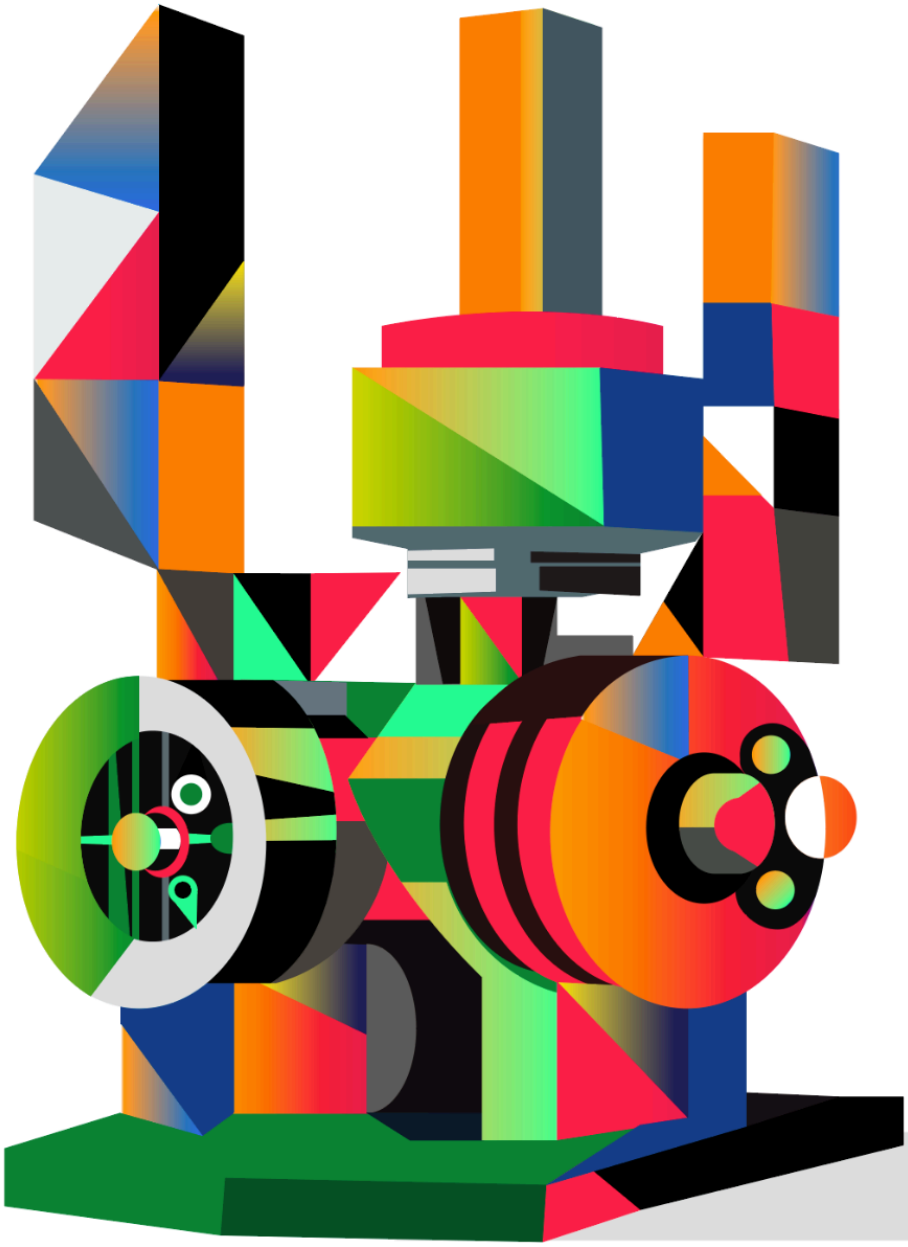
GENERALLY FASTER:

The Economic Impact of Generative AI



Andrew McAfee / 2023 - 2024 Visiting Fellow / Technology & Society at Google

Generally Faster

The Economic Impact of Generative AI

April 25th, 2024

Andrew McAfee
2023 - 2024 Visiting Fellow / Technology & Society at Google

Table of contents

Andrew McAfee is the Co-Founder and Co-Director of MIT's Initiative on the Digital Economy and a Principal Research Scientist at the MIT Sloan School of Management.

McAfee currently holds the inaugural Technology & Society Visiting Fellowship at Google. The fellowship invites renowned experts to produce original research or perspectives on technology's impact to cross-cutting societal themes like economic outcomes, sustainability, or the future of work and education. Throughout their fellowship, researchers engage with experts at Google across a variety of fields, including artificial intelligence, economics, social sciences, and public policy.

The opinions expressed in this report are solely those of the author.

Executive Summary

Generative AI is one of the rare technologies powerful enough to accelerate overall economic growth---what economists call a "general-purpose technology." These innovations have the potential to positively transform economies and societies.

By one estimate, close to 80% of the jobs in the U.S. economy could see at least 10% of their tasks done twice as quickly (with no loss in quality) via the use of generative AI.

Previous general-purpose technologies like the steam engine and electrification have brought their changes over decades. However, we anticipate that generative AI's effects will be felt more quickly due to its ease of diffusion.

This technology is already delivering large productivity gains, which will increase and spread as people and organizations come up with complementary innovations that leverage generative AI's capabilities. As a result, economic growth will speed up.

In addition to faster growth, generative AI will bring other changes. It will reduce demand for some skills, increase demand for others, and create demand for entirely new ones.

Fears of large-scale technological unemployment are probably overblown. The history of general-purpose technologies shows that the growth they bring is accompanied by strong demand for labor.

However, this increased demand is often in new occupations. For example, more than 85% of total U.S. employment growth since 1940 has come in entirely new occupations.

The rapid changes brought by the spread of generative AI will require prompt and effective reskilling efforts. These efforts will be able to draw on generative AI itself, a tool with the unique ability to help people learn how to use it better. And because Generative AI accumulates knowledge and makes it available on demand, it's particularly effective at improving the performance of entry-level employees, helping with wage inequality...

Previous general-purpose technologies have resulted in changes to the companies and countries leading the way in different industries. We believe that generative AI will be similarly powerful.

Introduction

Since the Industrial Revolution a handful of technologies have been powerful enough to accelerate the overall course of economic progress. These "general-purpose technologies" include the steam engine, the internal combustion engine, electrification, and the computer.

In this report we make the case that generative AI is a new general-purpose technology, and one that may spread more quickly than its predecessors. Generative AI is a recently developed type of artificial intelligence capable of producing new and original content such as text, images, videos, and audio. It accomplishes this by learning statistical patterns from existing data, then using these patterns to generate new and novel outputs upon request.

The arrival of generative AI is a significant development because, as the physicist Freeman Dyson put it, technology "is the mother of civilizations, of arts and sciences."
General-purpose technologies not only boost productivity and economic growth, but also contribute to many other kinds of advancement. We anticipate that generative AI will speed up scientific discovery, help innovators and engineers build better, and give creative people new ways to express themselves and move their audiences.

Of course we recognize that new technologies bring challenges as well as benefits. The internal combustion engine, for example, polluted the atmosphere, made conflict more lethal, and led to massive shifts in employment as workers moved from farms to factories.

But the long-run overall effect of tech progress has been hugely positive. In recent decades working hours have dropped while standards of living have improved around the world. Lifespans have increased and the burden of disease has eased. And key environmental indicators have started to move in the right direction. Technological progress is a fundamental reason for these and many other advances.

Exhibit 1

Health and wealth have increased alongside technological progress

Working hours
Average annual working hours across OECD countries declined more than 10% since 1970

Standards of living
Global median income per day has increased by about 150% since 1990

Lifespan
In 1900 the global average life expectancy of a newborn baby was 32 years. By 2021 this more than doubled to 71 years

Reduced global disease burden
Lifespan years lost to premature death and disability decreased by about 35% since 1990. In 1990, the disease burden in Bangladesh was 150% higher than in Belgium. By 2019, it was only 40% higher.

Positive trends in environmental indicators:
Air pollution deaths have declined globally by 45% since 1990. In 2000 61% of people around the world had access to clean water. By 2022 this had increased to 72%.

Previous general-purpose technologies have diffused relatively slowly. Decades have elapsed between their introduction and their economy-wide impact on productivity and other important outcomes. We believe, though, that generative AI's impact will be felt more quickly; its transformative effects will start to be felt this decade. This report explains our reasoning.

We begin by making the case that generative AI is in fact a general-purpose technology. We then explain why we believe that it will spread and boost economic growth more quickly than its predecessors did. Next, we explore implications of this fast-moving technology in four key areas: economic growth; skills, jobs, and wages; business transformation; and novel risks and harms. We conclude by highlighting important open questions about unlocking generative AI's potential; technological unemployment; social support for a fast workforce transition; and national competitiveness.

We caution that our findings and conclusions here are preliminary. Generative AI's first deployments are no more than a few years old. It is far too soon to say with confidence how it will affect entire economies and societies. But the long history of previous general-purpose technologies, combined with generative AI's short but impressive history, gives us a base from which to look ahead.

Generative AI is a general-purpose technology

How can we know whether generative AI is in fact a general-purpose technology? It might seem as though that question can be answered only in retrospect, by waiting to see if productivity increases significantly as it spreads. But economists believe that such technologies can be recognized in advance.

If a technology possesses three key characteristics — rapid improvement, pervasiveness, and complementary innovation — it's likely to have a large, positive, economy-wide impact on productivity growth. In other words, it's likely to be a general-purpose technology. Together, the trio ensure that a technology will not only be used in many sectors, but also transform them. James Watt's steam engine, for example, was originally used to pump water out of coal mines. But as it improved, it replaced the water wheels that powered factories and the sails that moved ships around the world. It also sparked the complementary innovation of the locomotive, thereby transforming land transportation. The steam engine, in short, kicked off the Industrial Revolution.

Even though generative AI is a recent development, there's already strong evidence that, like the steam engine, it possesses all three characteristics of a general-purpose technology.

Rapid Improvement

Generative AI has improved with remarkable speed at its core task of generating relevant and accurate content in response to prompts from users. As recently as 2019, the response from a state-of-the-art system to the prompt: "the best thing about AI is its ability to…?" was grammatical, but nonsensical:

"The best thing about AI is its ability to see through, and make sense of, the world around us rather than panicking and ignoring. This is known as AI "doing its job" or AI "run of the mill"…

Just a year later, though, the next release of the same system responded:

"The best thing about AI is its ability to learn and develop over time, allowing it to continually improve its performance and be more efficient at tasks. AI can also be used to automate mundane tasks, allowing humans to focus on more important tasks."

Generative AI has also improved quickly at real-world tasks. OpenAI's GPT 3.5 system, released in late 2022, performed better on a version of the U.S. bar exam than approximately 10% of human test takers. GPT 4, released in March of 2023, performed better than 90%.

In September of 2020 a team of researchers proposed the Massive Multitask Language Understanding (MMLU) benchmark, a test designed to assess generative AI systems' problem-solving abilities and knowledge of the world. It "cover[ed] 57 tasks including

elementary mathematics, U.S. history, computer science, law, and more." The answers provided by most available systems were only about as accurate as guesses when the MMLU was published. In December of 2023, however, Google Gemini Ultra became the first generative AI system to out-perform expert humans on the MMLU, scoring 90% across the tests' subject areas.

A final way to see the rapid improvement in generative AI systems is to look at the size of their "context windows," or how much information they can accept from users. If, for example, a user wanted generative AI to summarize or rewrite a report, the report would need to be included in the context window along with the request. In 2020 state-of-the-art systems had a context window that could accommodate about 7 and a half pages of text. By late 2023 the window was 40 times larger and was able to accept about 300 pages of text.

Exhibit 2

Generative AI has improved quickly in recent years

U.S. bar exam

In less than a year, OpenAI's GPT models went from outperforming 10% of people taking the bar exam to outperforming 90%

Problem-solving and knowledge

Three years after the creation of the multi-task MMLU benchmark, Google's Gemini Ultra became the first generative AI system to outperform expert humans, scoring 90% across test subject areas

Context windows

In three years, state-of-the-art generative AI systems grew their ability to accept text inputs by 40X, moving from the equivalent of 7.5 pages to 300 pages

Pervasiveness

A technology that can generate many different kinds of language is likely to become pervasive. Every industry and profession, after all, relies heavily on communication. Business leaders recognize this fact, and believe that generative AI will diffuse widely. In a 2023 survey of U.S. executives, almost two-thirds of respondents felt that the technology would have a "high" or "extremely high" impact on their organizations.

Recent research agrees. A 2023 study examined all the tasks done by workers throughout the American economy to see which of them could be done at least at least twice as rapidly with no loss in quality via the use of generative AI. The research concluded that for about 20% of all workers, half or more of their tasks fell into this category. When the threshold was reduced to 10% of tasks, 80% of workers qualified. For example, interpreters and translators, survey researchers, and public relations specialists all had at least two-thirds of their tasks eligible for significant productivity improvement via generative AI. At the other

end of the spectrum, workers including short-order cooks, athletes, and oil and gas derrick operators had no tasks in this category.

Complementary Innovations

Generative AI is already being applied to do more than generate text, pictures, and sound. A team at Google DeepMind, for example, has combined the technology with a robot and a machine learning system trained to recognize objects in images. The project's goal is to allow a person to control a robot not by specifying a sequence of steps for it to perform, but instead by simply telling it the task to be accomplished, like "pick up the bag about to fall off the table." In addition to successfully accomplishing such tasks, early results indicate that this system can also do basic reasoning. When given the prompt "I need to hammer a nail, what object from the scene might be useful?" the robotic arm picked up a rock instead of a piece of paper.

Generative AI is also being used not just to improve individual tasks but also to streamline and improve entire processes. A team of business school professors building a web-based game about entrepreneurship used the technology to suggest and incorporate improvements to the game. Instead of collecting feedback from human users, the team instead asked a generative AI system to assume the role of an MBA student playing the game and recommend changes. The same system then created prototype web pages that incorporated these changes. During the meeting to discuss these prototypes, team members asked for refinements. These were created on the fly by the technology, which also recorded, transcribed, and summarized the meeting and gave all participants their action items. A process that used to take 1-2 weeks was reduced to one day.

Early efforts give us confidence that innovations making use of generative AI's capabilities will accelerate science and engineering. For example, the technology is already being used to identify new materials with desired properties (like high magnetism and electrical conductivity or low cost and supply-chain risk), which complements alternative AI efforts to develop new materials. This work is obviously much more complicated than asking a generative AI system for a picture of a cat, then refining the result by asking for tabby stripes or a longer tail, but it relies on many of the same principles.

In summary, because of generative AI's rapid improvement, pervasiveness, and clear potential for complementary innovation, we are confident that it merits the label of "general-purpose technology." We now turn to the question of how quickly its impact will be felt.

Faster This Time

Previous general-purpose technologies have taken decades to boost entire economies. The electric motor, for example, was patented in the U.S. in 1837 and Edison's first power station began operating in 1881. However, electrification only began to have a significant positive effect on American factories' productivity in the 1920s.

Change was slow because these technologies diffused slowly, often requiring new infrastructure such as roads and electrical transmission networks. In addition, their biggest

benefits only appeared once users had time to come up with complementary innovations and put them in place. For example, it took many years for manufacturers to realize that electrification enabled conveyor belts, overhead cranes, and assembly lines, and that these innovations — especially when combined — would boost productivity so much that they justified replacing existing equipment and rethinking the factory.

There are grounds to believe, however, that generative AI's effects will appear more quickly than was the case with earlier general-purpose technologies. For one thing, much of the required infrastructure is already in place. Once new generative AI systems are developed they can be deployed around the world as quickly as web pages and apps can. A large and growing number of powerful applications using this technology are immediately available at no cost to anyone with an Internet-connected device. Others are available by subscription. This wide availability applies to both end users of the technology and developers who want to build new tools with it. Furthermore, as generative AI continues its rapid improvement, many of these improvements will propagate globally as soon as they're released.

The work of building complementary digital innovations for this general-purpose technology will probably also be fast. For most of the computer era systems, integration projects were long and expensive, but this is starting to change. Much modern software is modular; it has standard interfaces that allow components to be easily combined and recombined, as Lego bricks are. This means that generative AI will quickly be combined with other types of software, deployed over the internet, and available on demand.

Another reason to expect this technology to spread quickly is that it is an easy one for people to start working with. They just talk to it. Most of generative AI's users don't have to master a new user interface or programming language; they instead use natural human language. It requires time and practice to become proficient at interacting with generative AI, but it doesn't require many "computer skills." The technology, in short, is immediately available to people and quickly useful to them.

This easy access contributes to pervasive use. A 2023 survey of 14,000 users across a range of professions in 14 countries found 28% of respondents already using generative AI at work, even without much support from their organizations; of generative AI's users, 55% had worked with unapproved tools and 40% with banned tools. 71% of users said the technology made them more productive, and 58% reported feeling more engaged because of it. In some professions, generative AI use is already almost universal: by June of 2023, 92% of programmers surveyed were using it at work.

But perhaps the best reason to be confident that generative AI will bring its economic benefits quickly is that it's already doing so. Studies have been conducted on the technology's performance impact in a range of professional settings. Across this research, the conclusion is clear and consistent: generative AI brings large and rapid productivity boosts.

Exhibit 3

AI brings large and fast productivity boosts across occupations

Call center employees

Using a generative AI assistant resolved 14% more issues per hour, in addition to having lower employee turnover and higher customer satisfaction. These benefits began appearing within a month of the technology's deployment

Management consultants

Using a generative AI system completed 18 tasks 25% faster with, on average, 40% higher quality

Coders

Using an AI pair programmer completed programming tasks 56% faster

Professional writers

Using a generative AI chatbot completed occupation-specific writing tasks 37% faster with significantly higher quality

Physicians

Completed daily patient notes 83% faster thanks to automated transcription and summarization

In all of these cases, generative AI improved productivity on individual tasks. We stress, though, that this technology's greatest benefits will come not at the task level, but instead as innovators reimagine processes and entire organizations to take advantage of the technology's benefits. This reimagining is just starting. We anticipate that it will be relatively quick by historical standards but no less transformative than was the case with previous general-purpose technologies.

Investors also believe that this will be the case. Since late 2022, U.S. public companies with workforces that are more exposed to generative AI have seen their stock market valuations increase relative to less-exposed firms. More exposed firms have more opportunities to improve via the technology and are being valued more highly as a result.

Perhaps the boldest prediction about the economic impact of generative AI: it will soon boost productivity even for companies and industries that have lagged in realizing the benefits of the digital era. In recent years, smaller companies have not kept pace with the technology investments of larger ones. They've also fallen behind in both innovation and productivity. We expect that because of its low cost and ease of adoption, generative AI will help level the playing field between small and large firms.

For similar reasons, we expect that this technology will also speed things up in industries that have been slowing down. In the US, for example, important sectors like durable goods manufacturing, wholesale and retail trade, and transportation have seen their rate of productivity growth slow down during the 21st century. This has been the case even as the smartphone, machine learning, and other potent technologies have diffused. It is optimistic, then, to predict that generative AI could help reverse this slowdown. But that is what we foresee based on generative AI's unique combination of versatility, utility, ease of use, and diffusion.

Implications

What are the economic implications of a powerful technology that quickly diffuses and becomes pervasive throughout an economy? The most obvious one is faster economic growth. Along with that growth will come shifts in both the workforce and the competitive landscape. Finally, generative AI may bring novel risks and harms as it spreads.

A New Era of Economic Growth

General-purpose technologies are powerful engines of growth, and generative AI is no exception. Goldman Sachs estimates that over the next decade the technology will be responsible for a 0.4 percentage point increase in GDP growth in the U.S., 0.3 points in other developed markets, and 0.2 points in emerging markets.

Discussions about economic growth are often dry, but economic growth itself is vital. It's a wellspring of wellbeing. Greater per capita GDP is strongly associated with better health, higher life satisfaction, and other positive outcomes at the national level. It's also good news for our planet. Low-income countries are relatively heavy polluters; they can't afford cutting-edge green technologies or expensive waste treatment systems. More affluent countries can, and these deeper pockets enable them to spend on the environment. As Indian Prime Minister Indira Gandhi put it in 1972, "are not poverty and need the greatest polluters?" As low-income countries see continued economic growth, then, we should expect their pollution to decline.

Exhibit 4

Both life satisfaction and life expectancy trend upward with a nation's wealth

Self-reported life satisfaction vs. GDP per capita, 2022

Self-reported life satisfaction is measured on a scale ranging from 0-10, where 10 is the highest possible life satisfaction. GDP per capita is adjusted for inflation and differences in the cost of living between countries. (OurWorldInData.org)

Life expectancy vs. GDP per capita, 2018

The period life expectancy at birth, in a given year. GDP per capita is measured in 2017 international dollars, which adjusts for inflation and cross-country price differences.(OurWorldInData.org)

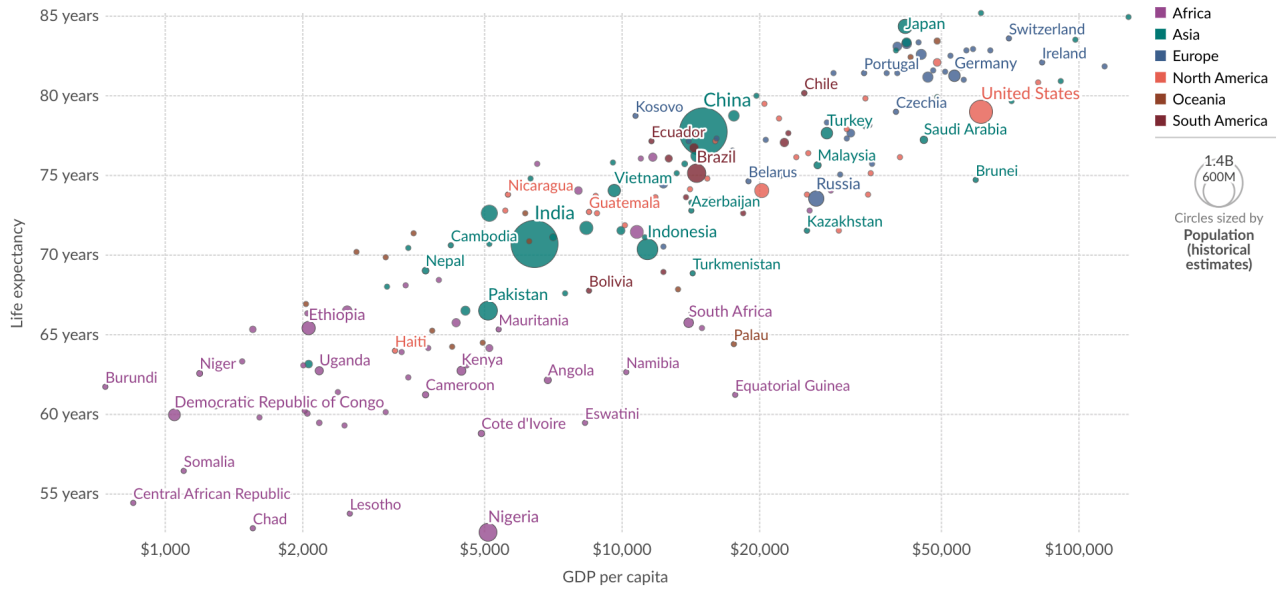
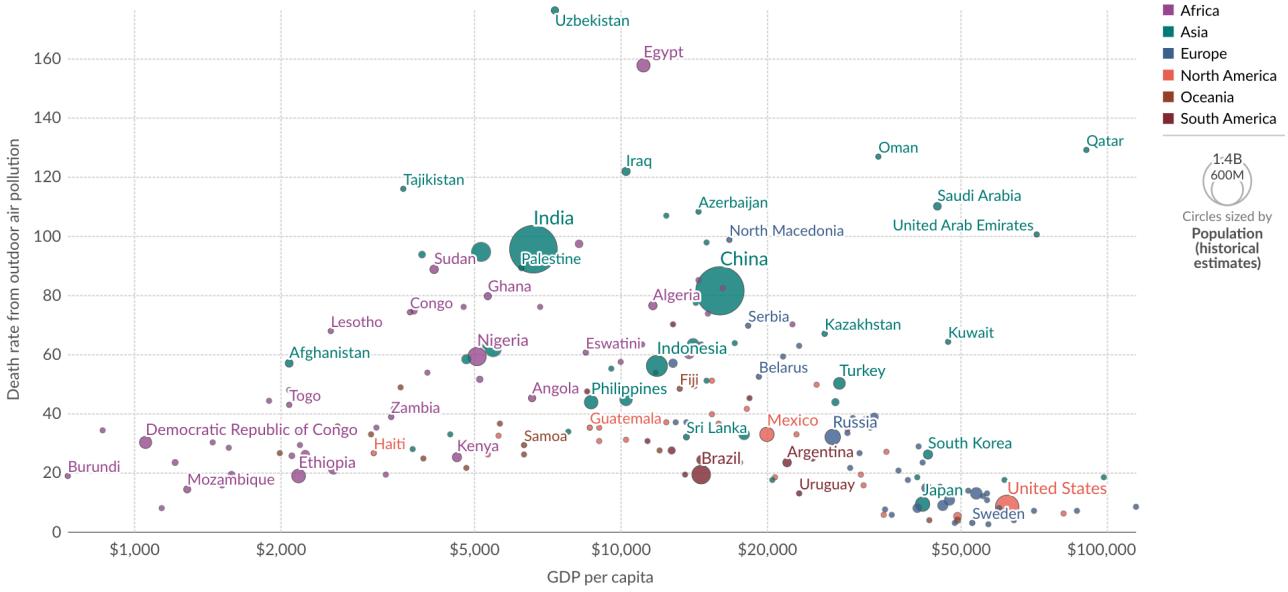


Exhibit 5

Pollution severity tends to decrease as countries become wealthier

Death rate from outdoor air pollution vs. GDP per capita, 2019

Death rates are measured as the number of premature deaths attributed to outdoor particulate matter air pollution per 100,000 individuals. Gross domestic product (GDP) per capita is measured in constant international-$. (OurWorldInData.org)



Furthermore, generative AI brings benefits that aren't captured in growth statistics. As it automates tasks, it frees up people to do work that's more valuable in every sense. Within health care, for example, it's enabling physicians to spend less time on lower-value administrative tasks and more time using their advanced training and caring for patients. Already, generative AI deployments are putting hours back in physicians' days by taking over some of their paperwork, allowing them to "be 100% present for [their] patients."

Examining generative AI's impact on healthcare reveals that the technology does more than improve productivity; it also improves quality. A 2023 study found that a generative AI system optimized for medical diagnosis was more accurate than unassisted physicians at diagnosing difficult cases. Physicians' accuracy improved significantly once they could consult the system; generative AI improved their diagnostic abilities more than did access to search engines and other resources.

A final reason to be optimistic about generative AI as an engine of growth and betterment is its ability to help people acquire new skills. One of the most common findings from research on this technology is that it most improves the performance of the newest and least-skilled workers. These are the people who need to tap into prior accumulated knowledge and apply it. Generative AI is well suited for this purpose. It generates helpful answers to many questions people have as they're going about their work. As such, it's a powerful and broadly useful upskilling technology, particularly for those with the most questions.

Exhibit 6

Generative AI seems to be a powerful upskilling technology

Management consultants
performing in the bottom half of their cohort saw a 43% improvement when using a generative AI tool; those in the top half only improved by 17%

Professional writers
initial performance inequalities were more than 50% erased once low- and high-performing cohorts used a generative AI chatbot

Call center employees
with the lowest historical performance increased their call resolution rate by 35% when using a generative AI assistant; the highest performing cohort saw no improvements

Law students
with the lowest performance improved their final exam scores by 45 percentiles when using a generative AI system

Shifts In Skills, Jobs, and Income

General-purpose technologies change the world of work. They reduce demand for some skills, increase demand for others, and create demand for entirely new ones. Across general-purpose technologies, a common pattern has been "skill-biased technological change;" over time, workers need more of the kinds of skills delivered by education. In the late 19th century, for example, dockworkers needed strength and endurance but not much schooling. A century later they needed computer skills, not muscle power, to unload ships full of containers at highly automated ports.

In the era of generative AI, the landscape of valuable skills will once again change. Current technologies have demonstrated expert-level performance at tasks requiring creativity, analysis, problem solving, persuasion, summarization, and other advanced skills. Some highly educated and well paid workers who make a living via these skills today will have to shift what they do in order to maintain or increase their value in the labor market.

But generative AI won't necessarily automate all of the tasks where it performs well. Initial research indicates that top performance comes as people continually interact with the technology. Mastering this interaction will be a valuable skill for people in many professions, even those at the highest levels of skill and education. Translators, for example, often no longer begin their work by translating an entire text themselves. They instead start with a machine-generated translation, then audit, refine, and improve it.

As general-purpose technologies can do more and more, one might expect that human labor will be needed to do less and less. And sure enough, in several advanced economies the number of people employed in manufacturing and agriculture has declined in recent decades even as the output of those industries has increased.

Yet those economies have not experienced growing joblessness. In fact, the opposite has happened: growing adoption of technology has resulted in unemployment at or near historic lows. Fewer workers are needed on farms and factories, but more are needed in restaurants, hotels, gyms, insurance companies, warehouses, airlines, and many other types of enterprises that make up a modern economy. Economic growth, in short, creates *more* jobs in large part by creating *new* jobs. A 2023 analysis concluded that more than 85% of total U.S. employment growth since 1940 has occurred within occupations that did not exist in that year.

This job creation engine has been powerful in recent years, to the point that demand for workers often exceeds supply. Labor markets remain tight in most OECD countries, including the U.S.. In late 2023, if every unemployed American worker were placed, the country would still have more than 3 million open jobs.

In Europe, recent analyses have found that hundreds of occupations were experiencing acute shortages. Many organizations in OECD countries now cite skill gaps and an inability to attract talent as key barriers to accelerating their businesses. Many of these challenges will become more acute in the coming years as today's "baby boomers" age out of the workforce.

Exhibit 7

Insufficient labor supply is already creating challenges: these may deepen

Tight labor markets
As of October 2023, the unemployment rate in the OECD, the European Union, and the euro area was at or within 0.1 percentage point of its record lows; and at 0.5 percentage points of its low for the U.S.

European occupational shortages
40 occupations received 'severe shortage' designations from 11 or more European countries in 2022: a handful of these, like software developers and application programmers, are directly relevant for generative AI

U.S. labor shortages
In late 2023, if every unemployed American worker were placed, the country would still have more than ~3 million open jobs

Future labor force challenges
Projections suggest U.S. workforce participation will be down to about 60% in 2032 driven by exits of Americans aged 65 and older. In 2002, workforce participation was nearly 67%

Global workforce aging
By 2050, individuals aged 65+ will be >2X the number of children under age 5 and the same as the number of children under age 12, or 16% of the global population.

Workforce aging by region
By 2050, individuals aged 65+ could be 25% of Europe and North America; 19% of Latin America and the Caribbean; and 26% of Eastern and South-Eastern Asia.

Previous general-purpose technologies did not cause massive technological unemployment, but there's good evidence that they did contribute to the "hollowing out" of the labor force: more low- and high-income jobs created, and fewer middle-income ones. General-purpose technologies played a role here by taking over much of the routine physical and cognitive work done by middle-class workers. Many automotive companies, for example, found that as automation advanced, they needed fewer assembly line workers (as robots took over tasks like painting car bodies) and payroll clerks (as information systems calculated paychecks and directly deposited them into workers' bank accounts).

If generative AI contributes to this hollowing out, it might do so among higher-paying jobs. Research about the suitability of this technology for all the work done in a modern economy finds that generative AI affects more of the tasks done by college graduates than by high-school only graduates. Professional writers, for example, are usually college graduates. On one popular online freelancing platform, both monthly income and number of jobs for people offering "writing-related services" declined in 2023 as online generative AI became widely available.

Meanwhile, workers without college educations have seen both job opportunities and wages rise quickly in recent years — quickly enough to reverse a decades-long trend of growing income inequality. Between 1980 and 2020, the income gap between the top 10% and bottom 10% of U.S. workers rose sharply. Since 2020, however, almost 40% of that rise has been reversed because of wage increases at the bottom.

The faster generative AI spreads throughout economies, the faster it will change skills, jobs, and wages. And if these changes are both deep and fast, they will bring novel challenges. Societies have had decades to respond to the workforce shifts caused by previous general-purpose technologies. In 1900, for example, 40% of the U.S. workforce was in agriculture and 40% of the population lived on farms. Four decades later, both figures had been cut in half. However large the stresses caused by this societal shift, they would have been larger if it happened in five years instead of forty. In a later section of this report we pose the question of what social support for a fast workforce transition might look like.

Business Transformation and Competitiveness

It's clear that generative AI will transform many if not most businesses and industries, but it's far from clear how. This uncertainty stems partly from the fact that the future evolution of the technology is unclear. It's also due to the unpredictability of the complementary innovations that accompany general-purpose technologies.

At the dawn of electrification, few people would have correctly predicted what factories would eventually look like. Similarly, it's difficult to foresee all the changes generative AI will bring to the world of work. We know that it's already improving the productivity and quality of many tasks. We also see that the technology is beginning to be used to redesign multi-step, multi-group processes, making them faster and less labor-intensive.

Task-level and process-level innovation with generative AI will continue and expand. But this technology's deepest impact on the world of work will come as it's used to reimagine entire organizations. This deep reimagination will be a decentralized and distributed phenomenon, carried out by innovators and entrepreneurs throughout the economy.

Because of their talent pools, and access to customers, and large amounts of data, today's large incumbent companies might seem to be well-positioned to lead the transformation of work in the era of generative AI. History, however, reveals a different pattern: the companies on top at the start of previous general-purpose technology-enabled transformations did not remain on top. Instead, a great deal of disruption occurred, with new entrants appearing and eventually dominating.

This disruption did not happen because incumbents were unaware of the new technology's power. They're usually keenly aware, in fact, and generative AI is no exception. A recent survey

of business executives found that more than half of respondents expected this technology to be moderately or severely disruptive to their industries. In the past, though, such executives were often unable to envision how much a new general-purpose technology could improve on the status quo, or unwilling to make large enough changes to their successful businesses. As a result, they fell behind bold upstarts.

We see evidence that a similar pattern of disruption is now playing out in the era of AI. As the digital transformation of the business world has progressed over the course of the 21st century, "superstar firms" have appeared in many countries and industries. These superstars are highly productive compared to their peers and have been gaining market share and profitability. In the U.S., many of them are relatively young companies.

If generative AI further empowers a small set of superstars and allows them to outpace their rivals, workforce changes will increase. Fading incumbents will conduct layoffs, and the number of people who need to find new jobs and acquire new skills will increase. Research conducted over the last decade reveals that companies investing heavily in machine learning are *not* the ones conducting layoffs. Workforce reductions come instead from companies that did not embrace the technology. We predict that a similar pattern will hold with generative AI.

Novel Risks and Harms

For all their benefits, general-purpose technologies can also introduce new risks and amplify existing ones: Cybercrime, for example, is expected to incur global costs of $10.5 trillion by 2025. Computers make all of us more productive — including criminals, unfortunately.

Google DeepMind researchers and partners have created a taxonomy classifying the potential harms from generative AI, along with a discussion of mitigation approaches. Some of these risks, while notable, are outside the economic scope of this report. For example, generative AI's ability to increase the volume and spread of disinformation could also make it easier for malicious actors to conduct personalized scams at scale, manipulate financial markets, and effectively sway public political opinions and actions.

While the risk of workforce disruption is a focus of this report, there are also other risks with economic implications. For example, most of today's generative AI models are trained heavily in English and may perform less well in other languages. Models that capture the language of one group with less accuracy – or not at all – may drive inequities by reducing underrepresented cohorts' abilities to develop or access generative AI applications. If done thoughtfully, however, the technology could accomplish the opposite outcome by helping speakers of "long-tail languages" access knowledge that was previously available only in English.

In the late 19th century, public fear over electricity's novel risks – driven by multiple incidents of electrocution from unsafe overhead wires – led one New Yorker to call electricity "a fearful source of death, [...] a constant menace to the lives of our fellow-citizens" and urge a return to gaslights. Fortunately, the publicity brought to electricity's risks helped drive reform that enabled safer use of the technology, like the eventual burying of Manhattan's overhead wires.

As with electricity, collective awareness of generative AI's risks, plus frameworks for assessing them in context, can enable us to enjoy the technology's benefits while triaging potential

harms. We next explore the open questions that a few key risks, including job disruption, make salient in the near term.

Open Questions

What Needs to Go Right?

Generative AI has all three characteristics of a general-purpose technology: rapid improvement, pervasiveness, and complementary innovations. This fact alone, however, does not guarantee that this new technology will be as transformative as the steam engine or electrification.Those innovations delivered their benefits because governments, companies, schools and universities, and civil society came together in ways that supported the useful diffusion of the technology, allowed its benefits to spread widely, and dealt with its negative consequences.

We will surely need a similar coalition with generative AI to find answers to the questions posed by this powerful new tool. How will education at all levels need to change? What's the right way to approach regulation? How can we best assess and minimize the biases of generative AI systems, especially ones that are used to make important decisions about, for example, employment, credit, justice, and health care?

Overconstraining generative AI will reduce its benefits, while underconstraining it will increase its harms and empower bad actors. The best points of balance between these two outcomes are not yet clear, in part because the technology is so young. What is clear at this early stage is that ignoring generative AI — refusing to confront the issues it raises — is a poor strategy. A better one is to start learning how to responsibly advance our collective use of this new general-purpose technology.

Will Generative AI Bring Large-Scale Technological Unemployment?

Is generative AI powerful enough to significantly change the historical relationship between technological progress and increased demand for human labor? It might seem so, especially since it can be applied to so many tasks. But the relationship between technological progress and labor demand is not a simple one. If generative AI can take over a quarter of a job's tasks, for example, we shouldn't automatically expect employment in that profession to fall by 25%.

To see why not, consider the profession of radiology. Beginning about a decade ago, a type of AI called deep learning quickly improved at the task of detecting patterns within images. Since that task is a central part of a radiologist's work, many observers felt that the profession would become highly automated, and that overall demand for humans would soon decrease. As a prominent AI researcher put it in 2016, "People should stop training radiologists now. It's just completely obvious within five years deep learning is going to do better than radiologists." And sure enough, by 2022 more than 200 AI-based radiology imaging products had been approved for commercial use in the U.S..

Yet demand for human radiologists didn't decline. Between 2016 and 2021, U.S. radiology employment increased by 3%, and demand in the profession remained strong. By 2022, in fact, a global shortage of human radiologists loomed. As one academic department chair put it, "The demand for imaging is outpacing what we're doing on the training side. The number of radiologists in the workforce is not growing as fast as [demand]."

It turned out that while deep learning helped with the interpretation of scanned medical images, it didn't completely automate it in most cases. What's more, the technology didn't touch many of a radiologist's other important tasks, such as speaking with patients and conferring with colleagues on a course of treatment.

As this example shows, there is no straight line between the diffusion of a powerful technology and unemployment. Generative AI is unlikely to change this fact, at least in the short run, because of its limitations. It is not yet able to reliably do multi-step work that involves planning, reasoning, or memory. A 2023 study created hundreds of questions whose solutions involved this kind of work, then administered it to both people and a top-performing generative AI system. Human solvers averaged 92% correct answers; generative AI 15%.

Of course, generative AI is improving quickly and intense research is underway at many organizations to address the technology's known weaknesses. It is far from clear how successful this research will be, and how fast it will progress. Will it succeed to the point that generative AI can do most, if not all, of the tasks that make up many of today's jobs? If so, will innovators and entrepreneurs quickly create enough new jobs that still require human labor? It is too soon to know the answers to these questions with any confidence, but not too soon to start asking them.

We conclude this discussion of the possibility of large-scale technological unemployment by observing that there is no shortage of important work to be done in every society. A great deal of this work, from installing the infrastructure needed to accomplish the global clean energy transition; to teaching children; to caring for the sick and elderly, can't be done by the robots and AI of today, as powerful as they are. We anticipate that this situation will not soon change and that much of our most important work will remain heavily in the hands of humans.

What Does Social Support for a Fast Transition Look Like?

If generative AI does in fact spread rapidly around the world and bring large changes to jobs, wages, and needed skills, then societies will need to respond quickly. This indicates that the approaches developed during the sudden COVID-19 pandemic to provide short-term income and wage support might well be effective in helping workers transition to new roles.

In addition to economic support, it will be important to help workers displaced by technological progress acquire in-demand skills and find new jobs. There are many approaches to accomplishing this, including apprenticeships and on-the-job training; vocational schools and university degree programs; and training that leads to certifications provided by professional groups and companies. Because generative AI is so new and its effects on the workforce still so uncertain, it's difficult to know at present how to respond to the challenges it could bring. We anticipate that the societies most successful at navigating

generative AI's possibly rapid workforce transitions will be those that encourage a range of responses, learn rapidly how well they're working, and concentrate on those that deliver results.

We also anticipate that many of the most successful reskilling efforts will be those that use generative AI itself. As discussed above, one of the most exciting aspects of the technology is its ability to accumulate knowledge and deliver it on demand to people who need it. In short, it's a tool that can teach its users how to use it. This is an important innovation. Throughout the digital era, there have been countless attempts to create technologies for knowledge management. Most of them have underwhelmed or failed. Generative AI seems to be succeeding, which makes it a key ingredient of any training and reskilling efforts.

Perhaps the most important element of any effort to successfully transition a workforce in an era of pervasive generative AI is rapid economic growth. Fast growth means greater demand for workers, greater upward pressure on wages, and greater willingness by employers to reskill and retrain people. If generative AI brings about a large and fast workforce transition, it will probably be because it also causes a boost in economic growth. The faster growth will make the transition easier to accomplish.

Which Countries Will Lead With Generative AI?

History shows that in addition to investing in training and education, the countries best able to harness the power of general-purpose technologies have a few things in common. They have market-oriented economies, high levels of infrastructure, educational systems that provide needed skills, and a well-functioning legal system that enforces contracts and property rights and establishes clear rules for where and under what circumstances liability may accrue. And they have accepted some degree of capitalism's "gale of creative destruction," preventing old industries from using legal or regulatory capture to block the emergence of disruptive new technologies.

These countries are also successful at converting ideas into useful innovations. In a modern economy, this work often involves government funding for basic research and research-oriented universities, clear paths to commercialization, and investors with an appetite for risk. As a rule, the countries that have been most successful with previous general-purpose technologies are those that found ways to tap into the talents and aspirations of their people. We anticipate that generative AI will not be an exception.

History also shows that the stakes are high. Some general-purpose technologies have shifted the global balance of power. The steam engine, which initiated the industrial revolution, was instrumental in making England the world's richest country in the 19th century and ensuring that "the sun never set" on the British Empire. America's success with the internal combustion engine and electrification helped it succeed the United Kingdom as the global superpower of the 20th century.

The countries most successful at developing general-purpose technologies and harnessing their power have reaped comparatively high and fast-growing standards of living, better national security, and a greater ability to pursue their interests and influence events around the world. They are also able to shape the diffusion of technologies in ways that reflect their goals and values. Countries far from the frontier with general-purpose technologies, meanwhile, tend also to be farther from these benefits.

We share the view that artificial intelligence will be one of the defining technologies of the 21st century and that generative AI is an especially important addition to the AI portfolio. This implies that the countries aspiring to global prominence will need to create an environment that fosters the development and deployment of this technology.

Acknowledgements

I sincerely thank the individuals who supported and advanced this research. Their contributions, in various forms, have been integral to the completion of this work.

Google Executives

Special thanks to James Manyika for sponsoring the Technology & Society Visiting Fellow program.

Additional thanks to Ruth Porat, Kent Walker, Jeff Dean, and Hal Varian, who, along with James, engaged on this report multiple times over the course of its creation.

Google Core Contributors

Travis Beals, Guy Ben-Ishai, Luke Garske, Elana Burton.

Google Interviewees

Adam Cohen, Alice Friend, Anoop Sinha, Anthony House, Ashley Zlatinov, Blaise Aguera y Arcas, Chris Ludwick, Conor Griffin, Diane Tang, Doug Eck, Greg Corrado, Jay Yagnik, Josh Woodward, Lisa Gevelber, Marian Croak, Mukund Sundararajan, Nick Fox, Nicklas Lundblad, Preston McAfee, Robert Wong, Ryan Harms, Alexander Chen, Shiv Venkataraman, Steve Seitz, Steven Johnson, Tulsee Doshi.

Other Interviewees

Daniel Rock, Erik Brynjolfsson, Joseph Briggs, Michael Mandel.

References

Executive summary

p. 1 **80% of jobs exposed to generative AI**: Eloundou, Tyna, et al. "GPTs Are GPTs: An Early Look at the Labor Market Impact Potential of Large Language Models." *arXiv*, March. 2023, arxiv.org/abs/2303.10130

Part 1: Introduction

p. 2 **Physicist Freeman Dyson**: Dyston, Freeman. *Infinite in all directions: Gifford lectures given at Aberdeen, Scotland*, April-November 198 Penguin, 1989. Google Books, https://www.google.com/books/edition/Infinite_in_All_Directions/e8TaAAAAMAAJ?hl=en&gbpv=0&bsq=gi

2 **Life expectancy growth**: Dattani, Saloni, et al. "Life Expectancy." *Our World in Data*, 2023, ourworldindata.org/life-expectancy

2 **Environmental indicators (CO2)**: World Bank, Global Carbon Budget, and various sources -- with processing by Our World in Data. "Change in per Capita CO_2 Emissions and GDP." *Our World in Data*, 2023, ourworldindata.org/grapher/co2-emissions-and-gdp-per-cap

2 **Working hours decline**: Bick et al (2019); Feenstra et al. (2015), Penn World Table (2021); Huberman & Minns (2007; and Organisation f Economic Co-operation and Development, Labour Force Statistics – processed by Our World in Data. "Annual Working Hours per Work Various Sources." *Our World in Data*, ourworldindata.org/grapher/compare-sources-working-hours?country=~OECD+Countries

2 **Standard of living growth**: World Bank Poverty and Inequality Platform (2022) – with processing by Our World in Data. "Median incom consumption per day, 1990 to 2019." *Our World in Data,* ourworldindata.org/grapher/daily-median-income?tab=chart&country=~OWID_WRL

2 **Burden of disease reduction**: Institute for Health Metrics and Evaluation, Global Burden of Disease (2019) – processed by Our World i Data. "Burden of disease, 1990 to 2019." *Our World in Data*, https://ourworldindata.org/grapher/dalys-rate-from-all-causes?tab=chart&country=OWID_WRL~BGD~BEL

3 **Air pollution deaths**: IHME, Global Burden of Disease Study (2019) -- processed by Our World in Data. "Death Rate From Air Pollution." *Our World in Data*, ourworldindata.org/grapher/death-rates-from-air-pollution

3 **Access to drinking water**: World Health Organization and UNICEF – processed by Our World in Data. "Share of the Population Using Safely Managed Drinking Water." *Our World in Data*, ourworldindata.org/grapher/proportion-using-safely-managed-drinking-water?tab=chart&country=~OWID_WRL

Part 2: Generative AI is a general-purpose technology

p. 4 **General purpose technology criteria**: Bresnahan, Timothy F., and Manuel Trajtenberg. "General Purpose Technologies 'Engines of Growth'?" *Journal of Econometrics*, vol. 65, no. 1, Jan. 1995, pp. 83–108. https://doi.org/10.1016/0304-4076(94)01598-t

4 **"The best thing about AI..."**: Wolfram, Stephen. *What Is ChatGPT Doing ... And Why Does It Work?,* Wolfram Media Inc, 2023

4 **GPT-3.5 and GPT-4 U.S. bar exam performance**: OpenAI. "GPT-4 Technical Report." *arXiv*, March 2023, arxiv.org/abs/2303.08774

4 **Massive Multitask Language Understanding (MMLU) benchmark**: Hendrycks, Dan, et al. "Measuring Massive Multitask Language Understanding." *arXiv*, Jan. 2021, arxiv.org/abs/2009.03300

4 **Gemini Ultra performance**: Pichai, Sundar, and Demis Hassabis. "Introducing Gemini: Our Largest and Most Capable AI Model." *Goog The Keyword Blog*, Dec. 2023, blog.google/technology/ai/google-gemini-ai/#performance

5 **7.5 page context window (2020)**: "What Is Context Window for LLMs?" *Hopsworks*, www.hopsworks.ai/dictionary/context-window-for-llms#:~:text=For%20example%2C%20in%20GPT%2D3,their%20usefulness%20acro %20various%20applications

5 **300 page context window (2023)**: "New Models and Developer Products Announced at DevDay." *OpenAI Blog*, November 2023, openai.com/blog/new-models-and-developer-products-announced-at-devday

5 **U.S. executive survey**: "KPMG Generative AI Survey." *KPMG*, July 2023, info.kpmg.us/news-perspectives/technology-innovation/kpmg-generative-ai-2023.html

5 **Exposure of tasks in the American economy**: Eloundou, Tyna, et al. "GPTs Are GPTs: An Early Look at the Labor Market Impact Poten of Large Language Models." *arXiv*, March. 2023, arxiv.org/abs/2303.10130

5-6 **Robotic actions as a complementary innovation**: "RT-2: New Model Translates Vision and Language Into Action." *Google DeepMind Blog*, July 2023, deepmind.google/discover/blog/rt-2-new-model-translates-vision-and-language-into-action

6 **MBA entrepreneurship game**: Mollick, Ethan. "Reshaping the Tree: Rebuilding Organizations for AI." *One Useful Thing*, November 202 www.oneusefulthing.org/p/reshaping-the-tree-rebuilding-organizations

6 **New material design (Microsoft)**: Fowler, Andrew, et al. "MatterGen: Property-guided materials design." *Microsoft Research Blog*, December 2023. https://www.microsoft.com/en-us/research/blog/mattergen-property-guided-materials-design/

6 **New material design (Google DeepMind)**: Merchant, Amil and Ekin Dogus Cubuk. "Millions of new materials discovered with deep learning." *Google DeepMind Blog*, November 2023, https://deepmind.google/discover/blog/millions-of-new-materials-discovered-with-deep-learning/

Part 3: Faster This Time

p. 6 **U.S. electric motor patent**: "U.S. Patent: 132 - Improvement in Propelling Machinery by Magnetism and Electro-magnetism." *Directory American Tool and Machinery Patents*, www.datamp.org/patents/displayPatent.php?pn=132&id=22442

6 **American electrification (1880s - 19020s)**: David, Paul A. "The Dynamo and the Computer: An Historical Perspective on the Modern Productivity Paradox." *The American Economic Review*, vol. 80, no. 2, May 1990. JSTOR, www.jstor.org/stable/2006600

7 **Survey of 14,000 professionals**: "More Than Half of Generative AI Adopters Use Unapproved Tools at Work." *Salesforce News & Insig* Nov. 2023, www.salesforce.com/news/stories/ai-at-work-research/?utm_campaign=amer_cbaw&utm_content=Salesforce_World+Tour&utm_mediu organic_social&utm_source=linkedin

7 **Programmer survey**: Shani, Inbal. "Survey Reveals AI's Impact on the Developer Experience - the GitHub Blog." *The GitHub Blog*, June 2023, github.blog/2023-06-13-survey-reveals-ais-impact-on-the-developer-experience

8 **Call center employees resolve more calls**: Brynjolfsson, Erik, et al. "Generative AI at Work." *National Bureau of Economic Research*, N 2023, www.nber.org/papers/w31161. Working paper

8 **Management consultants perform better**: Dell'Acqua, Fabrizio, et al. "Navigating the Jagged Technological Frontier: Field Experimen Evidence of the Effects of AI on Knowledge Worker Productivity and Quality." *Social Science Research Network*, Jan. 2023, https://doi.org/10.2139/ssrn.4573321. Harvard Business School Technology & Operations Mgt. Unit Working Paper No. 24-013

8 **Programmers code faster**: Peng, Sida, et al. "The Impact of AI on Developer Productivity: Evidence From GitHub Copilot." *arXiv*, Feb. 2023, https://doi.org/10.48550/arxiv.2302.06590

8 **Writers improve speed and quality**: Noy, Shakked, and Whitney Zhang. "Experimental Evidence on the Productivity Effects of Genera Artificial Intelligence." *Social Science Research Network,* Apr. 2023, https://doi.org/10.2139/ssrn.4375283. Working paper

8 **Physicians complete notes faster**: Lohr, Steve. "A.I. May Someday Work Medical Miracles. For Now, It Helps Do Paperwork." *The New York Times*, June 2023, https://www.nytimes.com/2023/06/26/technology/ai-health-care-documentation.html

8 **U.S. public company valuations**: Eisfeldt, Andrea L., et al. "Generative AI and Firm Values." *National Bureau of Economic Research*, M 2023, https://doi.org/10.3386/w31222 . Working paper

8 **Smaller companies lag in technology investments**: Govindarajan, Vijay, et al. "The Gap Between Large and Small Companies is

Growing. Why?" *Harvard Business Review,* August 2019, https://hbr.org/2019/08/the-gap-between-large-and-small-companies-is-growing-why

8-9 **Sector productivity slowdown**: Sprague, Shawn. "The U.S. productivity slowdown: an economy-wide and industry-level analysis." *U.S Bureau of Labor Statistics,* April 2021, https://www.bls.gov/opub/mlr/2021/article/the-us-productivity-slowdown-the-economy-wide-and-industry-level-analysis.htm

Part 4: Implications

p. 9 **Generative AI's GDP impacts**: "Upgrading Our Longer-Run Global Growth Forecasts to Reflect the Impact of Generative AI." *Goldman Sachs Research*, Oct. 2023, www.gspublishing.com/content/research/en/reports/2023/10/30/2d567ebf-0e7d-4769-8f01-7c62e894a779.html

9 **Better health from economic growth**: UN WPP (2022); HMD (2023); Zijdeman et al. (2015); Riley (2005); Maddison Project Database 2020 (Bolt and van Zanden, 2020); Gapminder - Population v7 (2022) and other sources; Our World in Data – with processing by Our World in Data. "Life Expectancy Vs. GDP per Capita." *Our World in Data*, ourworldindata.org/grapher/life-expectancy-vs-gdp-per-capit

9 **Indira Gandhi on poverty and pollution**: United Nations, Environment Programme. *Effective, inclusive and sustainable multilateral actions to tackle climate change, biodiversity loss, and pollution.* https://wedocs.unep.org/bitstream/handle/20.500.11822/43634/ED-Report-UNEA6-AdvanceUnEditedVersion.pdf?sequence=3&isAllowe y

10 **More life satisfaction with economic growth**: World Happiness Report (2023); World Bank (2023); Gapminder - Population v7 (2022) other sources; Our World In Data -- processed by Our World in Data. "Self-reported Life Satisfaction Vs. GDP per Capita." *Our World in Data*, ourworldindata.org/grapher/gdp-vs-happiness

11 **Pollution and economic growth**: IHME, Global Burden of Disease Study (2019); World Bank (2023); Gapminder - Population v7 (2022) other sources; Our World In Data – processed by Our World in Data. "Death rate from outdoor air pollution vs. GDP per capita." *Our Wo in Data*, https://ourworldindata.org/grapher/outdoor-pollution-rate-vs-gdp

11 **Hours back in physicians' days**: Lohr, Steve. "A.I. May Someday Work Medical Miracles. For Now, It Helps Do Paperwork." *The New Yo Times*, June 2023. https://www.nytimes.com/2023/06/26/technology/ai-health-care-documentation.html

11 **Accuracy of medical diagnoses**: McDuff, Daniel, et al. "Towards Accurate Differential Diagnosis With Large Language Models." *arXiv*, Nov. 2023, arxiv.org/abs/2312.00164

12 **Management consultant upskilling**: Dell'Acqua, Fabrizio, et al. "Navigating the Jagged Technological Frontier: Field Experimental Evidence of the Effects of AI on Knowledge Worker Productivity and Quality." *Social Science Research Network*, Jan. 2023, https://doi.org/10.2139/ssrn.4573321. Harvard Business School Technology & Operations Mgt. Unit Working Paper No. 24-013

12 **Writer upskilling**: Noy, Shakked, and Whitney Zhang. "Experimental Evidence on the Productivity Effects of Generative Artificial Intelligence." *Social Science Research Network*, Apr. 2023, https://doi.org/10.2139/ssrn.4375283. Working paper

12 **Call center employee upskilling**: Brynjolfsson, Erik, et al. "Generative AI at Work." *National Bureau of Economic Research*, Nov. 2023, www.nber.org/papers/w31161. Working paper

12 **Law student upskilling**: Choi, Jonathan H., and Daniel Schwarcz. "AI Assistance in Legal Analysis: An Empirical Study." *Social Science Research Network*, Jan. 2023, https://doi.org/10.2139/ssrn.4539836

12 **Skill biased technological change**: Autor, David, et al. "Extending the Race Between Education and Technology." *AEA Papers and Proceedings*, May 2020, scholar.harvard.edu/lkatz/publications/extending-race-between-education-and-technology

12 **Automated unloading of container ships**: Kay, Grace. "Meet the Port of Los Angeles' Dock Workers Who Make Over $100,000 Worki With Some of the World's Largest Robots." *Business Insider*, Sept. 2021, www.businessinsider.com/port-la-dock-workers-longshoremen-make-100k-salary-overtime-2021-9

12 **Interacting with generative AI enables top performance**: Mollick, Ethan. "Centaurs and Cyborgs on the Jagged Frontier." *One Useful Thing*, Sept. 2023, www.oneusefulthing.org/p/centaurs-and-cyborgs-on-the-jagged

12 **Manufacturing employment trends**: "U.S. Bureau of Labor Statistics, All Employees, Manufacturing." *FRED, Federal Reserve Bank of St. Louis*, Dec. 2023, kfred.stlouisfed.org/series/MANEMP

12 **Agriculture employment trends**: "Organization for Economic Co-operation and Development, Employment by Economic Activity: Agriculture: All Persons for United States." *FRED, Federal Reserve Bank of St. Louis*, Nov. 2023, kfred.stlouisfed.org/series/LFEAAGTTUSM647S

13 **85% of U.S. employment growth since 1940**: "Upgrading Our Longer-Run Global Growth Forecasts to Reflect the Impact of Generati AI." *Goldman Sachs Research*, Oct. 2023, www.gspublishing.com/content/research/en/reports/2023/10/30/2d567ebf-0e7d-4769-8f01-7c62e894a779.html.

13 **Tight labor markets in OECD countries**: "OECD Employment Outlook 2023: AI and Jobs, an Urgent Need to Act." *OECD*, 2023, oecd.org/employment-outlook/2023

13 **Tight labor markets in the U.S.**: Jefferson, Nathan and Jack Fuller. "A State-Level Look at U.S. Labor Market Supply and Demand." *FRI Federal Reserve Bank of St. Louis*, April 2023, https://www.stlouisfed.org/publications/regional-economist/2023/apr/state-level-us-labor-market-supply-demand

13 **American labor shortage**: Ferguson, Stephanie. "America Works Data Center." *U.S. Chamber of Commerce*, Dec. 2023, www.uschamber.com/workforce/america-works-data-center

13 **European occupational shortages**: "EURES Report on labor shortages and surpluses 2022." *European Labor Authority*, March 2023, https://www.ela.europa.eu/sites/default/files/2023-09/ELA-eures-shortages-surpluses-report-2022.pdf

13 **Skill gaps and an inability to attract talent**: "The Future of Jobs Report 2023." *World Economic Forum*, April 2023, https://www.weforum.org/publications/the-future-of-jobs-report-2023/

14 **OECD unemployment rates**: "Unemployment Rates, OECD - Updated: Dec. 2023." *OECD, Better Policies for Better Lives*, Dec. 2023, https://www.oecd.org/employment/unemployment-rates-oecd-updated-december-2023.htm

14 **Future U.S. workforce participation**: "Civilian labor force participation rate by age, sex, race, and ethnicity." *U.S. Bureau of Labor Statistics*, September 2023, https://www.bls.gov/emp/tables/civilian-labor-force-participation-rate.htm

14 **Workforce exits of Americans aged 65 and older**: "Economic News Release, Employment Projections 2022-2032 Summary." *U.S. Bur of Labor Statistics*, September 2023, https://www.bls.gov/news.release/ecopro.nr0.htm

14 **Workforce aging**: "World Population Prospects 2022." *United Nations Department of Economic and Social Affairs*, 2022, https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

14 **Hollowing out of labor force**: Canon, Maria and Elise Marifan. "Job Polarization Leaves Middle-Skilled Workers Out in the Cold." *Fred, Federal Reserve Bank of St. Louis*, January 2013, https://www.stlouisfed.org/publications/regional-economist/january-2013/job-polarization-leaves-middleskilled-workers-out-in-the-co

14-15 **College graduate tasks more exposed to generative AI**: Eloundou, Tyna, et al. "GPTs Are GPTs: An Early Look at the Labor Market Impact Potential of Large Language Models." *arXiv*, March. 2023, arxiv.org/abs/2303.10130

14-15 **Freelance writing pay and jobs**: Hui, Xiang, et al. "The Short-Term Effects of Generative Artificial Intelligence on Employment: Evidenc From an Online Labor Market." *Social Science Research Network*, Aug. 2023, https://doi.org/10.2139/ssrn.4527336

15 **Wage trends**: Autor, David H., et al. "The Unexpected Compression: Competition at Work in the Low Wage Labor Market." *National Bur of Economic Research,* Nov. 2023, https://doi.org/10.3386/w31010. Working paper

15 **40% of U.S. workforce in agriculture**: Klein, Ezra, and Susannah Locke. "40 Maps That Explain Food in America." *Vox*, June 2014, www.vox.com/a/explain-food-america

15 **40% of U.S. population living on farms**: Lusk, Jason. "The Evolving Role of the USDA in the Food and Agricultural Economy." *Mercatu Center*, June 2016, www.mercatus.org/research/research-papers/evolving-role-usda-food-and-agricultural-economy.

15 **Companies disrupted by general purpose technologies**: Caves, Richard. "The Decline of Dominant Firms, 1905-1929." *Quarterly Journal of Economics*, vol. 99, no. 3. JSTOR, www.jstor.org/stable/1885963

15 **U.S. executive survey**: "KPMG Generative AI Survey." *KPMG*, July 2023, info.kpmg.us/news-perspectives/technology-innovation/kpmg-generative-ai-2023.html

16 **Superstar firms in the 21st century**: Autor, David H., et al. "The Fall of the Labor Share and the Rise of Superstar Firms." *The Quarterl Journal of Economics*, vol. 135, no. 2, May 2020, pp. 645–709. https://doi.org/10.1093/qje/qjaa004

16 **Young U.S. superstar firms**: McAfee, Andrew. *The Geek Way: The Radical Mindset That Drives Extraordinary Results*. Little, Brown and Company, November 2023

16 **Companies conducting layoffs**: Babina, Tania, et al. "Artificial Intelligence, Firm Growth, and Product Innovation." *Journal of Financial Economics*, vol. 151, Jan. 2024, p. 103745. https://doi.org/10.1016/j.jfineco.2023.103745

16 **Global cost of cybercrime**: Muggah, Robert, and Mac Margolis. "Why We Need Global Rules to Crack Down on Cybercrime." *World Economic Forum*, Jan. 2023, www.weforum.org/agenda/2023/01/global-rules-crack-down-cybercrime

16 **Google DeepMind taxonomy of generative AI risks**: Weidinger, Laura, et al. "Ethical and social risks of harm from Language Models." *arXiv*, Dec. 2021, https://doi.org/10.48550/arXiv.2112.04359

16 **Electricity's novel risks**: Sullivan, J. P. "Fearing Electricity: Overhead Wire Panic in New York City." *IEEE Journals & Magazine | IEEE Xplore*, vol. 14, no. 3, 1995, ieeexplore.ieee.org/document/464629

16 **Google DeepMind framework for assessing generative AI risks in context**: Weidinger, Laura, et al. "Sociotechnical Safety Evaluatio of Generative AI Systems." *arXiv*, Oct. 2023, https://doi.org/10.48550/arXiv.2310.11986

Part 5: Open Questions

p. 17 2**016 prediction on future of radiology**: Windsor, Matt. "This Radiologist Is Helping Doctors See Through the Hype to an AI Future - th Reporter." *UAB Reporter*, Dec. 2022, www.uab.edu/reporter/people/achievements/item/9925-this-radiologist-is-helping-doctors-see-through-the-hype-to-an-ai-future

17 **200 AI-based radiology imaging products**: "Your Resource for Strategic AI Solutions." *American College of Radiology*, Data Science Institute, aicentral.acrdsi.org

17 **U.S. radiology employment 2016 - 2021**: "Percentage Change in the Number of Active Physicians by Specialty, 2016-2021 | AAMC." *Association of American Medical Colleges*, www.aamc.org/data-reports/workforce/data/percentage-change-number-active-physicians-specialty-2016-2021

17 **Imaging demand**: Henderson, Mary. "Radiology Facing a Global Shortage." *Radiology Society of North America*, May 2022, www.rsna.org/news/2022/may/global-radiologist-shortage.

18 **Planning, reasoning, and memory performance**: Mialon, Grégoire, et al. "GAIA: A Benchmark for General AI Assistants." *arXiv*, Nov. 2023, arxiv.org/abs/2311.12983

Appendix: Further Reading

- Acemoglu, Daron and Simon Johnson. *Power and Progress: Our Thousand-Year Struggle Over Technology and Prosperity.* PublicAffairs, 2023.
- Agrawal, Ajay, et al. *Power and Prediction: The Disruptive Economics of Artificial Intelligence*. Harvard Business Review Press, 2022.
- Artigas, Carme, et al. "What Global AI Governance Must Do." *Project Syndicate*, Dec. 2023, https://www.project-syndicate.org/commentary/ai-governance-un-advisory-body-five-principles-by-ian-bremmer-et-al-2023-12?barrier=accesspaylog
- Brynjolfsson, et al. "The Productivity J-Curve: How Intangibles Complement general-purpose technologies." *National Bureau of Economic Research,* January 2020, https://www.nber.org/papers/w25148. Working paper.
- Brynjolfsson, Erik. "The Turing Trap: The Promise & Peril of Human-LIke Artificial Intelligence." *Dædalus,* Spring 2022, https://www.amacad.org/publication/turing-trap-promise-peril-human-artificial-intelligence
- Manyika, James and Michael Spence. "The Coming AI Economic Revolution." *Foreign Affairs*, November / December 2023. https://www.foreignaffairs.com/world/coming-ai-economic-revolution
- McAfee, Andy and Erik Brynjolfsson. *The Second Machine Age: Work, Progress, and Prosperity in a Time of Brilliant Technologies.* W.W. Norton & Company, January 2016.
- Mckinsey & Company. *The Economic Potential of Generative AI: the Next Productivity Frontier.* June 2023, https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/the-economic-potential-of-generative-ai-the-next-productivity-frontier#introduction.
- Walker, Kent. "An opportunity agenda for AI." *Google: The Keyword Blog*, Nov. 2023. https://blog.google/outreach-initiatives/public-policy/google-ai-opportunity-agenda/