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Riding the Wave: Accelerating into the AI Era

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Who would have predicted more than 60 percent of today's jobs are in roles that didn't exist in 1940? In 1850, agriculture accounted for nearly 60 percent of American jobs. By 1950, that portion had fallen to just 15 percent. And today it's just around 2 percent. Over that same period, U.S. manufacturing employment rose from around 12 percent to 25 percent and then fell again, back to 12 percent.

Jarring technological transformations in artificial intelligence, robots, and biology will soon generate unimagined wealth and opportunity. But workers, firms, and states who are unprepared or complacent could fall even further behind than they are today.

How will existing jobs change? What are the jobs of the future? Matching the future economy's demands with a robust supply of talent and skills is a big part of the equation. Retraining and lifelong learning – both formal and informal – play an important role. Any attempt to merely accommodate onrushing disruptions, however, is bound to fall short. As Yogi Bera said, "It's tough to make predictions – especially about the future." Indiana's strategy, therefore, must rely on a pro-active corollary: The easiest way to predict the future is to build it.

Over the past three decades, three major shifts dominated the U.S. economic landscape.

(1) Information technology propelled an explosion of wealth, if not always job numbers, in technology and finance. Lots of talent migrated to the American coasts.

(2) Global manufacturing shifted to southeast Asia. For Indiana, an historic strength in manufacturing turned to relative weakness when information technology and globalization induced a rapid reorientation of the U.S. economy.

(3) Health, education, and services generated large gains in job numbers but not incomes. These sectors tend toward low productivity growth and thus low wage growth. And yet too much of Indiana's economy is concentrated in these mostly local industries.

Today, some of the trends are intensifying, others reversing. Information technology is poised for its next chapter – the artificial intelligence acceleration. Globalization, on the other hand, is in retreat. Will a new bipartisan skepticism of China lead to an American industrial renaissance – or a dangerous retrenchment from world trade? Meanwhile, healthcare spending is poised to swiftly pass 20 percent of GDP, potentially generating lots of jobs to serve an aging population – but also swamping state, local, federal, and company budgets.

In this chapter, we focus on technology. More than any other factor, it drives economies and thus history. The wheel, the printing press, the steam engine; automobiles and airplanes; lasers, microchips, and now AI.

INDIANA IN 2024

First, however, let's briefly consider the present. Prudent leadership over the past two decades has put Indiana on sounder financial footing than most of its Midwestern neighbors. While some states pushed away business and shed population, Indiana attracted new residents and investment.

This modest outperformance of struggling peers, however, will not be nearly good enough in the next 20 years. Indiana has weathered the downsides of globalization, supplied efficient government services, and contained living costs (save health care) better than many. But we've not fully leveraged the power of entrepreneurship, the internet,

or other breakthrough technologies. Indiana is a great place to live and raise families; yet our economy remains far too concentrated in low-productivity, low-wage sectors.

Booming peer cities like Charlotte, Nashville, and Denver highlight the challenge and possibilities for Indianapolis. Over the last 15 years, these three peers generated new jobs in high-income sectors such as finance and technology at rates 50 percent to 200 percent faster than Indianapolis and a fifth peer, Columbus, Ohio. Indianapolis compares favorably to the others in affordability but matches only Columbus in most of the crucial growth and income factors.

New research by Philip Powell, an economist at Indiana University, provides a jolting reality check for the Indiana economy. Among Indianapolis' 20 most abundant occupations relative to other metro areas, only three pay more than the national average wage – physicians, health educators, and financial specialists (due largely to payroll clerks at the Defense Finance Accounting Service headquarters).

These metro data fairly reflect Indiana's economy as a whole. Most of Indiana's highest paying jobs are concentrated in local, non-scalable work such as health care, education, and law. These are worthy professions. But every region has them, and they don't often grow much faster than the population. A region that sells mostly local services to itself cannot generate the kind of explosively growing firms nor attract the diverse talent necessary to fuel an upward economic spiral.

The true vibrancy of a regional economy is determined by high-value exports to other regions, often based on scalable ideas. Today, that means software, energy, advanced materials, financial products, pharmaceuticals, complex manufactured goods, digital content, and technical services.

Warsaw, Indiana's success as a biomedical hub is an example of tech-based scale. Other Hoosier cities and regions – Fort Wayne, West Lafayette, Bloomington, Evansville – are generating momentum in this direction.

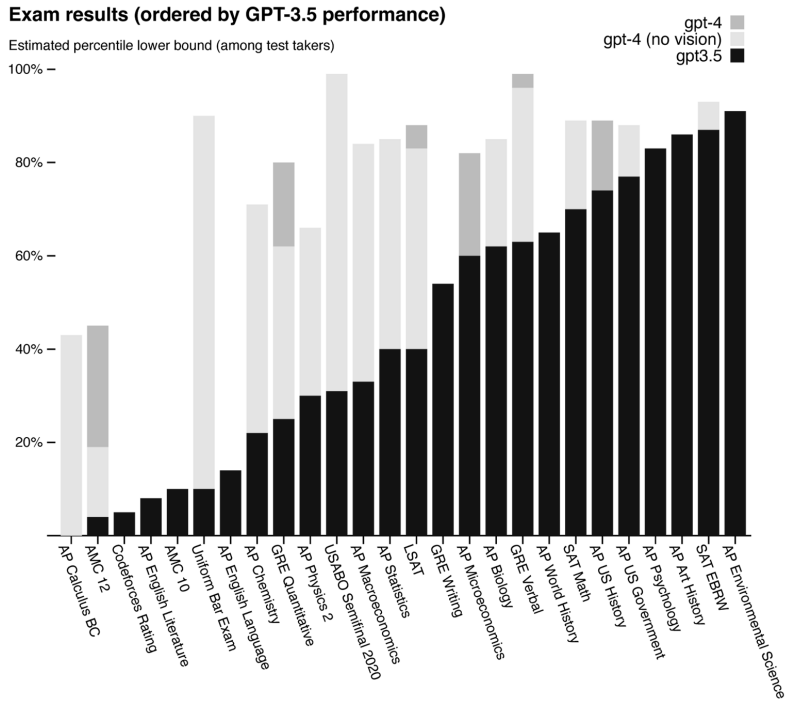
Our challenge is to encourage these leaders and expand similar efforts around the state.

THE CHALLENGE OF SCALE

To date, information technologies are the most scalable of all. The internet allows companies to quickly reach billion-person markets and trillion-dollar valuations. Now, AI. is poised to scale products, companies, and many people in unprecedented and unpredictable ways.

Technologists have dreamt of AI since at least the early 1950s. After many fits and starts over the decades, the dream finally seemed close at hand when OpenAI delivered ChatGPT in late 2022. Everyone immediately saw it was a quantum leap.

Figure 1-1. GPT-4 Matches Human Performance on Many Advanced Exams



Source: OpenAI (2023).

Standardized tests provided eye-popping evidence of AI's new capabilities. As you can see in the diagram nearby, OpenAI's GPT-4 model scored in the 80th to 90th percentiles on many diverse exams,

from AP biology and physics to the LSAT and bar exam. The Claude 3.5 model from Anthropic appears to beat even GPT-4's impressive results. Like all general purpose technologies, artificial intelligence will both render millions of tasks and jobs obsolete and also generate millions of new jobs, often in entirely new categories.[1] Single-person start-ups might be common.

Pessimists focus on obsolescence. But AI could reverse the knowledge economy trend that punished workers not expert in science, law, finance, or information technology. People whose natural talents don't include, say, computers or writing may find AI supercharges the skills they do possess but which they were previously unable to scale.

New research shows ChatGPT, for example, helps poor writers 40 percent more than excellent writers. Moreover, AI itself will tutor and train un- or underemployed workers for new jobs far better than previous re-skilling programs. MIT economist David Autor optimistically suggests AI could lead to a middle-class renaissance.[2]

The unique opportunity that AI offers humanity is to push back against the process started by computerization – to extend the relevance, reach and value of human expertise to a larger set of workers. Because artificial intelligence can weave information and rules with acquired experience to support decision-making, it can enable a larger set of workers equipped with necessary foundational training to perform higher-stakes decision-making tasks currently arrogated to elite experts, such as doctors, lawyers, software engineers and college professors. In essence, AI – used well – can assist with restoring the middle-skill, middle-class heart of the U.S. labor market that has been hollowed out by automation and globalization. Some have suggested AI could even lead to a liberal arts renaissance too.

Scalability does not mean every company or individual has to seek out maximum ambition and market size. The very scale of the opportunity means that millions of niches will also open up for creative companies, entrepreneurs, and workers to leverage the new tools, often in entirely new product categories. Small companies will disrupt today's monopolies, whose large scale is often an illusion not of innovation but intransigence and inefficiency. As technology hoovers

up value from unproductive tasks, creative companies will hollow out complacent ones. The key is to be the former, not the latter.

THE NEW INFORMATION INFRASTRUCTURE

To grasp the magnitude of the AI boom, consider the sudden leap of computer chip firm Nvidia. In the space of a few years, Nvidia exploded from relative unknown to, briefly, the world's most valuable company. Between the first quarter of 2023 and the first quarter of 2024, Nvidia sales of its AI chips quintupled from just under $5 billion to nearly $25 billion. As of July 2024, the company was worth $3.3 trillion, just slightly less than Apple and Microsoft, but more than Google and Amazon.

Nvidia was perfectly positioned for AI's new computing architecture, which required highly parallel processors. As the principle of Moore's law began to run out of steam on microprocessors (CPUs), Nvidia's graphics processors (GPUs) and other highly parallel chips took up the lofty exponential expectation.[3] The buildout of the AI computing infrastructure is now well underway. It will rival and may surpass the cost of building the Internet. Between 1996 and 2023, U.S. communications firms invested more than $2.5 trillion on cross-country fiber optic lines, mobile antennas and towers, switches, routers, and broadband links to homes and offices. We also invested hundreds of billions more on giant cloud-computing warehouses, which stored our data and powered millions of webpages, streams, feeds, and apps. This total rewiring of our communications infrastructure transformed the economy and society.

Now, AI computing is shifting data center infrastructure into an even higher gear. To generate everything from artificial images to machine-written essays, the AI companies must first train "models" with exabytes of data culled from all historical Internet content. In 2024, a leading-edge AI training cluster consisting of 100,000 chips might consume 100 megawatts of electricity, or enough to power 100,000 homes. By 2026, one AI training warehouse might contain one million chips and consume one gigawatt, or the capacity of a large nuclear reactor.

Training an AI model, however, is only the beginning. The second half of the equation is "inference" – or querying the models to generate

answers to our questions and commands. Delivering the services you and I want – reading, digesting, answering, and learning from our requests – will require yet more computation and power. One analyst predicts that by 2030, at least four of the large AI companies will each build a training cluster with 100 million chips, costing $1 trillion, and consuming 100 gigawatts, or 20 percent of current U.S. electricity production.[4] Such a projection may seem wildly implausible. Surely, today's overexuberant AI boom will by that time go bust. Supply will outpace demand; financing will dry up.[5] Or perhaps it will run into resource constraints – materials, power, construction workers.

Skeptics will correctly warn that the early internet building boom was violently interrupted by the tech crash of 2000-01. Hundreds of dot-com firms and dozens of large fiber-optic networks and broadband equipment companies went bankrupt. Nearly 25 years later, however, the temporary overeagerness and financial losses of the late 1990s and early 2000s look mild compared to the size and influence of today's internet economy. After a major stumble, the $3-trillion network and cloud-computing foundation propelled the mobile, app, software-as-a-service, and new media revolutions, with seemingly limitless video streams and podcasts fundamentally altering all entertainment, news, and commentary.

In the same way, the new multi-trillion-dollar AI infrastructure will unlock hundreds of companies and thousands of new applications across every industry, old and new, while generating a content tsunami even larger and more diverse than today's internet giants like Netflix, YouTube, and Spotify. Venture capitalist Marc Andreessen speculates about entirely new content categories, such as "massively multiplayer dreams."

Despite Nvidia's spectacular technology and well-deserved plaudits, the current GPU architectures, like CPUs before them, will run out of steam. We need to invent faster and far more energy efficient computing substrates and architectures, making today's mind-numbingly infeasible dollar and energy projections more achievable.[6] Graphene is especially promising as a substrate, and a return to analog computing may be the only way to surmount the trillion-dollar data center obstacle.

THE PRODUCTIVITY GAP

Technology is no mere toy. It affects wage and income growth for workers whose firms deploy it most aggressively and use it most creatively. In a 2017 study, Michael Mandel and I found a yawning productivity gap between firms that use lots of information technology and those that do not.[7] Productivity in the "digital industries," we found, grew at a robust 2.7-percent annual rate over the previous 15 years. But productivity growth in the "physical industries" plummeted, to just 0.7 percent per year.

A significant portion of this differential could be explained by the industries 'huge differential investments in – and creative use of – information technology. The physical industries at the time accounted for around 70 percent of U.S. output and 74 percent of employment but made just 30 percent of the investments in infotech.

This "information gap" may help explain the large pay divergence. At the end of 2016, average total compensation for the 90.5 million workers in the physical industries was $55,600. But total compensation for the 32.6 million workers in the digital industries averaged $92,000. Digital employees thus account for 26 percent of the private sector workforce but earn 37 percent of total pay. It's not just because of a few high-paid executives in Silicon Valley and Wall Street.

In separate work, Mandel found that wage premiums for mid-skill occupations in digital versus physical industries range from 15 percent to 38 percent.[8] For example, sales representatives in digital firms earn 15 percent more than non-digital sales reps. Workers in advanced distribution centers, such as Amazon's high-tech warehouses, earn 31 percent more than retail workers in the same geographic area. This tends to support the conclusions that productivity and pay are still linked, and technology differentials are a big part of the explanation.

Yes, skills matter. But regardless of skill level, moving more workers into more productive industries with more and better use of technology should be a chief objective of any workforce policy. TechPoint, Indiana's chief promoter of technology acceleration, is helping the cause through its Mission 41K effort, "a collaborative movement to address the largest problem tech employers are facing today – finding, hiring and retaining qualified tech talent."[9]

Today's projections for an AI productivity boom are all over the map. Some believe gains will be modest, perhaps bumping annual growth from a paltry 1 percent to a much better 2 or 3 percent. Others predict a "singularity," in which superintelligent machines invent more superintelligent machines, producing unlimited innovation. Bridgewater Associates, the world's largest hedge fund, has surveyed the highly variable productivity research and believes productivity gains will be real but not unprecedentedly large: "We think full-blown explosive growth is unlikely."[10]

Even short of economic nirvana, AI's radically deflationary effects will revolutionize specific tasks, jobs, firms, and industries. As Bridgewater reminds us:

> *The marginal cost of a given product falling to zero can be either a best-case or worst-case scenario for its sellers, depending on their pricing power. We saw this in the case of the IT revolution of the 1990s and 2000s, which brought the marginal cost of production or distribution to zero for many businesses involved in creating and disseminating information. Besides consumers, who benefited from a profusion of free and low-cost products, the "winners" included software companies that earned eye-popping margins by charging a premium for products that cost nothing to distribute. The "losers" (such as newspaper publishers and camera companies) could not compete with zero on a marginal-cost basis; they shrunk dramatically as consumers opted for much cheaper (often free) alternatives.*[11]

WEALTH AND WORRY

AI will be like computing is today – everywhere, embedded in everything we do. It will rewire every sphere, from the arts to investments. One of the first things the new software is transforming is the building of software itself. AI will turn lots of people into "software developers" even if they don't know it. Amjad Masad, the CEO of Replit, argues that adding Chat-GPT-like features to his own company's software tools boosts the productivity of his "10x engineers" – elite developers – by 30 to 50 percent. That's a huge improvement. Yet it may provide an even bigger boost to novices –

improving their ability to "write" code (often by just narrating what they want the AI to do) by a nearly infinite amount.

As the personal computer expanded computer accessibility to tens of millions of regular people, beyond the mere thousands of scientists who used them in university research labs, these new AI tools will also expand software, apps, and content generation to non-technical people. Indeed, software development may fade into the background of what everyone does, the way the iPhone touch screen allows anyone to manipulate a computer unconsciously. Of course, building the new tools that expand the user-friendliness of AI systems will still largely be the province of elite technicians. But the entire stack and value chain will have moved upward.

As AI empowers millions of people to do extraordinary things, it could also wipe out giant swaths of existing tasks and jobs, from office workers to vehicle drivers. Some have argued that where previous innovations in information technology automated lower-skilled jobs and benefited highly skilled workers, AI may automate many of those high-skilled jobs as well. Nick Bostrom, author of *Superintelligence*, believes AI and automation will lead to "full unemployment." Even Elon Musk, an AI enthusiast, believes "there will come a point when no job is needed."[12] Musk, however, makes an important caveat: "You can have a job if you want to have a job, for sort of personal satisfaction. But the AI will be able to do everything."[13] Musk's prophecy of unimaginable abundance and luxury jobs is still a dream well into the future. (Or perhaps it's a nightmare. He believes abundance may cause a crisis of meaning.) And yet it contains an important grain of truth for the nearer term.

In other words, AI could generate enough wealth in the productive and creative sectors that it helps pay for a realignment of people into new, more productive, more meaningful jobs. Or perhaps it allows people to reprioritize their lives – say, in a modest shift away from the modern necessity of dual income families. It might also be argued that a significant portion of today's jobs are superfluous. These jobs are often embedded in legacy industries or even modern tech monopolies, both of which face too little competition. Unproductive jobs can be found in government, but in truth every firm and industry has them.

They are all cost. They do not exist for purely economic reasons. Call them fake jobs.

One potential scenario is that AI advances so radically and heightens the gap between productive and unproductive jobs so clearly that superfluous employment can no longer be justified. A big policy question then arises. Will we *allow* massive productivity gains to occur? Or will we protect bloated firms, industries, and agencies with the stated objective of "saving jobs"? There's a real question whether productivity gains in some sectors – such as healthcare and education – are feasible or even legal. In other words, automation can't eliminate fake jobs. True productivity and thus income gains require pain. Economist F.A. Hayek called it creative destruction for a reason.

SUPERINTELLIGENCE?

Like previous generations of computing, AI is vastly superior to humans in many respects. Seventy years ago, the first computers performed basic arithmetic faster than human "computers" with pencil and paper, which is where the term originated. Today, they often exceed us in memory, pattern matching, and hundreds of specific tasks.

And yet the search for artificial general intelligence, or AGI, in which a machine emulates every facet of human capacity is still out of reach. Yes, predictions of AGI have drawn nearer in recent years. Some now say we will "achieve AGI" as soon as 2027. But "achieving AGI" is nearly impossible to define. As AI matches or exceeds more and more discrete human abilities, we learn just how special is the human mix of sense, perception, intuition, logic, physical agility, interaction, adaptation, motivation, and creativity. Biology continues to wow us with its still little-understood depth.

The human advantage is especially clear on the metric of energy efficiency. We simultaneously do amazingly versatile things, both conscious and unconscious, with very few calories compared to computers. Think back to one of the great AI breakthroughs of the last decade. In 2016, Google's Deepmind shocked the world when its new AI program, AlphaGo, defeated the great Lee Sodol at the board game of Go. It had been nearly 20 years since IBM's DeepBlue beat Gary Kasparov in chess, and Go far exceeds chess in complexity and strategy. AGI surely was now just around the corner.

Not so fast. AlphaGo was still a single-purpose machine. It played a well-defined game with clear rules and a limited playing field. It could not generate images or write essays. And the energy differential was enormous. A human brain consumes around 20 watts of power. AlphaGo, on the other hand, consisted of 2,200 computer chips consuming around one megawatt of power – 50,000 times more than its human Go opponent! A brain, moreover, had a million times more synaptic connections than the best artificial neural network at the time – thus giving humans something like 50 billion times the general purpose hardware per watt.

Since then, the computing and algorithmic advances of large language models (LLMs) have partially closed that gap. They are both more powerful and far more agile across a wider range of tasks. Yet the human brain is still around one million times more energy efficient than today's best neural networks. One reason innovation in the physical economy has lagged the digital economy is that people, objects, and natural environments are more difficult to computerize than numbers, text, and photos. Humans still excel in physical space. Humanoid robots and self-driving cars are making real progress. But the economic cross over points have come far slower than in natively information-intensive arenas – for example, financial services or video content.

The bottom line is that AI will in coming years match and exceed humans at many cognitive and even physical tasks. But our magical mix of biological hardware and software still towers over machines in important ways. Nowhere is this clearer than in what we call "creativity," perhaps the most profound of all human traits. And this is where AI skeptics make their stand. As smart as computers are, they will never anytime soon be creative. Computers are built to obey. We tell them to add, subtract, and multiply. Given a known input, we can predict the output.

Not so with LLMs, backers of superintelligence reply. For the first time, we have truly probabilistic computing. Ask an LLM the same question twice, and it may return different answers. It may even deliver fake citations, illogical ramblings, or pure nonsense. Engineers call these "hallucinations." Hallucinations are maddening when we want hard facts. But they may be necessary if AI is ever to approach

something like "creativity." True creativity is unpredictable. Regular computers were designed and built to be absolutely predictable. Obedient, in other words.

Creativity requires just the opposite. Art, innovation, and scientific discovery require outside-the-box thinking. Or as physicist David Deutsch puts it, disobedience is a prerequisite for true creativity. Can disobedient computers lead to creativity? The first steps toward creativity are already seen, but they are mostly hybrid. Let the AI brainstorm, while humans select the best ideas. The bottom line is that humans are still in charge. The most likely path over the next few decades will be intense human-machine cooperation, not relegation of humans to irrelevance.

POLICY IDEAS

The most productive ways to avoid or mitigate the downsides of technological disruption are to promote robust growth, rapid technological adoption, continuous education, strong families and communities, and flexible, adaptable labor markets. Entrepreneurship and economic growth generate new paths for those displaced. Wealth and strong communities provide resources to better take care of those who do fall between the cracks – and to help them rebound. Continuous education and re-skilling can reduce the time spent un- or underemployed. High quality education and healthy cultural habits help build resilient citizens.

Historically, continuing education and workforce re-skilling programs generated mixed results, at best. These top-down efforts often suffered from too much bureaucracy and an inability to predict the future. A more individualized, bottom-up approach may be far better suited to today's more diverse and fast-changing economy.

- Indiana should therefore consider adopting Career Scholarship Accounts (CSAs). These are flexible cash grants that individuals can deploy across a wider range of educational and training platforms. Instead of top-down predictions of what every worker should train for, CSAs provide an agile bottom-up path for both workers and providers of education and training. With individuals deciding when and how to deploy these flexible dollars, a more

diverse and innovative array of educational content and delivery channels should arise to meet personalized needs. Better incentives should better match workers with educational services. Providers competing for CSA dollars will likely adapt to real-world market signals at a much faster pace than a bureaucracy's out-of-date design.

- Support collaborative efforts to build Indiana's pool of technology talent, such as TechPoint's Mission 41K.

- Energy will be a crucial foundation of every industry and job, from advanced manufacturing to AI Indiana should prioritize low-cost energy abundance.

- Prioritize entrepreneurship, especially in scalable, high-productivity industries instead of the mostly non-scalable, local industries that dominate today.

- Ride the wave, don't cower from it. Rapid adoption of new technologies in existing and entrepreneurial firms is the best way to avoid disruption and displacement.

Avoiding or blocking AI is the surest way to get crushed by it. Many states, for example, are proposing highly restrictive AI laws. They fear it might be used in dangerous ways or it might destroy jobs. But such policies are likely to boomerang. Every technology can be misused or even deployed for illegal purposes. In general, existing laws and principles should be used to combat harmful acts, such as fraud, which happen to employ AI. Punish the criminal act, but do not preempt the general use of AI, which will have endless benefits.

States that restrict AI will have difficulty achieving their policy goals. Like the internet, AI will be everywhere, undeterred by physical borders. One sure way to lose economically would be to restrict AI at home, only for voracious AI firms and apps originating elsewhere to hollow out your own firms and industries.

Instead, we should *adjust* our legal tools and institutions to encourage healthy *adaptation* to the AI world. The CSAs mentioned above are one example of an adaptive approach. Another example: a

new AI content explosion may dwarf the swirl of social media which consumes teenage (and non-teenage) brains. Instead of outright bans, however, we might encourage technological tools and new cultural norms to help protect people from the attention-sapping effects and deceptions of a new content tsunami.

AN ENTREPRENEURIAL ACCELERATION

Indiana University professor and director of the Indiana Business Research Center, Phil Powell argues that "High-skilled creative talent is the main driver of economic success." But education and training are only half the story. Why are low- and middle-income Americans so much better off than their counterparts in highly-educated Europe? In large part it is because the U.S. produces six times more billion-dollar startups than Europe. These explosive firms deliver the productivity gains and wealth that make even our less innovative industries and workers richer.

Indiana may educate more bio-tech geniuses, mechanical engineers, software developers, and financial quants. If it doesn't have innovative firms for them to join, however, or provide the entrepreneurial sandbox where they can start their own companies, they will go where their unique skills are valued. Without top-line growth in Indiana, thousands of good jobs in construction, transportation, and support services will never happen.

Remote work will amplify and scramble the location equation. Working from anywhere paradoxically makes place both less and more important. No longer tied to their employers' central offices, many workers will even more strongly prioritize affordability, education, infrastructure, amenities, safety, and community.

An optimist might like Indiana's chances to build successfully upon its livability advantages. Likewise, entrepreneurial Indiana employers can leverage the talent of the world. On the other hand, if Indiana is complacent, its vulnerability to regions with better weather and more attractive work and life ecosystems could intensify.

All these factors only reinforce our thesis. Instead of playing defense against a changing world, we should aggressively build more high-growth, high potential firms and economic networks. This is the best way to shape the character of work, lift the overall trajectory of the

economy, attract creative talent, and ride rather than cower from the inevitable waves of the AI acceleration.

ABOUT ENTROPY ECONOMICS

Bret Swanson is president of Entropy Economics LLC, a technology research firm serving investors and technology companies. He is also a senior fellow at the National Center for Energy Analytics and a visiting fellow at the Krach Institute for Tech Diplomacy at Purdue. From 2009 to 2024, he was a trustee and chairman of the Indiana Public Retirement System (INPRS). Find his Infonomena newsletter and podcast at infonomena.substack.com.

CHAPTER NOTES

[1] For a good look at how the new LLMs are "general purpose technologies," see Tyna Eloundou, Sam Manning, Pamela Mishkin, and Daniel Rock. GPTs are GPTs: An Early Look at the Labor Market Impact Potential of Large Language Models. August 22, 2023. https://arxiv.org/pdf/2303.10130.

[2] David Autor. "How A.I. Could Help Rebuild the Middle Class." Noema. February 12, 2024. https://www.noemamag.com/how-ai-could-help-rebuild-the-middle-class/.

[3] See, for example, Bret Swanson. "Moore's Law at 50." American Enterprise Institute. 2015. https://www.aei.org/wp-content/uploads/2015/11/Moores-law-at-50.pdf. "The solution was found in parallelism. The rate of improvement in single-processor performance had indeed slowed a bit. But as clock speeds and voltages leveled off, firms began putting two, then four, then more processors on each chip, and the results were encouraging. This 'multicore' strategy was new to microprocessors, or CPUs, but it was already familiar in other types of chips that specialize in real-time processing of high-speed data, such as graphics processors (GPUs)…"

[4] Leopold Aschenbrenner. In section IIIa. Racing to the Trillion Dollar Cluster. Situational Awareness: The Decade Ahead. June 2024. https://situational-awareness.ai.

[5] Already, financial and venture firms are warning of an A.I. bubble. See, for example, analysis from Goldman Sachs (Gen AI: Too Much Spend, Too Little Benefit?" https://www.goldmansachs.com/intelligence/pages/gs-research/gen-ai-too-much-spend-too-little-benefit/report.pdf) and Sequoia Capital ("A.I.'s $600 billion question." https://www.sequoiacap.com/article/ais-600b-question/).

(Chapter Notes continue on following page)

Chapter Notes (continued)

[6] See, for example, upstart chip companies such as Groq, Cerebras, and Extropic, which are building new computing architectures; and new materials advances, especially in graphene.

[7] Michael Mandel and Bret Swanson. The Coming Productivity Boom: Transforming the Physical Economy with Information. March 2017. http://entropyeconomics.com/wp-content/uploads/2017/03/The-Coming-Productivity-Boom-Transforming-the-Physical-Economy-with-Information-March-2017.pdf.

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[9] "Technology Talent and Workforce Mission41K Impact Network." Techpoint. Accessed July 2024. https://techpoint.org/talent-impact/.

[10] See Bridgewater Associates' numerous analyses of A.I.'s economic potential; for example, "Are We on the Brink of an AI Investment Arms Race?" "Assessing the Implications of a Productivity Miracle." "Exploring How AI Will Impact the Economy."

[11] Greg Jensen, Lauren Simon, and Josh Moriarity. "Assessing the Implications of a Productivity Miracle." Bridgewater Associates. November 30, 2023.

[12] Bloomberg Quicktakes. Video of Elon Musk. November 2, 2023. https://www.youtube.com/watch?v=HbiyTZae61A.

[13] Bloomberg Quicktakes. Elon Musk.