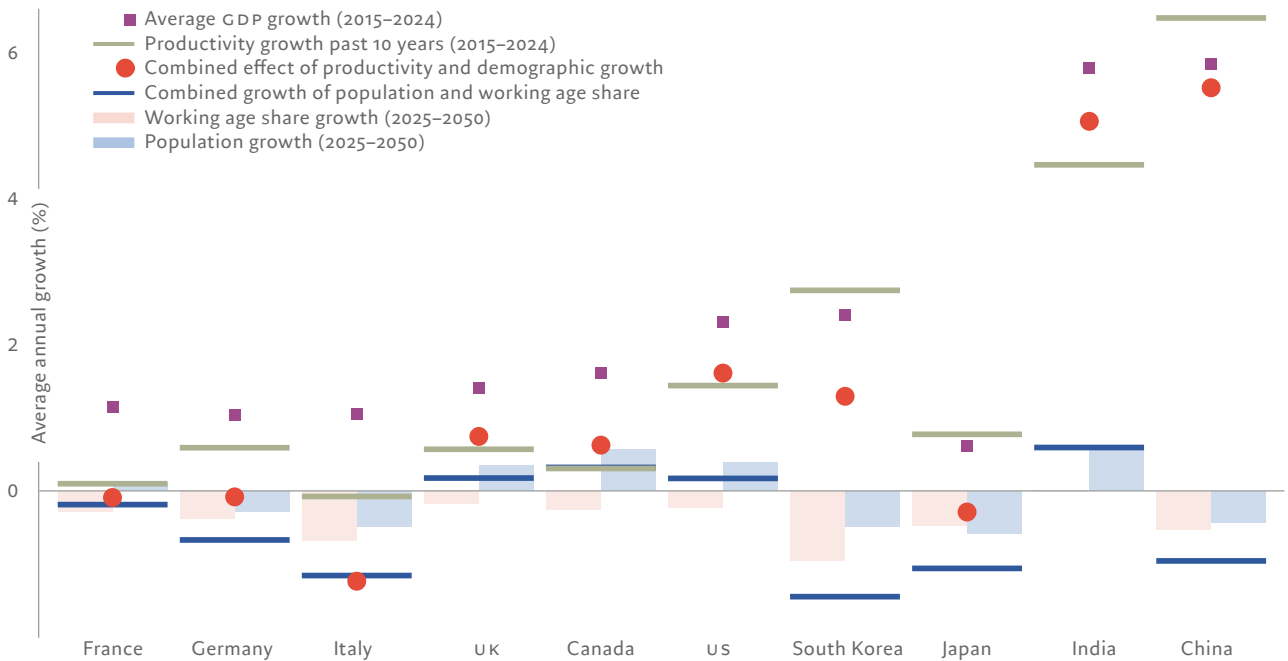
5. On the economic impact of AI and automation

To assess the net economic impact of new technologies and demographics, we break down GDP growth into three components: productivity growth, demographic factors (working-age population share growth and total population growth) and labour-related outcomes (growth in hours worked per worker and the employment rate). In doing so, we do not model the labour-related outcomes as they are heavily influenced by government policies which may change over time. We therefore keep these effects constant.

In the following analysis, we compare the demographic drivers of GDP growth to productivity growth to evaluate whether the challenges posed by demographic change could be overcome through productivity gains and, if so, what the requirements would be to achieve this.

FIGURE 15 depicts the magnitude of the forces at play in key countries. As explained above, demographic changes are expected to negatively affect GDP, but productivity

FIGURE 15
Comparison of demographic-relevant growth rates for 2024–2050 with past productivity growth (2015–2024)



Sources: UN World Population Prospects 2024, The Conference Board, Pictet Research Institute

Notes: The dark blue horizontal lines represent the sums of the light blue and light red bars, or the combined effect of demographic component growth (total population and working-age share). These elements represent the average annual growth rates from 2025–2050.

The green horizontal lines represent the average annual productivity growth rate from 2015–2024.

The red dots illustrate the projected impact on future GDP growth of both demographic growth and productivity growth, assuming that productivity continues to grow at its past rate.

gains are likely to counteract this trend. In every country, the working-age share of the population will decline, reaching almost 1% per year in South Korea from 2025-2050. On the other end of the demographic spectrum, India's population will grow, and the working-age share will remain constant for the next 25 years.

The US, UK and Canada have very similar demographic outlooks. Their populations are all ageing (negative growth of working-age share) but still increasing through immigration. Out of the countries examined, South Korea, Japan, China, Italy and Germany are most affected by population ageing and decline. While their demographic outlooks do not appear favourable, past productivity growth can provide a gauge as to whether they still have a buffer to maintain positive GDP growth in the long run.

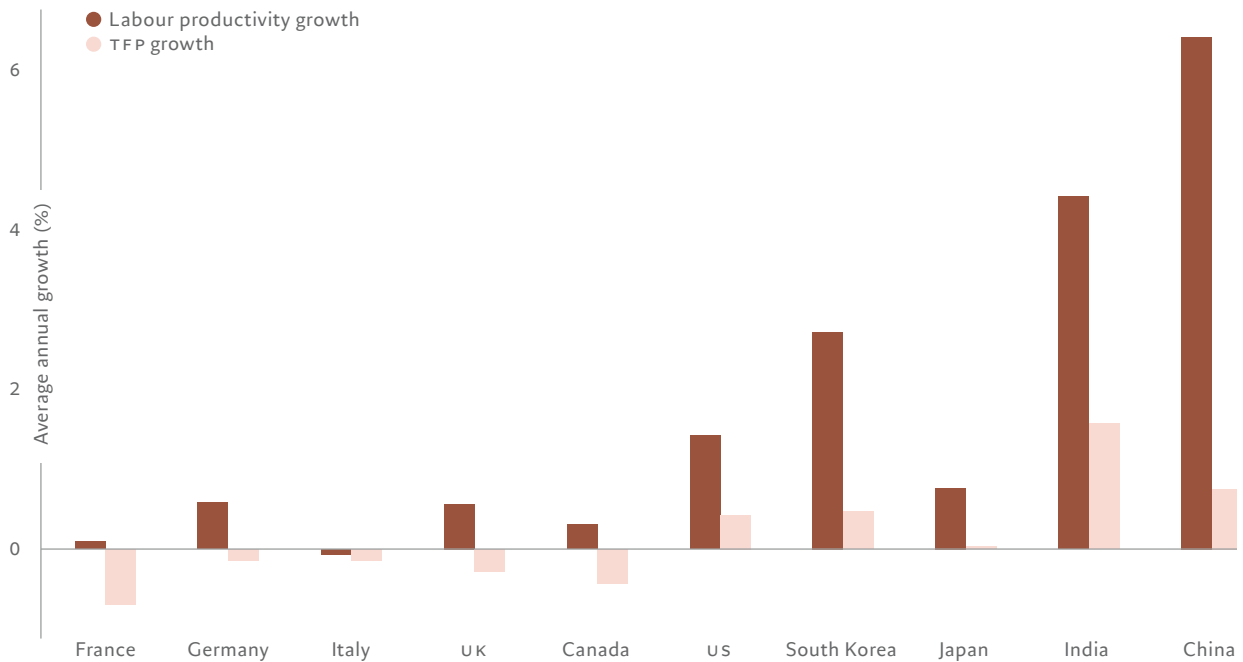
In China, average 10-year productivity growth stood at around 6.5% annually while its GDP growth was just shy of 6%. This shows that demographic and employment factors affected Chinese GDP growth negatively. Even though the impact of demographic change is expected to be around -1% annually, productivity growth in China is still very high and may grow further if automation is more widely used, showing that China still has a reasonable buffer to sustain positive GDP growth in the years ahead, albeit likely at lower levels than previously.

It is even more important for European countries to seize the opportunity that AI and automation offer to boost their GDP growth. If they do not, their economies will all but certainly stagnate.

Japan is facing its own dilemma. Despite its investments in automation, its shrinking population is keeping growth essentially flat. On the other hand, Italy, France and to some extent Germany are capping their GDP growth potential by not investing enough in automation. It is therefore even more important for European countries to seize the opportunity that AI and automation offer to boost their GDP growth. If they do not, their economies will all but certainly stagnate.

Improvements in productivity from increased use of AI can be understood as increases in TFP, which measures how efficiently capital and labour are used. FIGURE 16 shows how much of productivity growth over the past 10 years was due to TFP growth compared to simply labour productivity achieved through capital deepening. The graph shows that TFP growth does not represent a large part of productivity growth. In fact, some European

FIGURE 16
Labour productivity growth vs TFP growth (2015–2024)



Source: The Conference Board, Pictet Research Institute
Notes: Labour productivity is defined as output per labour hour.
Average annual growth rates from 2015–2024.

countries and Canada have negative TFP growth. At the other end of the spectrum, TFP represents an important part of India's productivity growth. Overall, FIGURE 16 shows that several countries are sitting on untapped potential and could increase GDP growth by making better use of existing labour and capital resources.

5.1 HOW AUTOMATION AND AI MAY AFFECT PRODUCTIVITY AND US DEBT SUSTAINABILITY

We now examine the impact of automation on GDP growth by assessing how reaching automation potential could enhance productivity growth, thereby boosting GDP. We then assess the implications for US debt-to-GDP dynamics, given the current emphasis on automation and technology and the growing concern about the sustainability of US debt.

Our analysis makes use of the relationship between productivity growth and increased robot intensity. According to Dauth et al. (2017), an increase of one robot per 1,000 workers results in a 0.54% rise in productivity growth (GDP per worker) over a decade.⁸ We use this estimate to express automation intensity in terms of likely productivity gains in the EU, Japan, China and the US assuming that each of the industries in these countries reaches peak automation intensity. As a conservative

⁸ This estimate is derived from the German market between 2004 and 2014. The authors obtain their estimate through a regression with instrumental variables and relevant control variables.

estimate of peak automation potential, we use the highest automation intensity observed in each industry across the countries considered. For most industries, peak automation is found in Japan, except in some select cases where it is seen in the US. We then express the industry-level automation potentials in terms of productivity gains by industry using the methodology in Dauth et al. (2017). Next, we weight each industry by its contribution to the country's GDP to calculate the possible impact that reaching peak automation potential in each industry could have on the country's productivity.

The results are summarised in TABLE 2. Our analysis only considers the impact of automation in manufacturing and agriculture as these are the only sectors that robotics data exist for. The two sectors combined account for 19% of GDP in the US but as much as 45% in China. This implies that the impact of automation and AI on services could be important for future GDP growth potential, especially in the US. We estimate the potential productivity growth of each economy based on two scenarios. In one,

TABLE 2
Estimated impact of increased automation
on productivity growth

	SHARE OF GDP ⁹		SCENARIOS: IMPACT ON ANNUAL PRODUCTIVITY GROWTH ¹⁰	
	INDUSTRY & AGRICULTURE	SERVICES	EQUAL IMPACT ON INDUSTRY AND SERVICES	REDUCED IMPACT ON SERVICES
CHINA	45%	55%	+1.7%	+1.1%
EU	25%	66%	+1.4%	+0.7%
JAPAN	28%	71%	+0.3%	+0.2%
US	19%	76%	+0.6%	+0.3%

Sources: CIA World Factbook, IFR, Pictet Research Institute.

⁹ Industry, agriculture and services shares of GDP might not total 100% due to non-allocated consumption not captured in sector-reported data.

¹⁰ Estimated effect on annual productivity growth based on Dauth et al. (2017) and IFR data. Robotics data available for industry only. Assumptions for the service sector: (1) the automation potential in industry and services is similar and the marginal impact of robots on productivity growth is also similar; (2) the marginal impact of robots on productivity growth in services is one third of the impact in industry.

we assume that manufacturing and services are equally conducive to automation. In the second, more conservative one, we assume that services are one third as conducive to automation as manufacturing and agriculture. In both scenarios, automation leads to substantial positive effects on productivity gains in the overall economy.

5.2 US DEBT-TO-GDP AMID TECHNOLOGY-INDUCED PRODUCTIVITY GAINS

According to the Congressional Budget Office (CBO), the ratio of US federal debt held by the public to GDP is forecast to climb from 100% in 2025 to 118% in 2035, not including any productivity gains from AI or further automation.¹¹ If automation were to boost US GDP growth as estimated above, the same debt-to-GDP ratio could rise less than that, to 112% in 2035, assuming that the impact on services and industry is equal and debt accumulation projections are the same as in the CBO forecasts.¹²

5.3 CHANGING CONSUMPTION PATTERNS IN AN AGEING POPULATION

Current projections for Japan suggest that by 2049, consumers over the age of 74 will represent around 28% of total domestic consumption – nearly doubling from 2004. The US is following a similar path but at a slightly slower rate, with the share of elderly consumption expected to increase from ~8% to 14%. How do consumption patterns change as a population ages? And what do these changes imply for economic growth and investment opportunities going forward?

Consumption data going back to 2004 across the EU, Japan and the US reveal remarkably consistent patterns in how consumption evolves as households transition between age groups. FIGURE 17 presents the results.¹³ It shows that as people age, they spend more on housing, healthcare and food, and less on clothing, transportation and recreation.

The biggest changes in consumption occur when households move from middle aged to elderly (defined as those above 74 years of age), with housing and health expenditure seeing the largest increases. As households make this transition, the share of housing in their consumption rises sharply, increasing by 7.2% in the US, 1.4% in Japan and 3.8% in the EU. These additional expenditures are driven by the growing costs of modifying homes for age-related needs, assisted living and healthcare requirements. The elderly also spend more on health, with US households increasing their share by 6.6% compared to their middle-aged years, while Japan and the EU see increases of 1.9% and 0.9%, respectively.

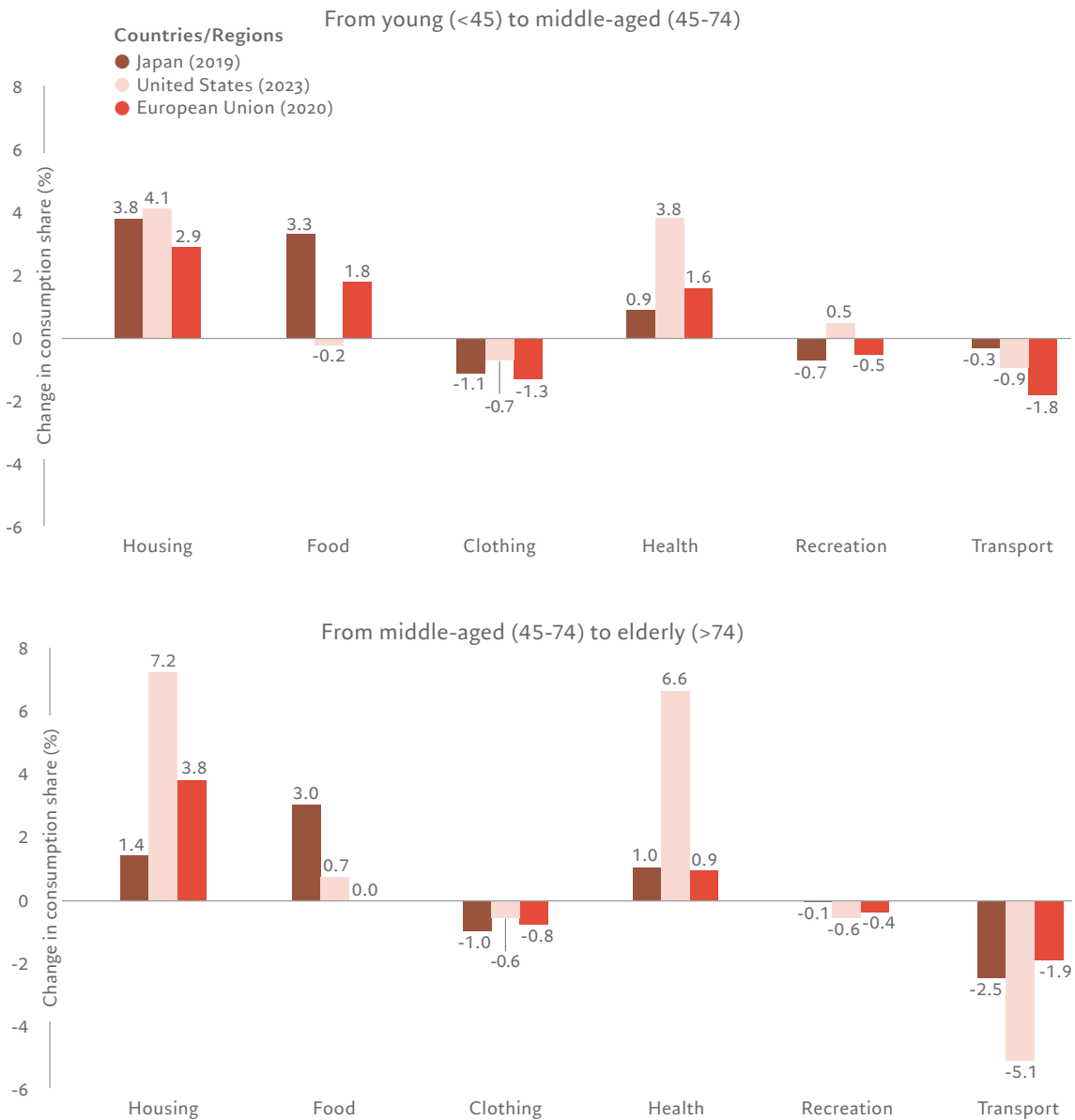
11 The CBO writes in its report: “Conversely, economic growth could be stronger than CBO projects. An increase in productivity – because of technological changes, for example – or the discovery and development of natural resources could cause such a development. In that case, revenues would be higher than CBO projects, and outlays, including those for income support programs, would be lower. The effect of artificial intelligence (AI) on the economic outlook is another source of uncertainty. Because AI has the potential to change how businesses and the federal government produce and provide goods and services, it could affect economic growth, employment and wages, and the distribution of income in ways that are difficult to predict. The direction of those effects (that is, whether they would increase or decrease federal revenues or spending), their size, and their timing are all uncertain.”

12 We assume that the impact on productivity directly translates into GDP growth, as Dauth et al. (2017) show that an automation boost does not impact the labour part of the production function. Under the scenario of reduced impact of services, the ratio could reach 115% in 2035.

13 To facilitate comparisons of spending patterns across countries with diverse reporting systems, we standardise all data using the international consumption classification framework published by the UN (2018). Population data for this analysis are sourced from the UN. For the EU, we adjust each country's data according to its population size, using official population figures from Eurostat. Similar methodologies for collecting and analysing household expenditure data have been utilised in other studies and further discussed (Browning et al., 2014; Crossley & Winter, 2013).

Consumers also adjust their spending habits between younger years and middle age. Japanese households allocate 3.8% more to housing, US households 4.1% and Europeans 2.9%. In contrast, every age group spends less on clothing in every region. Transportation expenditure also decreases with age, with elderly Americans cutting back by 5.1%, Japanese by 2.5% and Europeans by 1.9%, largely due to reduced mobility and changing transportation needs.

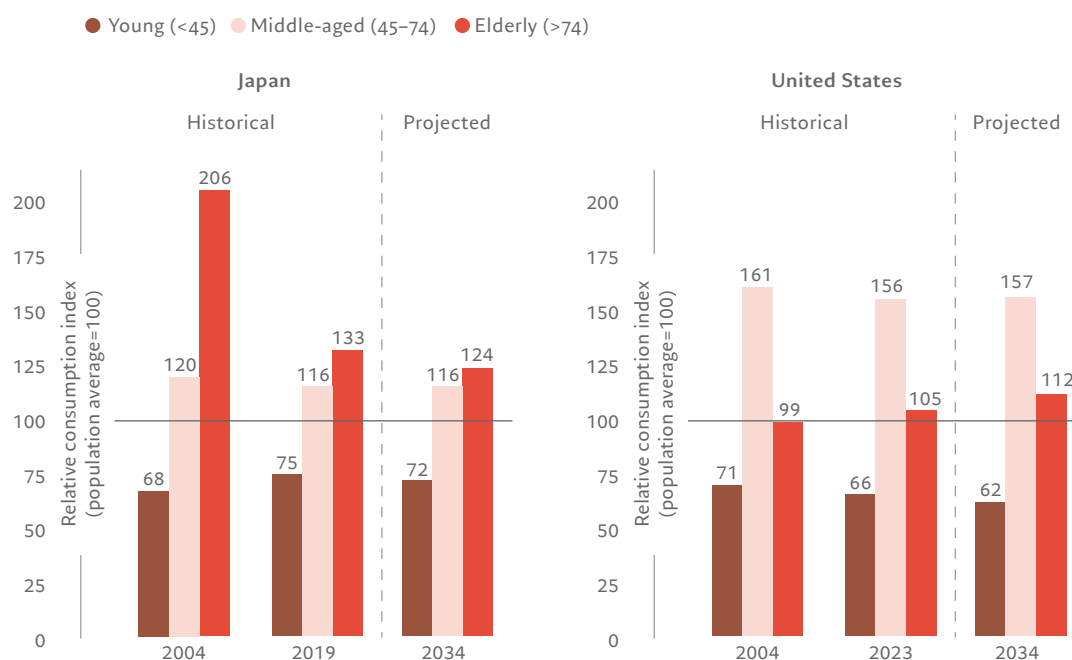
FIGURE 17
Age-based consumption trends: Japan, US & EU



Sources: Japan Portal Site of Official Statistics, U.S. Consumer Expenditure Survey, Eurostat, Pictet Research Institute

Note: Charts show percentage point changes in consumption shares as households transition between age groups.

FIGURE 18
Relative consumption per capita by age group:
Japan vs United States
(Relative to population average)



Sources: Japan Portal Site of Official Statistics, U.S. Consumer Expenditure Survey, UN World Population Prospects 2024, Pictet Research Institute

Notes: Index shows consumption per capita relative to population average (100 = average). Values >100 indicate above-average consumption per person in that age group.

Historical data: Japan (2004–2019), US (2004–2023)

Projections based on UN population data.

5.4 FUTURE DEMOGRAPHIC IMPACT: ACCELERATING CHANGE

To highlight consumption differences across countries and age groups in countries at different points in their demographic journey, we focus on Japan and the US – two developed economies at different stages of their ageing process. Our data go back to 2004. FIGURE 18 shows how much an average person in each age group consumes compared to the national average and highlights significant country differences between the US and Japan. The relative consumption per capita is determined by dividing each age group's consumption per capita by the total consumption per capita for the country's population. A value above 100 means that the average person in that age group consumes more than the national average, while a value below 100 indicates below-average consumption.

In Japan, elderly households stand out for their high per capita consumption, peaking at 206 in 2004 and remaining elevated at 133 in 2019, with a moderate decline to 124 projected by 2034. In other words, elderly individuals in Japan consumed over twice the national average in 2004. Their consumption is driven not only by their wealth and preferences, but also their share in the overall population. As their share increases, their consumption per capita converges towards the national average.

In contrast, consumption is more evenly distributed across age groups in the US. Middle-aged households consistently drive consumption patterns, maintaining stable levels between 156 and 161 throughout the period, indicating they consume around 56-61% more than the national average per person. This reflects their peak earning and family-rearing years, when consumption needs are the highest. US elderly households consume moderately above average at 99-105, while young households consume below average at 66-71, lower than in Japan.

Consumption in the United States should remain stable, with middle-aged households still spending the most through 2034.

From a demand perspective, Japan's ageing population drives the high per-capita consumption, as it accounts for an increasing share of the total population.

In contrast, consumption in the United States is expected to remain stable, with middle-aged households still spending the most through 2034. However, young households are likely to see a decreased relative consumption per capita by 2034, falling from 66% to 62% of the national average, which suggests reduced demand for industries and products catering to the young US population. Meanwhile, elderly consumption per capita is set to grow steadily, increasing from 105 to 112, indicating growth opportunities for industries and products catering to the elderly.

6. Investment implications: the future winners

Looking at the intersection of changing consumption patterns due to demographics and the productivity benefits that can be reaped from automation and AI, we can identify broad potential investment themes that could be winners going forward.

The pace of automation and AI diffusion is likely to differ across geographies and industries.

The results of the previous sections suggest that the pace of automation and AI diffusion is likely to differ across geographies and industries. They also show that consumption preferences will change across countries as their populations age, although not necessarily in the same way. Country differences will need to be taken into account. We do not yet know the full effects that AI could have on the services sector – a significant component of GDP, especially in developed economies. What we do learn from this study, however, is that the more automation a sector uses and the more it caters to an ageing population, the greater its growth and productivity potential, and therefore its profitability, so long as the specific economy has the infrastructure in place for a particular technology to be adopted and achieve its potential productivity gains. Furthermore, taking into account country differences in consumption preferences among ageing populations may provide useful guidance as to the geographies where a particular investment idea may find most fertile ground.

TABLE 3
AI automation winners and losers

	SECTORS	EXAMPLES OF SUBSECTORS
Winners	Housing	Construction materials Smart home technology
	Health & related industries	Medical devices Pharmaceuticals Longevity-related products
	Food	Production Processing
Losers	Transport of people Clothing	

Based on these findings, TABLE 3 provides some general ideas of sectors and subsectors likely to benefit from the demographic transition and the technological revolutions underway. The indicative “winners” and “losers” in TABLE 3 are likely to apply to most countries facing an ageing population. However, as mentioned above, for the “winners” to be in a position to “win”, the economies in which they operate will need to have the required infrastructure for the technology to be able to produce the productivity gains expected.

Housing emerges as a potential big “winner” from our analysis, based on the importance it gains as populations age and the level of automation that can be applied, in both the production of construction materials as well as the AI- and robotics-related technology used to make housing more conducive to older households.

The more automation a sector uses and the more it caters to an ageing population, the greater its growth and productivity potential, and therefore its profitability.

Healthcare has been at the forefront of innovation and technology for a long time and has been one of the relatively early adopters of robotics and AI. But with an ageing population that lives longer, investment opportunities may extend beyond the traditional pharmaceutical and medical devices industries into areas that meet longevity-related needs and make products designed to prolong the healthy years of the population and not just treat diseases in old age.

The food sector has largely inelastic demand, but it is also amenable to automation and AI applications, both in its production phase and during processing and packaging. Demographic changes and longer lifespans may affect food preferences and demand for particular subcategories that may further vary across geographies. But the overall sector is likely to offer several potential opportunities once the demographic and automation lenses are used to evaluate related investment themes.

As is often the case, some sectors are likely to see decreased demand as a result of population ageing, which could compress their profit margins. To the extent that such sectors are also not conducive to automation and AI, they may be much less attractive from an investment standpoint. Examples of such sectors may be clothing and transportation, particularly autos. However, opportunities will always exist, even within those sectors, if they can use innovation and technology to provide new materials, products and applications that appeal to the changing demographics.

7. Concluding remarks

Most of the research on demographics focuses on the perils of a shrinking labour force for economic growth and price stability, but it ignores the positive impact that automation and the AI revolution could have on productivity and growth. At the same time, most research on automation and AI focuses on the jobs that may be lost to those technologies, but it overlooks the demographic issues they may be able to solve. This study examines the intersection of demographics and technology to identify their combined effect on future productivity, economic growth and investment opportunities. We identify three factors that need to converge for a promising investment opportunity to arise. Specifically, it needs to:

1. cater to the **demographic shifts** in a particular economy or geography;
2. be in an industry that is conducive to **automation and AI technologies**; and
3. be developed in an economy with the necessary **infrastructure** for those technologies to achieve their full productivity potential.

These factors provide a new lens for evaluating investment themes and opportunities and reinforce once more how the changing world around us requires a changing approach to investing. In this transformational environment, we need to adjust our investment framework away from broad country or sector bets and towards opportunities where demographics, innovation and infrastructure forces align.

Adapting to morphing population dynamics will require countries and industries to plan strategically and take well-timed policy and investment decisions. The historical examples of the scaling of electrification and the internet revolution, facilitated by legislation in both cases, illustrate the payoffs in store for those countries that can harness robotics and AI. As they adjust to demographic change, which will only build momentum in the coming decades, governments and businesses may need to negotiate trade-offs between robots that can quickly substitute for workers, and investments in more expensive productivity-enhancing systems that take longer to deliver results. Those that fail to confront these trade-offs and challenges are likely to struggle. Those that do so successfully are bound to mitigate the consequences of demographic change and unleash new powerful catalysts for growth.

In this transformational environment, we need to adjust our investment framework away from broad country or sector bets and towards opportunities where demographics, innovation and infrastructure forces align.

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