Chapter 4
Other Megatrends

If something cannot go on forever, it will stop.[1]—Herbert Stein

The introductory quote is often referred to as Stein's Law. Pundits have likely generalized the statement more than was intended by the author, Herbert Stein, in the original article. Nonetheless, the concept is simple and relevant to the purpose of this book and particularly useful to consider in this chapter. Chapter 1 defined the techno-realism narrative via a similar statement attributed to Kenneth Boulding that only madmen or economists think there can be exponential growth on a finite planet. Stein's Law represents a more general rephrasing of the concept. If a certain trend cannot continue, then it won't. But how do we know if a trend cannot continue? Before we address this question in Part II, we need to consider the trends.

This chapter presents many economic and demographic data and trends for which we can decide if they can "go on forever" or not. We can contemplate which economic narrative best explains these trends: techno-optimism and infinite substitutability or techno-realism and the finite Earth. The answer could be neither. Keep in mind that the characteristics of the energy system, and the energy trends of the previous chapter, inherently influence and are influenced by the "non-energy" trends of this chapter. Every viable energy and economic narrative must be consistent with the data, and not for just a short time period within the history.

Think about Stein's Law as follows. If for one reason or another you know that some statistical trend cannot continue on its present or long-term trend, then you

[1]Stein, H. (1989) Problems and Not-Problems of the American Economy, *The AEI Economist*, June, 1989. This citation is noted per column by Robert J. Samuelson (May 30, 2013), http://www.washingtonpost.com/opinions/robert-j-samuelson-is-steins-law-real/2013/05/30/716942f2-c942-11e2-8da7-d274bc611a47_story.html, "…an intern who waded through a decade's worth of "AEI Economists." Stein's Law appeared on Page One of the June 1989 issue under the headline "Problems and Not-Problems of the American Economy." The reference was inspired by America's trade and budget deficits, which have probably lasted longer than Stein imagined likely."

C. W. King, *The Economic Superorganism*,
https://doi.org/10.1007/978-3-030-50295-9_4

cannot use that trend as a basis for thinking about the future. For example, recall the food and energy cost trends of Chap. 2. We witnessed that until the end of the twentieth century, the cost of energy and food relative to economic output had been generally declining since the start of the Industrial Revolution. But since the turn of the century, energy and food have no longer continued getting cheaper. Stein's Law tells us to expect, at some point, that this cost trend would in fact cease to decline as it had done for over 100 years. There are only two ways that the trend of energy and food expenditures divided by gross world product (GWP) could eternally decline. Energy and food costs would have to decline to zero cost, or GWP would have to grow to infinity. Neither of these are likely on a finite planet, at least one that has a human population and economy that resemble anything what we have today. One could pontificate that machines take over the human population, and thus food expenditure would go to zero if our population dies out. However, that world would no longer resemble ours today.

In addition to the energy and food trends of Chap. 2, there are many other important long-term megatrends that are important to understand the state of the world. This chapter presents these trends, and they reinforce the unlikely event that the world will reverse its recent course and pay less for food and energy than that already achieved around the turn of the century. These trends also make the case that the Finite Earth Narrative more plausibly explains how we have reached the state of the world today. I start with population.

Population and Age Demographics

Population is one of the most important metrics informing the state of society. To the techno-optimistic/infinite substitutability economic narrative, an increasing population is a sign of progress, an indicator that the human condition is improving for more people. After all, if the human condition is worsening, then why is population still increasing? Why is total energy consumption per person still increasing (Fig. 4.1)? Why are people living longer with reduced infant mortality? To the techno-realistic/finite Earth economic narrative, human population cannot increase indefinitely. Thus, there is no reason to postulate, promote, or praise an ever-increasing population that would seemingly rise only for the reason that it can, until it ultimately can't. There is no intelligence in that pursuit.

Regardless of the costs and benefits of increased population, we can look at the data and at least understand how population is growing. Analysts and pundits often discuss population growth as "exponential." Strictly speaking, exponential growth means that the growth of some stock, such as people, depends on the amount of that stock already in existence. While many times we hear someone exclaim that population is growing exponentially, they often imply (without acknowledgment or clarification) that population growth is "rapid" such that we need to take some action to ameliorate or mitigate potential impacts from too many people on the planet. However, just stating that population grows exponentially is no more than

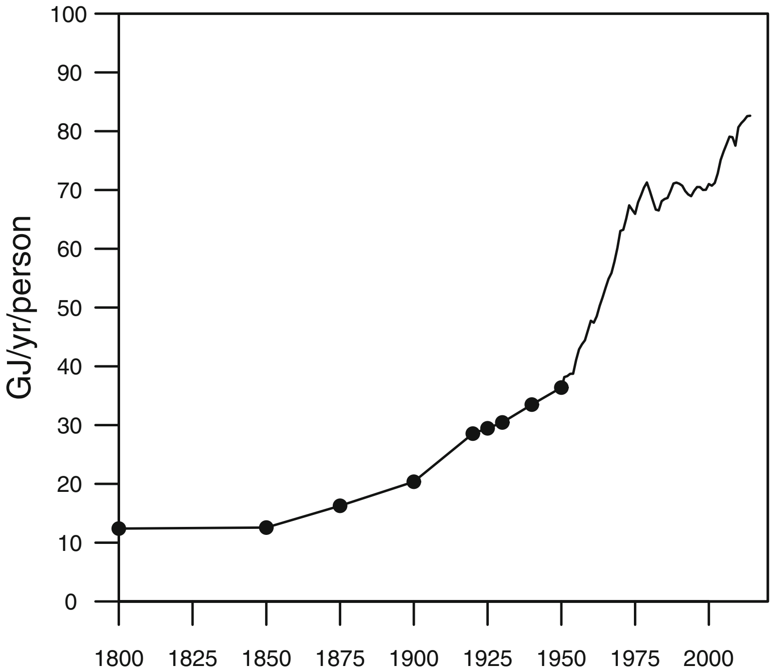

Fig. 4.1 Global energy consumption per person (1800–2014) is still increasing despite a stagnation in this trend from the 1970s–2000s. Energy data from 1800–1899 are as used in [10], and data from 1900–2014 are from International Institute for Applied Systems Analysis Primary, Final and Useful Energy Database (PFUDB) [6]. Population data up to 1950 are from Kremer [17] and from 1950 to 2014 are from the United Nations *World Population Prospects, the 2017 Revision*

a definition. It is also true that population can decline exponentially. That is to say, the more people there are, the more deaths occur as well as more births. If there are more births than deaths, population rises, and if the reverse, population declines. In both cases the growth or decline is exponential.

Instead of inferring the meaning of exponential population growth, let's just look at the data in Fig. 4.2. Until the early 1970s, world population had been growing faster and faster every year since the 1700s. That is to say, not only was the *absolute* number of people increasing each year (seen in Fig. 4.2a), the *growth rate* was also increasing each year (seen in Fig. 4.2b).

Consider the increasing growth rate. Before 1940, rate of global population growth was less than 1.0%/year. Then by 1950, population grew at 1.4%/year, and by 1970 the growth rate was 2.2%/year. Thus, the population growth rate itself grew from less than 1 to 2.2%. This is the concept of *acceleration* that you experience when driving a car, and why the pedal you push to make the car go is called the accelerator pedal. The more you push the accelerator pedal, the faster the growth rate of the speed of the car. For over a century leading up to 1970, the accelerator pedal of population growth was getting pressed more and more. In addition, Fig. 4.1

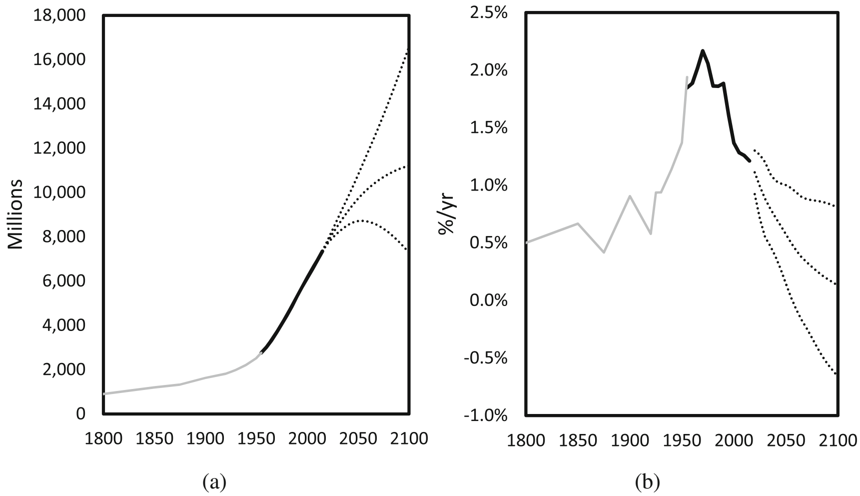

Fig. 4.2 Historical (solid) and projected (dotted) (**a**) world population (in millions of people) and (**b**) population growth rates (%/year) indicate that while world population is still growing, it is growing at a slower rate since approximately 1970. Pre-1950 data from Kremer [17]. 1950–2015 data and post-2015 projections (low, medium, and high variants) from the United Nations *World Population Prospects, the 2015 Revision*

shows that per capita energy consumption was increasing faster than population, also at an exponential increasing rate up to the early 1970s.

By witnessing the accelerating rate of population growth during the 1960s, an adherent to the finite Earth narrative might have easily seen a ticking "population bomb" ready to explode and outstrip the ecological limits of the planet to support human life:

> Sometime in the next fifteen years the end will come. And by the end I mean an utter breakdown of the capacity of the planet to support humanity.[2]—Paul Ehrlich (1970)

While the rate of population growth, not the absolute growth, has declined since Paul Erlich wrote his 1968 book *The Population Bomb* and made the above statement in 1970, 45 years later, he stuck to his original premise:

> I do not think my language is too apocalyptic in *The Population Bomb*. My language would be even more apocalyptic today.[3]—Paul Erlich (2015)

[2] Video footage from 1970 as part of Retro Report video (time 6:50) "The Population Bomb?" by Clyde Haberman, available at https://www.nytimes.com/2015/06/01/us/the-unrealized-horrors-of-population-explosion.html.

[3] Interview as part of Retro Report video (time 11:20) "The Population Bomb?" by Clyde Haberman, available at https://www.nytimes.com/2015/06/01/us/the-unrealized-horrors-of-population-explosion.html.

While the 2015 population of over 7.3 billion is a number that many see as already too large, barring large-scale warfare, we are likely going to add at least two billion before global population stops growing. I will not speculate on the timing or the quantity of the peak global population as I need not do that to know that the finite Earth is already providing a feedback signal to mitigate population growth.

This signal is in the population data: *the population growth rate has been decreasing* for over 40 years. Further, an annual rate of global population increase above 1%/year is the exception rather than the rule. While the deaths during World Wars I and II certainly took their toll on population growth (mostly in Europe and Asia), they did not halt the drive to growth rates above 1% starting in the 1940s. For the entire history of mankind leading to the 1930s, global population grew at slower than 1%/year. It is likely (but not for certain) that by 2050 the global population growth rate will again be less than 1%/year. Thus, there might be only one single span of 100 years in which humans experience population growth greater than 1%/year, and we are living during that time.

Just what might be the causal mechanism for the declining population growth rate? A common answer is that as people get richer, they decide to have fewer children. This is more of an observation than an explanation. By plotting data on net births (birth rates minus death rates) versus income per person, one can draw this conclusion (see Fig. 4.3).

If population growth declines as we get richer, then we should just work to ensure everyone becomes as rich as possible. Right? Eventually, we might become so rich as to no longer increase population. Of course, the correlation among data does not mean one variable is the cause of the other, but it could be. While the correlation of per capita income and to net birth rate is undeniable, I classify this "income" explanation within the techno-optimism economic narrative because the answer itself is usually devoid of any hint of the consumption of physical resources that drive the increase in income. If you believe the Earth doesn't constrain economic or population growth, then perhaps you can believe that socio-economic growth will self-limit population. No biological or physical explanation is required. For the finite Earth and techno-realism economic narrative, there is no need to resort to socio-economic data: a limit to population growth is a biophysical constraint, pure and simple.[4]

Importantly, both the fossil and renewable energy narrative proponents typically take some sort of socio-economic choice as the causal reason for declining population growth rates. The narrative is that birth rates have declined, by choice, because we don't need as much farm labor as we did in agrarian and early industrial times. It is true we don't need a large family of farm hands any longer. Fossil-fueled tractors, fertilizers, and irrigation removed the need for a large fraction of population

[4]The biophysical constraint could range from the basic Malthusian idea of population outgrowing food supply (with food supply limited from inputs such as energy and fertilizers or distribution costs) to an ultimate far-reaching scenario of running out of physical space for people live because there are too many people right next to them (you can only put an infinite number of angels on the head of a pin).

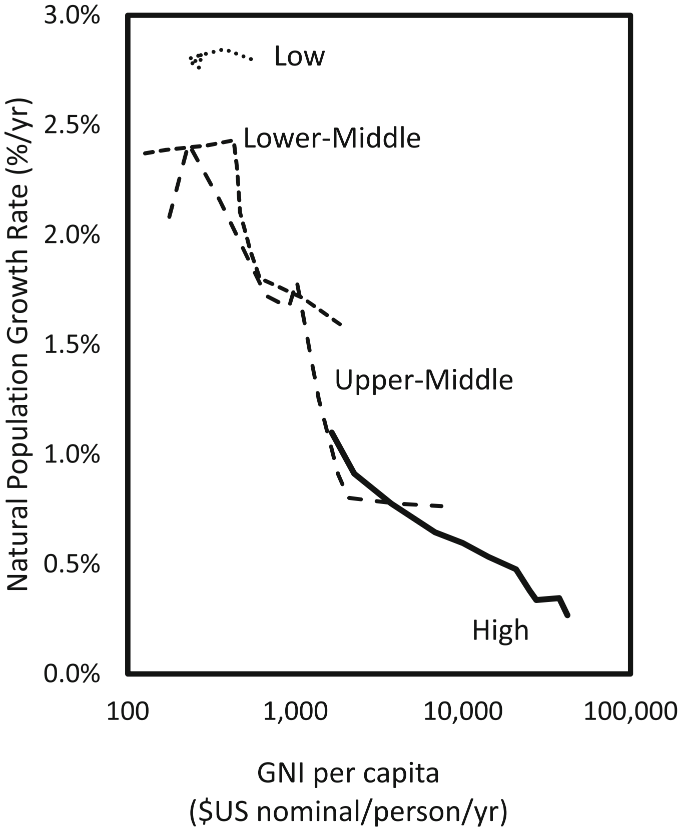

Fig. 4.3 Natural population growth of countries, grouped by income category, versus gross national income (GNI) per capita (on logarithmic scale). This growth rate represents the portion of population growth (or decline) determined exclusively by births and deaths (i.e., no immigration or emigration). The 1950–2015 population change data are "Rate of natural increase by region, subregion, and country, 1950–2100 (per 1000 population)" from the United Nations *World Population Prospects, the 2017 Revision*. Data for Gross National Income per person are from World Bank as "GNI per capita, Atlas method (current US$)"

to perform physical work in agriculture.[5] Some facets of developed economy agriculture still require significant labor today, such as harvesting vegetables typically performed by immigrants in the U.S., but engineering designs continue to mechanize more farming tasks.

[5]In the grand scheme of agriculture, the use of mechanized tractors is recent, starting in 1905. Tractors and other agricultural productivity gains lowered U.S. farm labor from 7 h per ton of wheat grain in 1900 to about 90 min per ton in 2000 [24, p. 307]. Modern agriculture technologies in the U.S. lowered the percentage of the total workforce in farming from 40% in 1900 to 15% in 1950 and less than 1.5% in 2015 [24, p. 307].

As fewer people could earn a living farming, more people were forced to move to cities in search of work as selling even a larger quantity of crops didn't make up for the drop in crop prices. Productivity increases on farms lowered the cost of food, and farm revenues no longer supported large farming communities. Agriculture shifted from relatively large farming communities selling relatively high-cost food to small farming communities selling low-cost food. While there seems to be a growth-enhancing effect of cities that drives their formation as a city's economic output increases faster than its population [3, 30], the energetic gains on the farm first drive people to leave farms and increase the population of cities. Thus, urban area formation is a socio-economic adaptation to integrate the portion of the population that is no longer needed to feed itself. This is one reason why data show increased urbanization accompanies declines in population growth rates for countries spanning vastly different cultures and histories. Chapter 9 revisits this farm-to-city migration in the context of economic thought, private land ownership and capitalism, and the early industrialization of England.

There are important economic improvements that do not require as much of a "physical work" explanation as explained for farming. Foremost is that scientists eventually developed basic biological knowledge (e.g., of bacterial infections and diseases) leading to practical medical care (e.g., antibiotics and vaccinations) and provision of clean drinking water and wastewater treatment. With this knowledge, infant mortality and overall death rates declined. Fewer deaths means that fewer births are needed for any given growth rate. The term "developing countries" largely refers to those countries that still do not have the levels of health and water services that exist in the "developed," or relatively rich, countries. Of course, municipal water supply systems do require infrastructure and energy inputs to operate reliably at city scales. This is one direction of the *energy–water nexus* [16, 25, 29]. While the energy inputs for municipal water and wastewater services are critical for cities to function, these services require a relatively small proportion of the total energy supply. Further, because water storage is easy, water treatment is one of the few core health services that does not have to be performed continuously each minute of the year. Thus, it is entirely viable to power water services with variable renewable energy (e.g., from wind and solar power).

This story of scientific and technological progress of developed countries still doesn't address basic questions regarding population. Why have the relatively rich countries, in mass, chosen to have fewer births when they became richer? Were the choices independent of finite Earth effects?

Certainly there were policy choices and health improvements that are highly influential. Two examples are the choices to develop and distribute contraceptives (i.e., birth control) and the one-child policy in China. The Western use of contraceptives is a bottom-up use of technology to enable people to have sex with minimal chance of pregnancy, and it is indicative of the economic and cultural technological solutions promoted by the infinite substitution economic narrative. China's one-child policy was a top-down economic doctrine, associated with economic penalty, applied to reduce population growth without specification of the methods. Other top-down programs have enforced sterility on some poor and underprivileged populations, such as in the 1970s in India, where issues with targeted sterilizations remain.[6] Given past policies and technologies that deliberately reduce birth rates, why has this occurred in countries that span many cultural and religious doctrines?

The human societal responses to reduce birth rates are consistent with the feedbacks from a finite Earth. If you assume human population is confined to the physical space of the surface of the Earth, which to date it has been, then the human population cannot grow forever. Some proponents of the economic techno-optimism narrative do not make this Earth-limiting assumption. For example, due to possible space travel, humans could leave Earth and increase human population on other planets. Aside from speculation on interplanetary colonies, are there experiments we can perform that inform us about population growth in a finite space? Yes. These are well-known growth experiments on bacteria colonies.

Bacteria colonies confined to a closed medium experience four phases of growth: lag phase (no appreciable growth), exponential growth phase, stationary phase where growth stops due to running out of nutrients or space, and death phase when the live population of bacteria declines exponentially as the reverse of the growth phase.[7] There is no policy, decision, or technology development required to curb the bacteria population growth.

To investigate the time of transition from the bacterial growth to stationary phase we can track the slowing of the growth rate of bacteria. To go from the growth to stagnation phase, the growth rate must go from a positive number to zero. This transition from positive to zero growth does not happen instantaneously. Thus, by looking at the growth rate over time, you can determine the "beginning of the end" of the growth phase as the time when growth rates start to decline. This investigation of growth rate is a way to interpret the declining human population growth rate in Fig. 4.2.

Unlike us humans, as far as we can tell there are no mother and father bacteria taking care of baby bacteria or grandma bacteria. In our society not everyone works, and only those working in the economy can provide for those that are too young or old to work. This point provides a mechanism to think about population *age demographics* in relation to population size, economic growth, and the structure of society.

A calculation called the *dependency ratio* estimates the number of "dependents," or non-working people, relative to the number of working people. If there are more working people than dependents, then the dependency ratio is less than 100. In this case it is relatively easy for workers to support the dependents, via direct care of a child or indirect contributions via redistributive taxes, assuming each worker can support himself or herself plus one dependent.

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[6]Soutik Biswas, BBC News, November 14, 2014, "India's dark history of sterilisation," accessed January 20, 2018 at: http://www.bbc.com/news/world-asia-india-30040790.

[7]Todar's Online Textbook of Bacteriology, "The Growth of Bacterial Populations (p. 3)," accessed January 10, 2018 at http://textbookofbacteriology.net/growth_3.html.

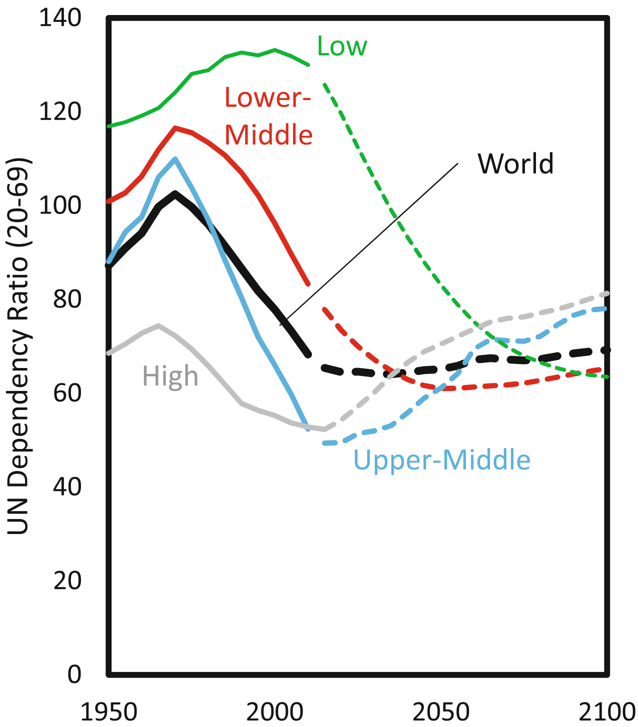

Fig. 4.4 The dependency ratio (scaled to 100) is the percentage of people theoretically too old (≥70) or too young (<20) to work divided by the "working" population aged 20–69. A ratio below 100 indicates more working people than dependents. Labels ("Low," "Upper-Middle," etc.) refer to subsets of countries by income level. Dependency ratio data from United Nations *World Population Prospects, the 2017 Revision*

A simple way to estimate the number of workers and dependents is to assume ages to enter and exit the workforce. Figure 4.4 assumes working age starts at 20 and retirement ends at 69. With these assumptions, over the last 40 years the world working population has become increasingly capable of supporting its dependents primarily because the middle income countries experienced a "demographic dividend" with many young coming into their working ages. The data indicate the low-income countries experienced an increasing fraction of global births. As of the last decade, the high income countries have approached a time of transition in which they shift from an increasingly young to an increasingly aged population.

Thus, the second decade of the twenty-first century might mark a fundamental turning point in age demographics for the world and the high income countries such as the United States. Starting about now, the United Nations population projection expects high income countries will experience increasing average age because birth rates are below replacement rates. *This aging demographic trend is a natural consequence of a slower growing or declining population.* This trend is not something to avoid or fret about. It is something to expect. Declining population growth is a natural consequence of living within a finite space—thus, support for the finite Earth economic narrative. Later in this chapter we will see how the same aging concept applies to U.S. energy infrastructure.

Population: Education and Growing Up

We've learned that population growth is slowing, and it is likely a consequence of the population approaching its confine. Slower population growth in turn translates to an aging population. At the same time a relatively large population today creates pressure to invent new technologies to overcome real and perceived constraints to higher population, higher resource consumption levels, or both. The challenges we face today are fundamentally different than economic challenges of the 1950s just like the challenges of the 1930s were different than those before then.

We cannot overcome new societal challenges for free. There are costs of money, resources, and time. Joseph Tainter uses the phrase the "energy-complexity spiral" to discuss the costs of increasing societal complexity [26, 27]. Generally a more complex society has a larger and a more diverse number of roles in society. Tainter states that "…most of the time complexity increases to solve problems.", and that societies "…subsequently must produce more energy and other resources to pay for the increased complexity." [28].

We can again explore population demographics and the need for increasingly educated workers to find ways to continually grow the economy (assuming for now that is a goal). Over time, society collectively acquires more knowledge. Thus, to make additional intellectual contributions, it takes more time for each person to come up to speed with the present level of knowledge. This increased time is spent in education, including in university that many see as a route to the middle-class. However, we should not be complacent that our educational system will continuously educate all people to a basic level of understanding. Recall Chap. 1 mentioned that 34% of American 18–24-year-olds are not sure that the Earth is round.[8]

Consider the changes in the correlation of education and income. In the U.S. in the 1950s a male worker with a high school diploma could obtain a job with middle-class income and a defined-benefit pension. Very little knowledge of science or mathematics was required for these jobs. Today, a college degree is required for most middle-class jobs that usually have defined-contribution pensions (e.g., 401K plans) that are less onerous to the employer and less secure for the employee. Over the last several decades there has been a steady increase in the number of Americans with

[8]Hoang Nguyen, YouGov (April 2, 2018), "Most flat earthers consider themselves very religious," accessed April 7, 2018 at https://today.yougov.com/news/2018/04/02/most-flat-earthers-consider-themselves-religious/.

college degrees since they are increasingly required to obtain middle and upper class incomes.[9] Recent research has suggested that the need for increased education time is one factor in determining that today's adolescence practically extends through age 24 instead of only ages 19 or 20 [22]. In a more complex society, more education is required to make a new contribution, and this education time delays the starting age for working and earning an income.

Consider the world in 1950. If people could start work at age 15, with relatively little education, and retire at age 64, then there were 1.8 workers for every young person and 12 workers for each old person. This is indicated by the "15–64" working age line in Fig. 4.5. In 2015, if you could start working at 15 and retire at 64, then there would still be plenty of workers relative to those too young or old.

But the world in 2015 is much different than that immediately after World War II. Consider the concept that adolescence extends through age 24 because young people have to go to college to learn enough before working to make a good living. If people still stop working at age 64, then there are more dependents than workers because the "25–64" working age line in Fig. 4.5 is to the left of the dashed curve representing a dependency ratio of one. Thus, it is easy to imagine pressure on people to work longer or for governments to delay pension benefits such as Social Security in the U.S.[10] By assuming people work through age 69, this extends the number of workers to again be greater than the total number of dependents in 2015 (see the "25–69" working age line), but just barely.

Population: Summary

A finite world places limits on population growth. The world population growth rate peaked in the 1970s, and it has been declining since (Fig. 4.2). A slower growing population leads to an aging population. A finite world also increasingly constrains physical and economic growth, leading to a need for increased complexity to solve new social problems. A more complex world in turn drives the young to become more educated and places increased pressure on people to start work later in youth and end work at an older age.

Just as we can track the growth rate in the stock of people, we can track the growth rate in the stock of money. One way to do this is to count how much money is borrowed. If we are easily paying for what we want and repaying money that we've borrowed, then our stock of debt would not accumulate. Are we paying back the money we have already borrowed? To further explore if there are signals from a finite world emerging from economic data, it is into the world of debt that we now turn.

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[9] "Census: More Americans have college degrees than ever before": http://thehill.com/homenews/state-watch/326995-census-more-americans-have-college-degrees-than-ever-before.

[10] Two-thirds of Americans have retired by age 65, and full Social Security retirement age for Americans born after 1960 is 67: https://money.com/ages-people-retire-probably-too-young-early-retirement/.

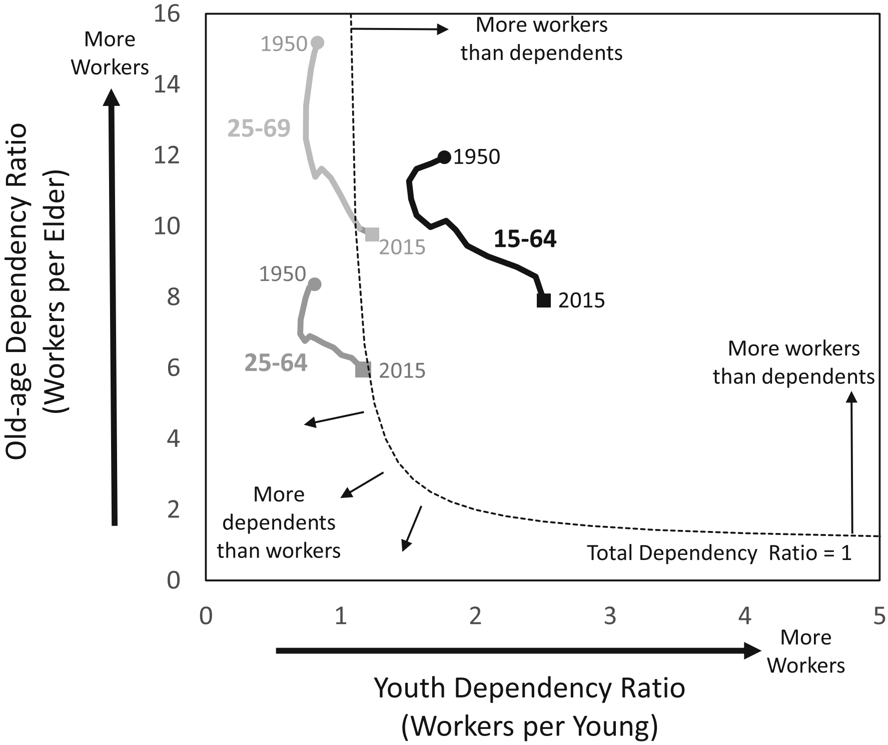

Fig. 4.5 The world dependency ratio disaggregated between its old and young components using three definitions of "working age" (15–64, 25–64, and 25–69). The thick solid lines represent historical estimates (1950–2015). The thin dashed curve represents the threshold of dependency ratio (equal to one) where working population equals the non-working population. A value residing below the threshold indicates the world has a larger old than working population, and a value the left of the threshold indicates the world has a larger young than working population. The population age demographic data are from the United Nations *World Population Prospects, the 2017 Revision*

Debt and Interest

Debt and Interest: Debt

> The consequences arising from the continual accumulation of public debts in other countries ought to admonish us to be careful to prevent their growth in our own.[11]—John Adams (1797), First Address to Congress, Nov. 23, 1797.

[11] Attributed at John Adams Historical Society, The Official Website at http://www.john-adams-heritage.com/quotes/ accessed on November 12, 2017.

> And I sincerely believe with you, that banking establishments are more dangerous than standing armies . . . [12]—Thomas Jefferson (1816)

> Let us control the money of a country and we care not who makes its laws.[13]—T.C. Daniel (1913)

Debt The concept can be a confusing one. The 2008 Global Financial Crisis forced us to think more critically about what debt actually is in our modern society. We need to consider whether the amount of debt in the economy, say relative to GDP, is affected by the rate of consumption and cost of energy and other natural resources.

After the 1970s, the rich economies experienced rapid increases in debt. Another rapid increase occurred in the overall worldwide economy after the year 2000. Is this rise in the amount of debt in the economy, say relative to GDP, affected by the rate of consumption and cost of energy and other natural resources? In this chapter we look at the data before Chap. 6 discusses some theoretical foundations and calculations for linking energy consumption to debt levels. This look at debt is critical for explaining the low economic growth rates of the world economy, primarily in the developed countries, since the 2008 financial crisis.

David Graeber's following passage, from his book *Debt: The first 5000 Years*, provides context for thinking about debt in our modern financial economy. He states, we can think of both moral obligations and debts:

> What does it mean when we educe moral obligations to debts? . . . On one level, the difference between and obligation and a debt is simple and obvious. A debt is the obligation to pay a certain sum of money. As a result, a debt, unlike any other form of obligation, can be precisely quantified. This allows debts to become simple, cold, and impersonal—which, in turn, allows them to be transferable. If one owes a favor, or one's life, to another human being, it is owned to that person specifically. But if one owes forty thousand dollars at 12-percent interest, it doesn't really matter who the creditor is; neither does either of the two parties have to think much about what the other party needs, wants, is capable of doing—as they certainly would if what was owed was a favor, or respect, or gratitude.[14]—David Graeber (2014)

We might feel obligated to help our family members in times of medical or other crises. We also might loan them money, but not with the same detailed terms and interest as a bank. Further, when we speak of how much money one country's government and citizens owe to governments and citizens of other countries, it is not some sort of moral obligation, such as a promise to show up at your best friend's wedding.

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[12]In a letter to John Taylor, May 28, 1816, transcription at https://founders.archives.gov/documents/Jefferson/03-10-02-0053 viewed November 12, 2017.

[13]Attributed to T.C. Daniel, 1857–1923 in letter to President W. Wilson, May 8, 1913; reported in his statement for the joint hearings before the subcommittees of the Committees on Banking and Currency of the Senate and of the House of Representatives, charged with the investigation of rural credits, Sixty-third Congress, second session, part 1, p. 764, February 16, 1914. See https://archive.org/stream/ruralcreditsjoin01unit#page/764/mode/2up pages 764 (transcript of letter to Woodrow Wilson) and 771 (quote during Congressional hearing).

[14]Graeber [13, p. 13].

Both of the words *loan* and *debt* describe money owed by some entity or person to another. However, there are important differences. A loan is a quantity of borrowed money that is owed to the lender—a specific person or company, such as a bank. The borrower can also be a person or a company. Loans are usually repaid via regular payments (e.g., a monthly mortgage or car payment) where a portion of the repayment reduces the principle, or amount of money borrowed, and the rest is the interest payment to the lender.

In our modern banking economy, debt is not the same as a loan. Debt usually involves companies or governments borrowing money rather than an individual person. However, this borrowed money is lent by entities within the general investing community that is composed of individual people, banks, and other investment entities such as pension funds. To do this the borrowing entity issues bonds at a certain price, an interest rate or yield, and a maturation time period. For example, on behalf of the federal government, the U.S. Treasury issues bonds with maturities from a few months to a few decades. Over the life of the bond the price and yield can fluctuate, and the bonds can be bought and sold in a similar manner as company stock. Bondholders are essentially a group of lenders. Similarly to lending for a loan, they receive regular interest payments equal to the yield times the price. But unlike a loan, the repayment of the price of the bond comes at the end time of bond maturity, whereas the loan principle (the amount lent up front) is repaid throughout the time period of the loan.

It is useful to understand how the difference between loans and debt has become blurred in over the last several decades. Consider the time depicted in Frank Capra's 1946 film *It's a Wonderful Life*. Jimmy Stewart's character, George Bailey, convinces the citizens of Bedford Falls not to start a "run" on his savings and loan bank by removing their deposits. He explains that their deposits are *not in the bank*. They exist in the form of loans given to their neighbors, *people they know*.[15]

George pleaded, "We've got to stick together. We've got to have faith in each other." The citizens of Bedford Falls didn't want to force harm on their friends, so they didn't demand 100% of their deposits. In essence, the monetary loans still had hints of moral obligation because the people loaning the money personally knew the people borrowing the money. Today debt is largely a transaction between people that don't know each other.

Can you convert loans into debt? Yes. This type of conversion was at the heart of the 2008 Global Financial Crisis. First, banks lent money as *mortgage loans*. Second, the banks converted the loans into debt. Third, the banks sold this debt to the general public.

Banks lent money in the form of mortgages to U.S. citizens to enable these citizens to "buy" and "own" houses. The words buy and own are in quotes because

[15]"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?"

in many cases the families who were lent the money and lived in the homes did not provide any down payment. Thus, they did not own any equity, and financially speaking, they were not homeowners. This loaned money did not previously exist. It was created by banks that lent the money for the mortgages. Yes, *banks created money from nothing when they made the loans*. If you don't believe me, then ask the Bank of England: "...the majority of money in the modern economy is created by commercial banks making loans." [20].

While the bankers did not necessarily live in the same communities and personally know the borrowers, there was a known relationship between lender (the bank) and borrower (mortgage owner). However, the mortgage loan was clearly not a *moral obligation* since that the banks originating these loans didn't have a personal or community connection to the new mortgage borrowers. In short order, banks converted their mortgage loans into debt. They turned loans into sellable debt by aggregating multiple loans into a group that they could sell to others as an investment much like a bond. This is what was meant when people spoke of packaging, bundling, or securitizing loans. These aggregated mortgage loans were called mortgage-backed securities. These securities repaid owners like a loan, but could be bought and sold like a bond, or debt.

As we learned in the aftermath of the 2008 Financial Crisis, the banks sold the mortgage-backed securities to investment funds and citizens in the U.S. and other countries. These mortgage-backed securities, which included many high risk sub-prime mortgages, were sold to investors as if they were as good as money in the bank. However, the banks selling these contracts knew they were *not* as good as money in the bank. The buyers of mortgage-backed securities did not know the securities were more risky than they were rated, and they certainly didn't know the credit worthiness of the indebted individuals on the other end of the contract.

Why would a bank want to convert its loans into debt-like concepts? One answer is to sell the risk of loan repayment to someone else. Since the banks knew the incomes of the debtors, they knew many of the loans were unlikely to be repaid, and they did not plan on receiving the interest and repayment of principle from the borrowers. However, they charged a fee to create this newly loaned money out of thin air. Thus, the banks could make a fee on the transaction and let someone else worry about collecting the loan payments.

In 2007 and 2008 when the mortgage debtors finally could no longer afford to make their mortgage payments, sometimes only the interest payments, they began to default on their mortgages. Some other people somewhere else in the world, who did not know these mortgage debtors, were losing the money that they traded to the originating banks in order to own the right to repayment of the mortgages.[16]

So let's summarize. Banks created money from thin air to loan to people to "buy" homes, and many of these people did not have the income to pay back the loans. For this, banks charged a fee. They then put many loans into a bundle, and sold the

[16]Many were not mortgage holders were not "homeowners" in the sense that they did not outright own any portion of equity in the home in which they lived.

bundle to someone else, pocketing that sale. Creating money is a good way to make money. Selling money you created is even better!

So how much debt and loans are there? A common format to state the level of debt is in relation to income (for people) and net output, or gross domestic product (for countries). For the world, this metric is debt relative to gross world product. The Institute of International Finance estimates total global debt was near 250% of GWP in 2002 and near 320% of GWP in 2016 and 2018.[17] The McKinsey Global Institute estimates global debt in the same ballpark at 250% in 2000 and 290% in 2014 [7].

The United States total quantity debt and loans resides at slightly higher levels than the global estimates (see Fig. 4.6). The peak level of total U.S. credit (debt and loans) relative to GDP was 380% in 2009 during the midst of the Great Recession. As of 2016, the U.S. total credit to GDP ratio was still 350%.

In aggregate, the time period before and after 1980 stand out as starkly different. Before 1980, one can see that total U.S. credit (debt and loans) grew only slightly from the 1950s near 140% of GDP to near 160% of GDP in 1981. The U.S. experienced significant post-war prosperity and productivity driven by abundant and cheap energy, largely oil. During the three and a half decades after World War II, the federal government generally paid off debt (from 90% of GDP in 1947 to 26% in 1974), and the private and consumer sectors of the economy accumulated debt and loans (e.g., mortgages) in an offsetting manner. Before the 1970s, the accumulation of mortgage loans was a sign of increasing confidence of a growing middle class investing in homes and education. The middle class was confident because their material lives had been improving for decades. Confidence comes after observing a trend of improvement, not before. Chapter 9 returns to this concept of consumer and investor confidence as drivers of economic growth.

U.S. credit changes primarily via the federal debt, mortgage loans, and private financial debt. Other major categories do not change as much. For example, state and local government debt increases slightly from the 1950s through 2016, peaking in 2009 at 21% of GDP, but usually residing at 10–20% of GDP. The mandate for states to have balanced budgets is a major driver of this stability. In addition, corporate (non-financial institutions) debt increases slowly but steadily from about 10% of GDP in 1947 to 30% of GDP in 2016.

However, just as so many trends change their direction in the 1970s so do a couple of major categories of debt. First, the federal government debt-to-GDP rose after 1980 through 1993 (to 55%) before declining to around 40% in 2000.

The second category of debt that changes its trend in the 1970s is the debt taken on by financial institutions. Relative to GDP it was almost non-existent coming out of World War II. Financial institution debt steadily increases from about 1% of

[17]Data from Institute of International Finance reported by Chibuike Oguh and Alexandre Tanzi, *Bloomberg*, January 15, 2019, "Global Debt of $244 Trillion Nears Record Despite Faster Growth" https://www.bloomberg.com/news/articles/2019-01-15/global-debt-of-244-trillion-nears-record-despite-faster-growth.

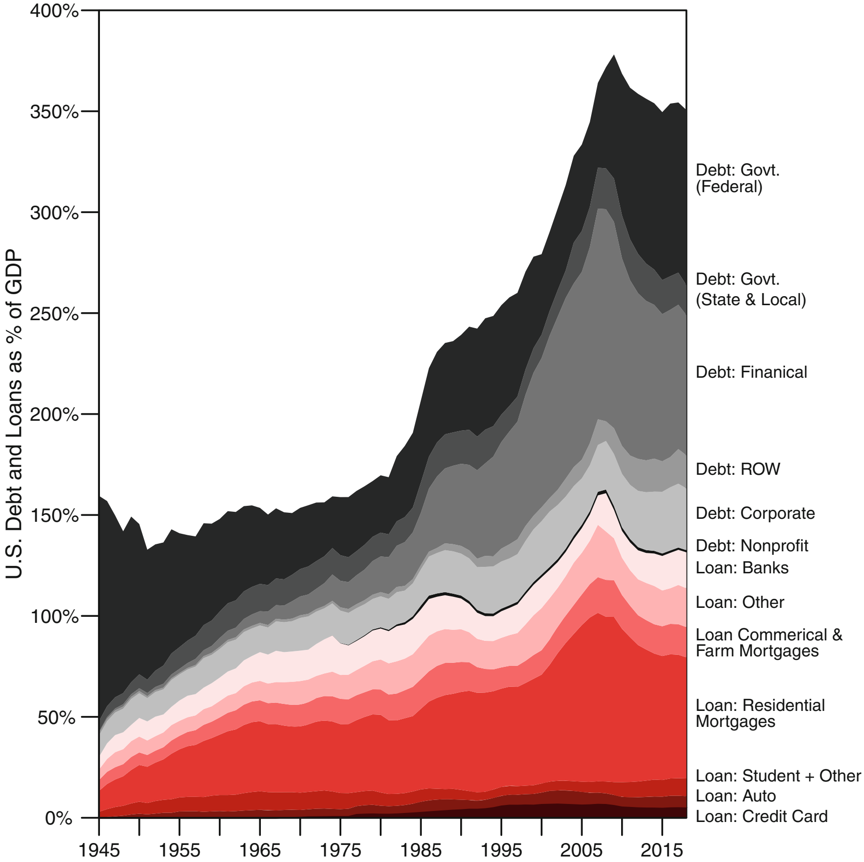

Fig. 4.6 Total U.S. Debt and Loans by category as a percentage of GDP (1945–2018). Data come from U.S. Federal Reserve Bank z.1 Financial Accounts of the United States, tables L.208 (Debt, listed as liabilities by sector), L.214 (Loans, listed by instrument), and L.222 (Consumer Credit, as four categories as a subset of Loans: credit card balances, automobile loans, student loans, and "other.") GDP from St. Louis FRED data series GDPA

GDP in 1947, to 17% in 1980, to its peak of 104% in 2008. This demonstrates the "financialization" of the economy that accelerated after the 1970s.[18]

The turn of the twenty-first century saw new swings in debt and loans. At the beginning of this century, the financial and household sectors increased debt the most rapidly. A rapid rise of loans provided for residential mortgages started around the year 2000 and increased until 2007. The quantities of these loans dropped off substantially after 2009 as mortgage owners defaulted and paid off loans.

[18]See Nicholas Shaxson's *The Finance Curse: How Global Finance Is Making Us All Poorer* for an extended discussion on financialization of the economy [21].

After the financial crisis ensued, central governments bailed out banks by taking on their debt, and thus government debt and central bank assets rose substantially for several years after 2007. Starting in 2009 the federal government debt grew from 40 to 83% of GDP by 2014, remaining at 86% in 2016. Financial institution debt decreased to 72% of GDP by 2015 because the Federal Reserve purchased much of the bad mortgage securities. Consider that the Federal Reserve Bank of the U.S. had assets of $960 billion in 2007 rising to $4.5 trillion in 2014.[19]

The post-2008 jumps in U.S. government debt and Federal Reserve Bank assets is the government bailing out commercial banks by taking their debt and putting that burden onto U.S. citizens. It is a perfect example of socializing losses from private companies.

But why would private companies and banks need a bailout? Think of the relative growth rate of economic output, or GDP, to the growth rate of debt. This metric is called the *marginal debt productivity* of the economy. This metric helps answer the following question: "How much additional economic output, or GDP, is added for each additional dollar borrowed?" Businesses borrow money to invest in new capital (machines, buildings, etc.) to produce more products and hopefully increase profit. If companies make increased profits, this translates to growing economic output. If borrowing money no longer increases economic output, then that is important to know. If debt accumulates faster than GDP grows, we must understand the social and economic ramifications.

Figure 4.7 shows the change in U.S. GDP relative to change in debt of state and federal governments as well as financial and non-financial corporations. If this number is greater than one, the debt-to-GDP ratio declines. If it is less than one, the debt-to-GDP ratio increases. It is just another way to look at the data in Fig. 4.6, but in this case only the debt and not the loans.

From the end of World War II through 1980, marginal debt productivity is greater than one. For every dollar borrowed by U.S. companies and governments, there was more than one dollar of GDP during that time. The economy was "productive" because it generated more annual value for every borrowed dollar. Since 1982 marginal debt productivity is below 1, and it has hovered near 0.5 with a noticeable dip in the few years leading up to the Great Recession of 2008. After 1980, every extra dollar borrowed only paid back an extra 50 cents. A practically identical "loan productivity" trend occurs when considering loans instead of debt. In the case of loans, individuals borrow money for home mortgages, cars, and education. Since the early 1980s, loans accumulated faster than the growth in GDP.

Companies choose how much of their profit to invest. After paying workers, taxes, and interest, profit is money companies use to invest and provide dividends to investors. Part of investment replaces capital that is outdated or is no longer functional. The rest creates new capital. Historically U.S. companies invest more than their profit, 50–150% more as shown in Fig. 4.8. How do companies invest

[19]Central Bank total assets as reported in Table s.61.a of the Federal Reserve Statistical Release, Z.1 Financial Accounts of the United States.

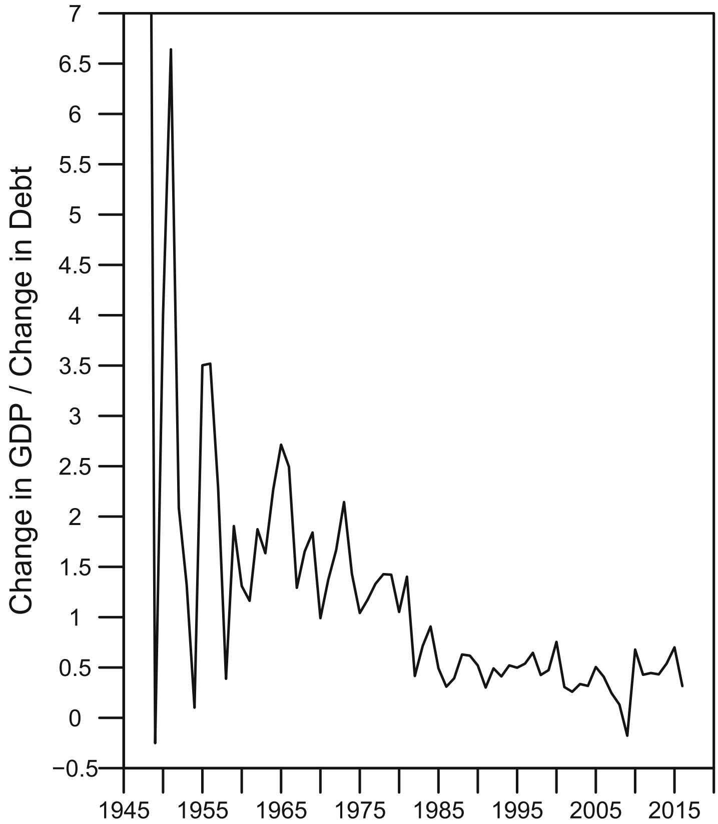

Fig. 4.7 The change in U.S. GDP per the change in total U.S. debt. Debt data are from St. Louis Federal Reserve data series ASTDSL

more than the money they have for investment? One way is to borrow money from banks, and this creates debt. Companies borrow money just like people do for mortgages. The nature of capitalism rewards those that are optimistic and take investment risks. If you believe future economic growth will enable you to pay back your debt, you are more willing to take the risk of borrowing. Chapter 6 discusses how most economic growth models ignore the role of debt, but by including the concept of debt and investment behavior as observed in Fig. 4.8, we can mimic the overall debt-to-GDP trends in Figs. 4.6 and 4.7.

Why should we care about debt productivity and debt-to-GDP ratios? Just what does it mean for U.S. and global debt ratios to be over 300% of their respective economic output? Debt is a stock of money, say in units of dollars. GWP is global "net output," in aggregate equal to "value added," say in units of dollars per year. Value added is essentially the flow of money that is split among paying wages (to workers), profits (to owners of businesses and stocks), rents (to those that own

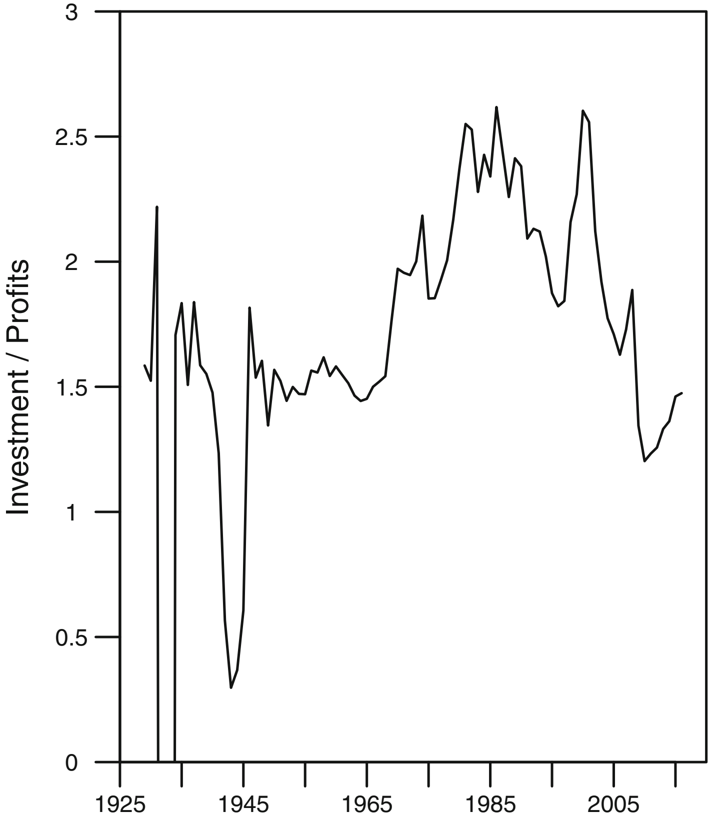

Fig. 4.8 U.S. gross corporate investment is typically greater than 150% of corporate profits. Data are gross private domestic investment (BEA Table 1.1.5, series A006RC), and corporate profits with inventory value adjustment, IVA, and capital consumption adjustment, CCAdj (BEA Table 1.1.12, series A051RC)

property), government taxes, and interest payments on loans and debt (to those that lend money).

By dividing debt by GWP, you get units of time, or years. Thus, a debt-to-GWP ratio of 330% means that if all GWP was allocated to paying off debt, it would take about 3.3 years to pay off the debt. During that time no one would receive a paycheck for over 3 years.

Of course we don't have to pay down all of our debt right away at the expense of paying wages and profits. As previously stated, we only repay some partial amount each month, the interest payments that depend on the *interest rate*, and interest rates change over time.

Debt and Interest: Interest and Interest Rates

Interest payments equal the amount of debt owed times the interest rate on that debt. The previous subsection discussed the first half of that equation (the level of debt), and this subsection summarizes the second half (the interest rate). If there is zero debt, there are no interest payments. Likewise, if interest rates are 0%, there are also no interest payments. People, largely central bankers, set interest rates in response to observed trends in the economy. The purpose of this subsection is to provide the data that allow us to consider whether historical changes to interest rates were responses to the effects of energy costs and consumption.

People and companies that lend money receive income as the interest payments on that loan. Those that borrow money pay the interest. A new company might need a loan to purchase machinery or pay wages before it has time to make enough revenue to be profitable. An existing company might obtain a loan in anticipation that future revenue increases more than the amount of the interest payment on the new loan. Thus, companies obtain loans with the anticipation of obtaining future profits.

Broadly speaking, the profits of a company are reduced by its interest payments. If there is not enough economic activity, lower interest rates on existing or future loans should entice more lending. This is why central banks lowered interest rates during the recession after the 2008 Financial Crisis. With the economies in recession, they wanted to entice businesses to obtain loans with which to invest in business ventures that would in turn hire workers.

Figure 4.9 shows the interest rates as set by the central banks of four countries: England, Japan, Canada, and the United States. These are *nominal* interest rates. One striking aspect of the data is that, while interest rates change frequently within a year and from year-to-year, they have historically resided in the range of 2–8%.

We see three regimes of interest rate change over the last couple hundred years. The first is witnessed by the relatively constant rate of the Bank of England since its inception until the Great Depression. England has a long history of banking and investing because of its colonial and sea trading history. For around 100 years in the 1700s the interest rate for the Bank of England was 5%. The principals of the Bank of England would loan money to England and receive 5%/year rate of return on that loan. In the 1800s the rate fluctuated between 2 and 7%, but usually near 3–4%/year. During that century, British companies could borrow money at these relatively low rates because they were effectively backed by the soundness of the global British Empire, including its navy and military, upon which "the sun would never set."[20]

The second regime for interest rates is from the end of World War II until the 1980s as interest rates rose for more than 30 years. As shown in Chap. 2, global and developed economy energy consumption grew at its fastest rate ever during this time as the middle classes became established in the U.S. and Western Europe. The

[20]Galbraith [11, p. 101].

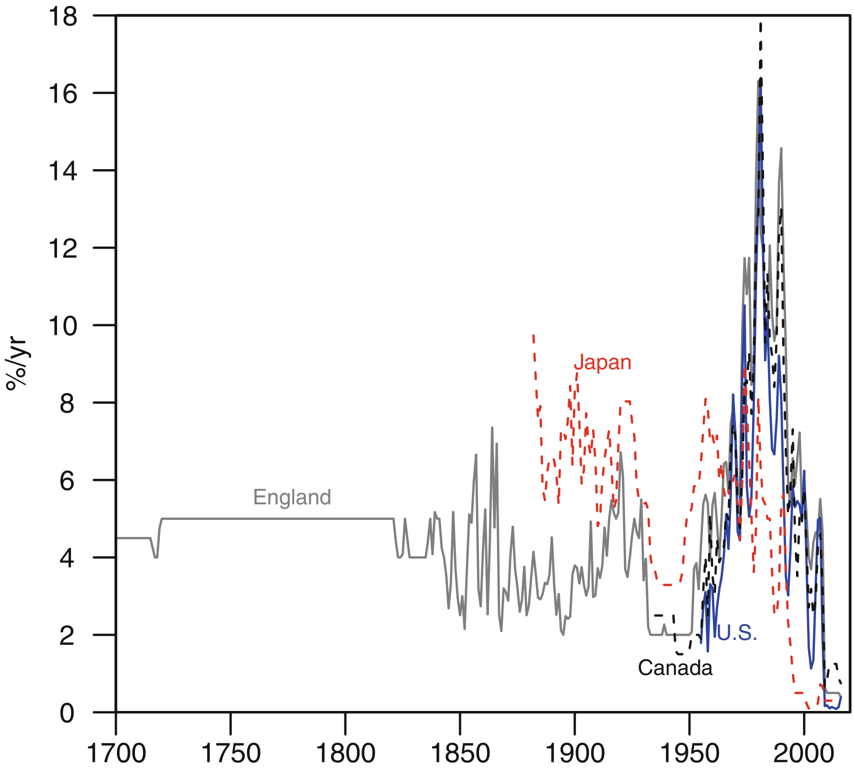

Fig. 4.9 Central bank interest rates (to 2016) of the U.S. (Federal Funds Effective Rate: H15/H15/RIFSPFF_N.A), England (Bank of England), Japan (Basic Discount Rate and Basic Loan Rate), and Canada (annual average of monthly bank rate v122530)

1970s and 1980s are the only time in which interest rates were *above 10%*. These high interest rates were set as a reaction to the increasing energy costs and wages, and the next major section expands upon the change in the growth of wages before and after the 1970s.

The final regime is one of declining interest rates from the mid-1980s until the financial crisis in 2008. The decade after 2008 is the only time in which central bank rates for many Western countries resided *below 1%* for any extended period of time. Only during the Great Depression and immediately after World War II did central banks set interest rates almost as low to spur economic activity, such as rebuilding after the war. Before the 1970s, the central bank rates for Japan are notably higher than the Western countries, but after the 1970s Japanese rates declined ahead of the others. Japan's central bank rate has been less than 1% since 1996.

Economists have stated that the post-2008 Western economies were seemingly stuck in a "new normal" situation of "secular stagnation" characterized by low economic growth, low interest rates, and stagnant wages [11]. As witnessed via the data in Fig. 4.9, there has not been a "normal" direction of change in interest rates since before the Great Depression. There were rising interest rates from World War II until the 1980s, and then there were falling interest rates through 2008. This up-down reaction by central banks was a response to changes in costs to businesses, namely wages and energy costs, or inflation.

Debt and Interest: Get Real

What I've discussed so far are *nominal* interest rates, specifically those that central banks adjust in response to the overall economic conditions such as employment and inflation. The *real* interest rate is (approximately) the nominal interest rate minus inflation, and it ultimately determines whether a person is earning more on an investment relative to how the prices of goods and services are changing. If you earned 5% nominal interest last year on the money in your savings account, but the prices of the things you buy also increased by 5%, then your real interest rate for your bank account is really 0%.

Fast rising prices are the same as high inflation. If inflation is high, central banks tend to raise nominal interest rates to make it more expensive to borrow money. More expensive money raises the cost to run a business and obtain a mortgage. If employment is too low or prices are not rising, they tend to lower interest rates to incentivize borrowing that increases economic activity.

Figure 4.10 shows both nominal and real interest rates for the U.K., U.S., Japan, and Canada. From the 1960s through the 1980s, real interest rates were below nominal rates. The difference is most stark for the U.K. and Japan. During this time prices were rising at a slower rate than the central bank interest rate. After 1990, real interest rates more closely match the nominal interest rates.

During the 1990s and 2000s Japan experienced negative inflation, or deflation. Prices were declining such that real interest rates were positive, while nominal rates were near zero. Japan's real interest rate declined from 3.2% in 2011 to −1% in 2015. What happened in 2011? In March 2011 an earthquake off the coast caused a tsunami that flooded and destroyed a significant amount of Japanese coastal infrastructure, including the 4.7 GW Fukushima Daiichi nuclear power station. Japan's government reacted by shutting down almost all nuclear facilities, removing about 13% of Japan's energy supply.[21] Japan experienced higher energy prices because of a declining supply of electricity, and by replacing some of the lost nuclear electricity with natural gas power plants. Japan imports all of its natural gas from

[21]The primary energy from Japan's nuclear fleet from 2010 to 2014 was 66.2, 36.9, 4.1, 3.3, and 0 million tonnes of oil equivalent (Mtoe) out of a total primary energy consumption of 503.8, 477.8, 475.0, 471.3, 456.7 Mtoe. Thus, in 2010, nuclear served 13.1% of Japan's primary energy, and in 2014, it served 0%. Data from the BP Statistical Review of World Energy, 2018.

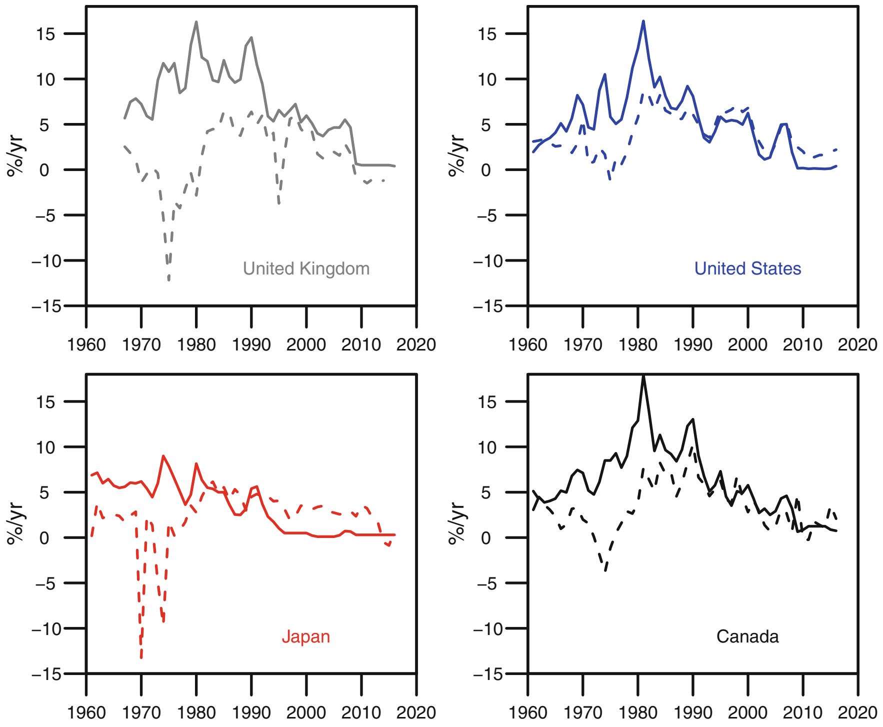

Fig. 4.10 Nominal (solid line) and real (dashed line) central bank interest rates of the U.S. (Federal Funds Effective Rate: H15/H15/RIFSPFF_N.A), United Kingdom (Bank of England), Japan (Basic Discount Rate and Basic Loan Rate), and Canada (annual average of monthly bank rate v122530). Real interest rates are from the World Bank (indicator FR.INR.RINR) defined as "Real interest rate is the lending interest rate adjusted for inflation as measured by the GDP deflator"

liquified natural gas (LNG) tankers, and LNG prices were very high during this time.

Increasing energy prices cause inflation and thus can be one reason that real interest rates decline. The OPEC increase in oil prices at the beginning of 1974 coincides exactly with the sharp decline in real interest rates shown in Fig. 4.10. The year 1974 experienced the lowest real interest rates in the U.K. and Canada, and second lowest in Japan. Since 1960, 1975 is the only year in which the U.S. experienced a negative real interest rate.

When economists speak of the economic rate of inflation, or the rate at which prices are increasing, it is common to discard "volatile food and energy prices" from the calculation. It is thought that energy prices are always relatively constant over the long term, but can fluctuate more wildly in the short term. Thus, we are told we can ignore the short-term variability in energy prices. Economist James Galbraith, in his book *The End of Normal*, says we should not so quickly dismiss the idea that significant changes in our energy system are crucial factors behind the major shifts in inflation, and thus interest rate responses:

> So far as I'm aware, no study of the [2008] *financial* crisis has yet suggested that resource costs lie at the heart—or near the heart—of it. But it remains equally true that resource costs have moved from the shadows, and are now understood by all informed, practical people to play a central role in economic performance–even though formal economics continues to neglect them. They are the simplest, clearest way to understand the crisis of the 1970s, and why inflation emerged then but disappeared in the 1980s and 1990s. They can also help explain why the energy-using world fell into troubles again after 2000, just as resource costs roughly doubled in relation to the prices of goods and services produced in the resource-using lands. And why, meanwhile, the energy-producing world, in the Middle East and in Latin America, experienced no financial crisis at all. No one suggests that resource costs alone are the full story of the Great Crisis–only that they are one underlying part of it. For now, that is enough.[22]—James Galbraith (2014)

Galbraith is right. Look back at Fig. 2.13. When energy costs rise, sparking inflation and a recession, central banks tend to respond by increasing nominal interest rates to prevent negative real rates. This sequence happened in the 1970s and with more muted dynamics during the 2000s leading up to 2008. Following each major recessionary period was a time of cheaper energy that enabled a downward adjustment in nominal interest rates. Historically, moderate nominal interest rates have been associated with the trend of steadily decreasing food and energy costs with increasing energy consumption. The last 10–15 years are unique in that rich countries have not increased their energy consumption despite relatively moderate energy costs and a low interest rate regime.

Debt and Interest: Is That Your Negative Bond Yield Showing?

Not only are the post-2008 near-zero central bank interest rates unprecedented, but investors buying government debt are also betting on zero, and even negative yields. As of mid-2019, several major countries such as Germany, Japan, and Switzerland have issued bonds for government debt that returns a *negative yield*. Normally you might lend to a government, and for the privilege of borrowing your money today (by you buying their bond), each year they would pay you a few percent of what you lent them. But globally in mid-2019 about 15–17 trillion dollars worth of government bonds had negative yields, near a quarter of the global bond market.[23] This means that people are effectively *paying governments to borrow money*. Along

[22]Galbraith [11, pp. 110–111].

[23]Bloomberg, August 20, 2019, "What trillions of dollars in negative-yielding debt means for markets," https://www.bnnbloomberg.ca/economics/video/what-trillions-of-dollars-in-negative-yielding-debt-means-for-markets~1757903. CNBC, August 13, 2018, "Negative bond yields are not reflecting economic reality, Fitch warns," https://www.cnbc.com/2019/08/13/negative-government-yields-dont-support-credit-rating-fitch-warns.html. CNBC, "How bonds with negative yields work and why this growing phenomenon is so bad for the economy," August 7, 2019, https://www.cnbc.com/2019/08/07/how-bonds-with-negative-yields-work-and-why-this-growing-phenomenon-is-so-bad-for-the-economy.html.

with near-zero interest rates, these negative bond yields for 10-year bonds (and even 30-year bonds for Germany) are unprecedented in history.

But who would do this? Who would lend a government a dollar, euro, or yen only to expect to actually lose money? One answer is that when bond yields go down, bond prices go up. It is largely the increasing demand to buy bonds that drives down the yields. If you think you can buy a bond for one dollar today at −0.5% interest, but then the price increase to 1.05 dollars at −1.0% interest next week, you can then sell the bond and make a quick profit. So some investors are not looking to earn money from bond yield payments, they are looking to buy bonds at "low" prices and sell at higher prices later. This flipping of bonds sounds just like flipping houses before the financial crisis—who cares if you borrowed too much money for too much house because, hey, housing prices always rise!

These negative bond yields are good for the government because people are actually paying off the government's debt. Perhaps investors are just patriotic, or nationalistic, or they ran out of charities to which to donate all of the money they have. Why might investors have so much money they can invest in bonds with negative yields? Many say it's because too much of total national income, or GDP, has been going to too few people. For the last 50 years, the average worker hasn't received much of a real pay raise, and this is why the topic of income inequality has come to the forefront of political discussion since the 2008 financial crisis. We now discuss income distribution.

Wages and Income Distribution

How, if at all, are wages and the distribution of income related to energy consumption and/or costs? To answer this question, we first have to look at the wage and income data.

The topic of wage and income inequality has been at the forefront of economic discussions since the 2008 financial crisis, particularly in Western countries. However, it is useful to consider income distribution both globally and within any given country. In the context of the global population, there are data to estimate income distribution among countries and individual citizens. The trends are different whether considering countries or individuals as the decision making "agent" of interest. We can also consider the level and direction of change in income inequality among countries.

We cannot translate the trends in any one country or group of similar countries to be representative of the world trend. In terms of income distribution, the data indicate that since the 1970s the U.S. and many Western economies are becoming less equal. However, since around the year 2000, the distribution of income across the entire world has become more equal. Thus, much of the economic angst in the U.S. is in part due to "shifting" economic gains from the West to poorer and developing countries (e.g., China, India). In addition, there have been policy changes within developed countries that influenced income distributions within their borders. All of these changes can be considered in the context of access and cost to energy and other resources. First, a look at the United States trends.

Wages and Income Distribution: U.S. Economy

Figure 4.11 indicates one driver of U.S. workers' economic angst that was brewing in the 1970s and that has been revitalized since the Global Financial Crisis. The plot compares U.S. economic "net productivity" to the average hourly wage of private production and nonsupervisory workers [4]. The net productivity is the net

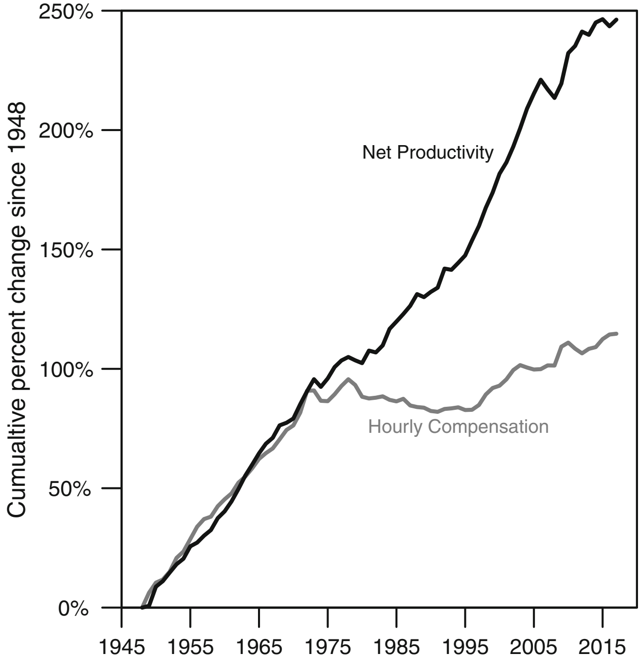

Fig. 4.11 From World War II until 1973, U.S. worker hourly compensation tracked the productivity of the economy. After 1973, net productivity continued to increase, while real (inflation adjusted) hourly compensation stayed the same. Calculations from https://www.epi.org/productivity-pay-gap/ per method of [4]. Note: Data are for average hourly compensation of production/nonsupervisory workers in the private sector and net productivity of the total economy. "Net productivity" is the growth of output of goods and services minus depreciation per hour worked

domestic product of the U.S. divided by all hours worked.[24] Higher productivity means fewer workers are needed to produce the same quantity of economic output. Economically speaking people generally see increased productivity as a good thing. It is often viewed as a measure of "technological progress," but this type of label is vague and misleading. Productivity is usually a word used to describe a statistical trend of "progress" but without explanation of what is driving that trend. For now, just keep in mind that "productivity" and "technological progress" are often poorly defined terms yet used interchangeably. Chapter 6 goes into some detail on economic interpretations of technology, and how energy-focused interpretations provide significant insight.

Hourly compensation is real (inflation adjusted) average compensation for about 80% of the U.S. workers that are neither managers nor executives. This compensation is primarily composed of wages and salaries but also includes supplemental pay (such as paid leave) and employer contributions to health insurance and retirement benefits. There is a stark break in the trend between productivity and hourly compensation starting in 1973. From 1948 to 1973, both productivity and hourly compensation went up together. After 1973, productivity continued to increase, but hourly compensation stayed approximately the same for 40 years.

Other economic data confirm the same breakpoint in U.S. wage trends in the 1970s, as well as one around the year 2000, and Chap. 7 summarizes all in one place. Instead of considering hourly compensation, these data indicate the share of total income going to Americans via different income streams. At the simplest level, there is income going to labor (hourly and salaried workers, as in the top two lines in Fig. 4.12) and income going to capitalists (owners of capital and their profits, as in the bottom line in Fig. 4.12). The top line represents total worker compensation from wages and salaries as well as other employer-provided benefits like health care and retirement pension contributions. The middle line represents only wages and salaries. A 2015 study by the International Labour Organization and the OECD shows this same declining wage share, starting at the same time, also holds for a group of nine rich countries [14].[25]

One takeaway from Fig. 4.12 is that for almost a century there has been a clear tradeoff between worker and capital shares of U.S. national income: one goes up when the other goes down, and vice versa.

There are three phases of change since World War II. Phase 1 is from the end of World War II until the early 1970s. Total workers' compensation share increased by 6% (from 60 to 66%) and capitalists' share decreased by 6% (from 31 to 25%). Phase 2 is from the early 1970s to around 2000. During this phase, both the workers' and capitalists' shares remained constant. Phase 3 is from around 2000 until the

[24]Net Domestic Product is equal to gross domestic product minus depreciation of capital, and is thus a metric of economic value added each year after subtracting the costs of maintaining machines, factories, and infrastructure.

[25]From Figure 1 of the report [14], the nine countries are Australia, Canada, Germany, France, Italy, Japan, Spain, the United Kingdom, and the United States.

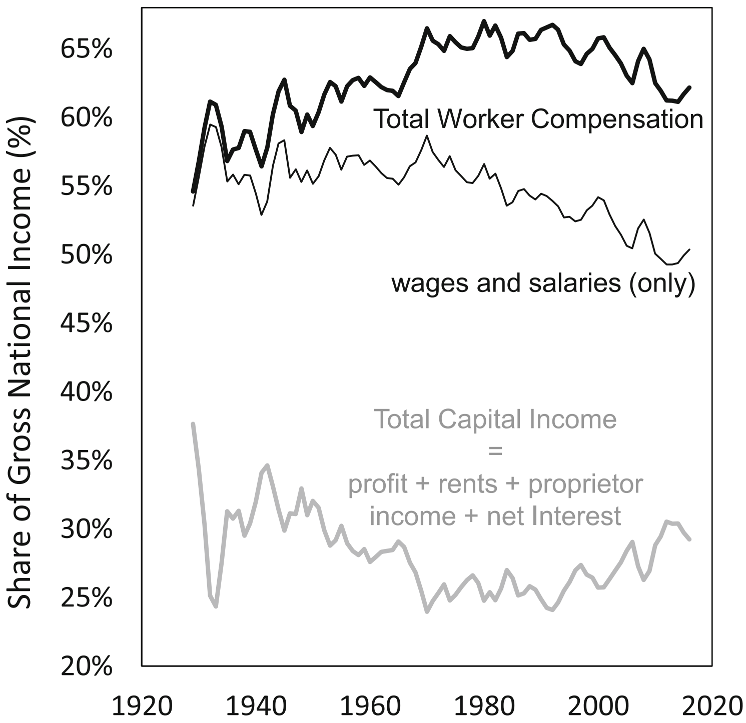

Fig. 4.12 The share of U.S. Gross National Income (GNI) going to workers (upper curve) as total compensation (equal to wages and salaries plus supplements as health insurance and pensions) is a mirror image of the share of GNI going to owners of capital (lower curve) in the combined forms of property (rents), businesses (proprietor income), corporate profit, and net interest to banks (banks earning income by lending money at a higher interest rate than at which they borrow). When one curve goes up, the other one goes down. The middle curve is worker compensation only as wages and salaries. Data are from 1929 to 2016 using U.S. Bureau of Economic Analysis Table 1.12. "National Income by Type of Income"

present. Workers' share decreased by 4.7% from 2001 to 2104 (from 65.8 to 61.1%) and capitalists' share increased by 4.7% (from 25.7 to 30.4%). Thus, while the total U.S. worker compensation share increased to the 1970s and declined after 2000, the opposite occurred for total share of gross national income to owners of capital in the combined forms of property (rents), businesses (proprietor income), corporate profit, and net interest to banks.

Of course in the context of profit and wage shares, any given person can be both a worker and a capitalist earning profits on investments. A person working for a company earns a salary or hourly wage, but she might also separately invest in the stock market and have her employer contribute money to a retirement investment account. This money invested in personal and retirement accounts represents capital that can earn profits (and losses) based on ownership of stock in companies.

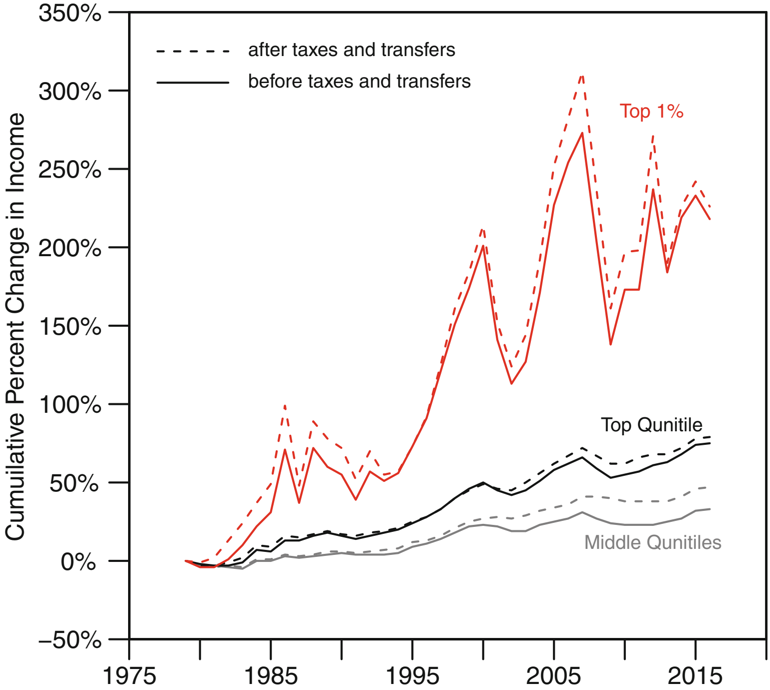

Fig. 4.13 The cumulative percentage change in income both before (solid lines) and after (dashed lines) taxes and transfers for the top 1%, top quintile (top 20%), and middle three quintiles (top 20–80%) of income earners in the United States. Data from U.S. Congressional Budget Office [5]

However, for the vast majority of U.S. workers, the vast majority of their income comes from salaries, wages, and supplements, not capital gains.

U.S. workers also receive transfers of tax revenue via benefits from the federal government. Figure 4.13 shows the cumulative growth in income (for example, wages, capital gains, social security, and Medicare), from 1979 to 2016, both before and after taxes and receiving benefit transfers from the U.S. government.[26] Some argue that income inequality is not too extreme because there is a net transfer of tax revenue to lower incomes, and one should measure inequality based on these after-tax income. The data indeed show higher income for the lower (not shown) and middle income quintiles. However, all income brackets have a higher income after paying taxes and receiving transfers. Further, the Top 1% of income earners

[26]**Income before transfers and taxes** consists of market income plus social insurance benefits (including benefits from Social Security, Medicare, unemployment insurance, and workers' compensation). **Means-tested transfers** are cash payments and in-kind services provided through federal, state, and local government assistance programs. Eligibility to receive such transfers is determined primarily on the basis on income, which must be below certain thresholds. **Federal taxes** consist of individual income taxes, payroll taxes, corporate income taxes, and excise taxes.

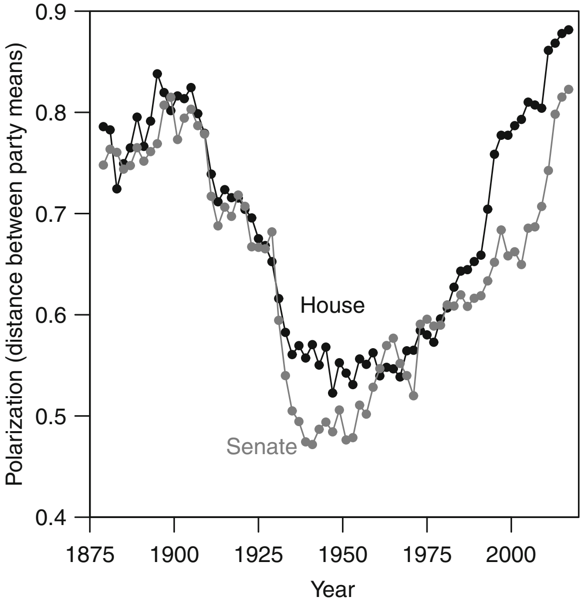

Fig. 4.14 The political polarization of the U.S. Congress was lowest (less than 0.6) from the Great Depression though the 1970s. Higher values represent higher polarization and less cooperation. Data are from Voteview website: https://www.voteview.com/articles/party_polarization

have clearly increased their incomes much more than the rest, and they still receive a net positive transfer of income from the government. After taxes and transfers, relative to 1979, the top 20% of income earners had 79% higher income in 2016, the middle quintiles earned 47% more, and the lowest quintile earned 85% more. Before taxes and transfers the percentages are 75%, 33%, and 33%. Clearly net transfers from the government have a greater "growth effect" for the lower incomes, but that is because their incomes are, well, lower. The transfers do not overcome the increasing allocation of national income to the top 1% of income earners.

Studies of political polarization in the U.S. Congress show a correlated pattern to labor-capital distribution. When more money was going to workers, our elected officials were less polarized. Figure 4.14 shows that the lowest political polarization occurred from the 1930s through the 1970s.[27] This is the same period when the share of national income going to workers was either increasing or at its highest levels, with the opposite trend for the share going to owners of capital.

In addition to the changes in the worker and capitalist share of national income, the distribution of total wages among workers has become less equal since the 1970s. The paychecks of high income workers grew much faster than the paychecks of low-income workers. Common explanations given for this stagnant growth in low-income wages are automation (e.g., factory mechanization and robots),

[27]Jeffrey B. Lewis. UCLA Department of Political Science, Voteview website, accessed March 19, 2019: https://www.voteview.com/articles/party_polarization. Plotted data are variable "party.mean.diff.d1."

globalization, and a loss of bargaining power of workers. For example, the authors of the hourly compensation calculation shown in Fig. 4.11 note, “Finally, it also seems worth noting that this decoupling [of net productivity from hourly compensation] coincided with the passage of many policies that explicitly aimed to erode the bargaining power of low- and moderate-wage workers in the labor market.” [4] This statement is correct, but there is an additional, perhaps more fundamental question. Why were 1970s workers unable to prevent the loss of bargaining power that they gained in the previous three decades?

In a capitalist economy, the overall goal is to increase, or at least maintain, profits. One way to increase the chance to earn profits is to minimize costs. Business costs fall into three general categories: capital spending on physical and monetary assets (machines, infrastructure, property rents, interest payments on debt), wages for skilled and unskilled labor, and natural resources (energy, environmental regulations). If one or more of these costs are higher at home, then it might make sense to move company activities to another country. This act in turn impacts the global distribution of income.

Wages and Income Distribution: Global Economy

Many of the same trends in inequality within the United States are prevalent in Western Europe and other countries in the “rich club” of the Organisation for Economic Cooperation and Development (OECD). The World Inequality Database (WID) indicates that from the early 1900s to the 1980s the top 10% of population of each of the following large economic regions had a *decreasing* share of income: U.S. plus Canada, Europe, Russia, China, and India [18]. By contrast, from 1980 to 2000 the richest 10% of these population regions increased their share of income, leaving the vast majority of citizens behind (see Fig. 4.15). This trend is corroborated by data from the University of Texas Inequality Project that uses a different method to calculate measures of income inequality. Gini coefficients for several countries are shown in Fig. 4.16 (Gini = 0 means all people earn the same income; Gini = 1 means one person earns 100% of all income).[28] Thus, the higher the Gini coefficient, the more unequal is income distribution. The Gini coefficient calculations and fraction of income going to the top 10% show similar broad trends even though they derive from different data sources, with some differences between metrics for specific countries. Nonetheless, we can discuss general differences in income distribution among OECD countries.

For example, the Scandinavian countries have a lower share of income going to the top 10% than the Western Europeans, Japanese, Australians, and Americans. Cultural differences that influence governmental structure play a large role, and

[28]The “UTIP-UNIDO” data of the University of Texas Inequality Project. See https://utip.lbj.utexas.edu/datasets.html.

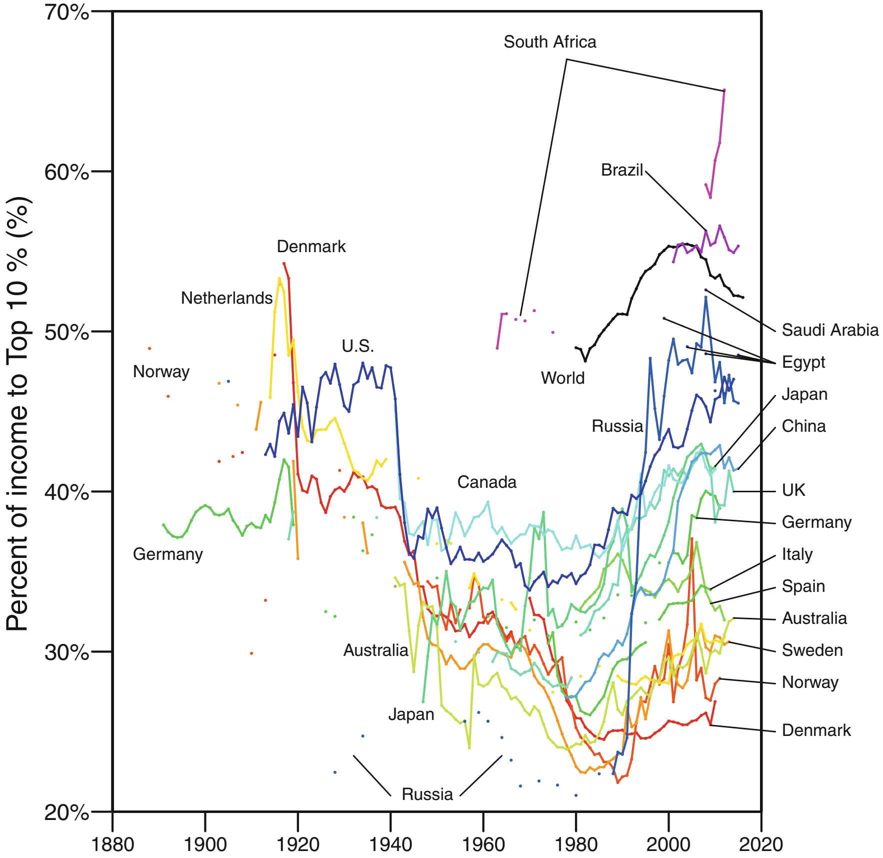

Fig. 4.15 The share of total country income going to the top 10% income earners of the country's population [1]

thus there are choices that affect income and livelihoods.[29] However, practically all OECD countries have steady or declining income inequality during the few decades before 1980 versus increasing inequality after 1980. China also shows an increase in income inequality from the 1980s (when citizens were more equal, but poorer) to the 2000s. However, since 2000 Chinese income inequality is stagnant to declining as it increasingly opened up its economy to the globe and experienced high economic growth rates. The general pattern of the U.S. trend of income to the top 10% and Gini coefficient match that of the share of income to capitalists in Fig. 4.12. There

[29]For example, Scandinavian countries are largely socialist democracies with high taxes, large welfare states, and high labor union membership. In contrast, the U.S. since the 1980s has seen several declines in tax rates, lower union membership, and reluctance to move toward universal health care.

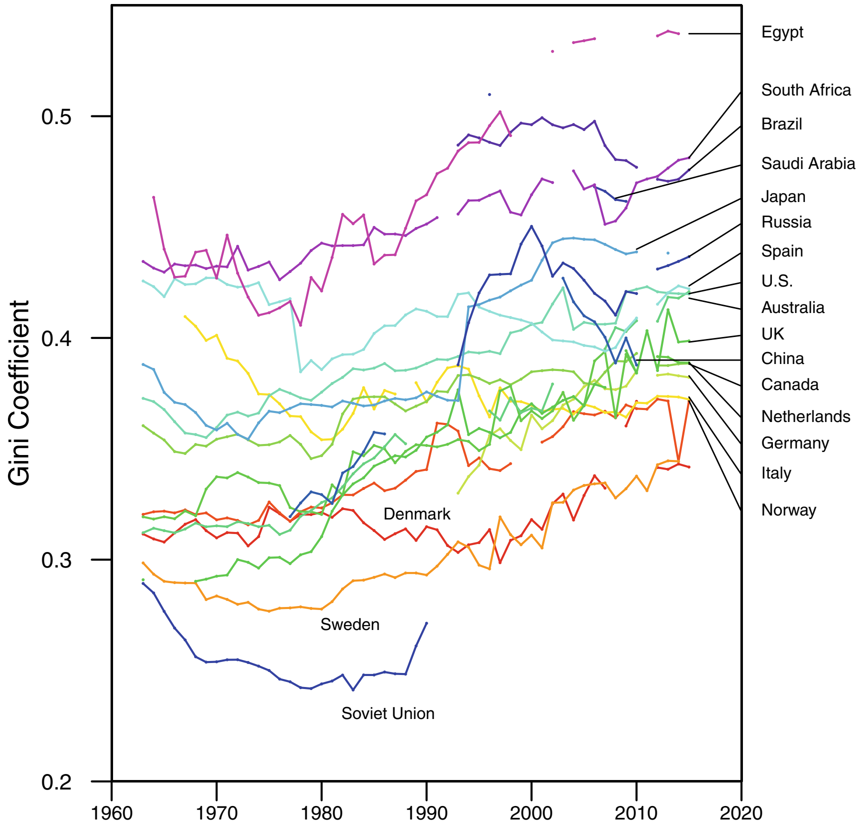

Fig. 4.16 The Gini coefficient is a measure of income inequality. The higher the Gini coefficient, the more unequal is income distribution. Source: The "UTIP-UNIDO" data of the University of Texas Inequality Project

were three phases for the richest income share after World War II—down (to the 1970s), flat for a decade, then up (after the 1980s).

The World Inequality Database (WID) also estimates a value for world income distribution. The top 10% of global income earners capture just over half of all income. From 1980 until the mid-2000s, the global top 10% earned an increasing share, and since that time a decreasing share. Thus, the income data provide some evidence that the recent globalizing economy enables more equal income distribution, particularly due to significant increases in international trade after China joined the World Trade Organization in 2001. However, this decline in the top 10%'s income share is far from some people's vision of a more equal society. The top 10% income earners, largely the middle incomes of OECD countries, still take about half of all global income, and the super elite top 1% of global population increased their share of income more than the bottom 99%.[30] While the global data for low incomes are quite sketchy, the WID data suggest the poorest 50% of global individuals received 10% of global income.[31] Also, the gains of the middle class and wealthy in developing countries (who compose a large portion of the "middle 40%" of global income earners in the income bracket just below the top 10%) have come at the "expense" of low-income growth for the middle class of wealthy countries (part of the global top 10% of income earners).

These trends in income distribution show that middle income groups in the U.S. and Europe are justified in their frustration from experiencing stagnant wage growth. The gains they made in *les trente glorieuses*, the French term for the immediate three post-World War II decades, have for the past four decades gone to poorer individuals in developing countries as well as the richest few percent in rich countries.[32]

Policies emphasizing globalized trade forced a shift in income gains from workers in rich countries to workers in developing countries. As stated by Nobel Prize economist Joseph Stiglitz: "Trade in goods is a substitute for the movement of people. Importing goods from China—goods that require a lot of unskilled workers to produce—reduces the demand for unskilled workers in Europe and the U.S. This force is so strong that if there were no transportation costs, and if the U.S. and Europe had no other source of competitive advantage, such as in technology, eventually it would be as if Chinese workers continued to migrate to the U.S. and Europe until wage differences had been eliminated entirely. Not surprisingly, the neoliberals never advertised this consequence of trade liberalization, as they claimed—one could say lied—that all would benefit."[33]

Economist James Galbraith, who has spent much of his career studying income inequality, agrees with Stiglitz. He states:

> ... the rise in global inequality from 1980 to 2000 was the by-product of a reactionary global financial regime, directed largely from Washington, New York and London [neoliberal policies, or "Washington Consensus"]. ... And the modest reduction in global inequality and poverty, particularly after 2000, can be traced first and foremost to those countries that defied the regime, ... This progress has now ended [by 2018]; we are back to the conditions that generate rising inequality, and the need for comprehensive stabilizing control over global finance is as urgent as it ever was.[12]

In short, Galbraith posits that economic growth in the 2000s, leading up to the 2008 Financial Crisis, was not driven by lending from the rich countries to developing countries, such as from U.S.-led Western development agencies and banks. Another important point is that the reduction in global inequality in the 2000s

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[30]Table 2.1.1 of [1].

[31]See Galbraith [12] for a discussion of the quality of data and methods within the World Inequality Database that call into question the accuracy of data for low-income countries.

[32]Project Syndicate (2016), Globalization RIP?, https://www.project-syndicate.org/onpoint/globalization-rip-2016-08.

[33]Stiglitz (August 5, 2016), Globalization and its New Discontents, Project Syndicate, accessed August 10, 2017 at https://www.project-syndicate.org/commentary/globalization-new-discontents-by-joseph-e--stiglitz-2016-08.

corresponded with the fastest growth in energy consumption since the 1960s (refer back to Figs. 2.10 and 4.1), largely in China. Higher wages in China occurred with high growth rates of per capita energy consumption in the 2000s just as occurred in the U.S. during the 1950s and 1960s, and Chap. 6 discusses this relationship. Since U.S. wages remained stagnant in the 2000s (and wages as a share of national income dropped), to keep up spending, consumers borrowed money (against rising housing prices) to consume what China was producing, leading to the 2008 Financial Crisis.

But just how much control do we have in affecting the distribution of income? Tax policies are highly influential, but how much? To explore this idea further, I turn to physicists.

Wages and Income Distribution: A Physics-Based Explanation

Discussions of income distribution usually focus on policy choices. How much should we tax the rich, who own many assets and earn high incomes, versus the poor, who own few assets and earn low incomes? Is enough of the population sufficiently educated? How much do historical inequities, such as slavery and inability to own property, translate to outcomes today? These and other questions are perfectly valid and important questions. However, even if we don't contemplate how historical human relations and government policies affect the current state of economic affairs, we can still say something about why we *should not* expect equal incomes for everyone. To understand this we enter the world of *econophysics*.

Econophysics is a word coined by Gene Stanley, scientist and professor at Boston University [31]. It means what it sounds like.[34] For example, some of econophysics has been based on understanding short-term commodity and stock prices for trading purposes. "More precisely, statistical mechanics links the macroscopic, thermodynamic properties of a system to its microscopic constituents. In financial applications envisioned by econophysicists, the market is the macroscopic system while the individual financial agents are the microscopic constituents. Understanding how the principal features of financial markets arise from the microscopic interactions is the main task of econophysics."[35] Econophysicists were some of the "quants" that integrated into Wall Street over the last couple of decades. Some founded consulting firms using econophysics principles to govern stock trading algorithms.

[34]Eugene Stanley, The Back Page: Econophysics and the Current Economic Turmoil, *APS News*, 17 (11), 2008. Accessed March 30, 2018 at: https://www.aps.org/publications/apsnews/200812/backpage.cfm.

[35]WorldQuant (2017) Perspectives: Wall Street on a Lattice: Finance Meets Physics, https://www.weareworldquant.com/media/1455/063017_wq-perspectives_wall-st-finance-meets-physics-v2.pdf.

In the late 1990s and 2000s, econophysicists rediscovered the idea of applying statistical physics to monetary transactions and income distribution that sociologist John Angle pioneered in the 1980s [2, 31]. In effect the physicists wondered if, in aggregate, all of us economic "agents" act just like gas molecules as described by statistical and thermodynamic laws. It turns out that most of us do.

The concept is as follows. Each molecule of gas in a room has a temperature. The average of all of these temperatures is what we call the temperature of the room. However, some molecules have temperature below the average, and some above. It is the *distribution* of temperatures that is described by physical and mathematical principles in what is known as the Boltzmann–Gibbs formula.[36] The distribution describes what fraction of all molecules reside at a certain temperature. Each molecule is floating around and randomly bumping into other molecules. In doing this they exchange energy. Some molecules gain energy, and their temperature increases, and vice versa. However, after a long period of time, at thermal "equilibrium," the proportion of molecules at a given temperature no longer changes as long as the total amount of energy of all molecules is the same.

The translation from physics to economics is to compare the temperature of a molecule to the income and wealth of a person or business (or even the GDP of countries). Instead of molecules bumping into each other exchanging energy, people are bumping into each other exchanging money. You might go to the grocery and pay $100 for groceries. Thus, you gave up $100 and the grocery store owner received that same $100. You now have less money, and the grocery store owner has more. Further, the grocery store owner has employees and pays them. In paying wages, the grocery store owner reduces his money supply and the workers increase theirs. Everyone in the economy is both gaining and giving money, and these transactions, big and small, occur billions of times every day.

Physicist and econophysicist Victor Yakovenko and his past students have put the theory to the test using income data from various countries [8, 9]. For the example of the United States, over 97% of people have their incomes distributed as would be expected from the statistical physics, or thermal equilibrium, perspective [23]. This vast majority of the population earns income primarily from wages and salaries, and this "additive" process of getting a paycheck every 2 or 4 weeks is characteristic of the Boltzmann–Gibbs formula. However, the upper 1–3% of the U.S. population with the highest individual incomes cannot be described using the same mathematical pattern. They are "superthermal." They have higher incomes than would be expected using the Boltzmann–Gibbs formula. One of the explanations is that their incomes come primarily via the "multiplicative" process from investments and capital gains that are based on earning some percentage of a quantity of money invested. In 1983 this top 1–3% of income earners took home 4% of all income. This percentage increased such that in 2000 the top 3% earned 18%

[36]The fundamental law of equilibrium statistical mechanics is the Boltzmann–Gibbs distribution. Yakovenko (2009) describes some of the historical translation of the Boltzmann–Gibbs distribution to economics via a variety of independent investigations of social scientists and physicists [31].

of all U.S. individual income [23]. When the top 3% of the population takes home 18% of the income, only 82% is left for the other 97%.

Some might doubt the value of the statistical mechanics viewpoint of wealth and income distribution because they think it ignores the influence of our choice of policy. But this is not the case, and the next few paragraphs explain why.

This statistical mechanics viewpoint is tremendously informative given its ridiculously simplifying assumptions. Consider its underlying assumptions for wealth distribution: all persons start with the same amount of money, the minimum wealth and income for any person is zero, the maximum wealth and income is infinity, no person knows anything more than any other person (and there actually isn't anything to know), each person exchanges money (positive or negative) with another randomly chosen person each time step (e.g., each day, year, etc.), and the amount of money (or GDP) in the economy does not increase during the analysis.

Clearly these conditions do not fully describe many important real-world details. However, despite this simplified view, the statistical mechanics concept accurately describes the income distribution for about 97% of U.S. income earners. In doing so it provides valuable insight for thinking about what we mean by words such as equality and fairness. It says that even if everyone were exactly equal in capability, exactly equal in knowledge, and had the same initial amount of money, due purely to random exchange over time the distribution of wealth and incomes would not be equal *if* we allowed the potential for the highest paid person to take an infinite amount of income and prevent the lowest income from going below some threshold, say zero.

This last sentence provides the opening for policy because it can affect the maximum and minimum incomes. In fact, the historical data show that *policy did impact income distribution* in a way we can interpret from the econophysics viewpoint. Because 18% of U.S. income went to the top 3% in 2000 after only 4% did in 1983, this means that the wealthy must have had some additional information or ability to exchange money than did the bottom 97%. Yakovenko's explanation that the superthermal top 3% of earners used multiplicative means of acquiring income through investing represents this additional ability. Quite simply, the ability to make money based on investing money you already have is an additional ability over those that don't have any savings to invest. Air molecules don't have investment accounts!

Since the 1980s and particularly more so in the late 1990s, stock market valuations increased faster than inflation and wages. Thus, those with money were able to acquire more disparate incomes not by working on an hourly basis, but by investing in the stock market, selling stock for gain, and acquiring dividends from stocks and other investments. Further, the early 1980s still had relatively high marginal tax rates on the highest incomes. The top marginal income tax rate fell from 70% in 1980 to 50% in 1983 and has resided between 28 and 40% since. For those with high incomes, starting in the 1980s wealth accumulated at a higher rate than the previous three decades. This is because high income earners both reaped the benefits of compounding wealth accumulation from keeping a larger share of pre-tax income and also reaped the benefits of investing that accumulated income. This is like some "rich" molecules having more information than some "poor" molecules, and we would expect more deviation from the statistical mechanics viewpoint. That is exactly what happened as a lower fraction of total U.S. income could be described by the statistical mechanics approach in 2000 as compared to 1983 [23].

As already noted in this chapter, while income inequality increased in developed countries since the 1970s, it has generally been decreasing when considering the world population overall. Much of the reason for increased global equality in the last one to two decades is because of a decrease in *between-country* average income equality [1]. That is to say if we treat each country as a single entity characterized by its total income divided by population and compare countries on this metric, then the world is becoming more equal.

What happens if you make the same comparison for *energy consumption* per person? Amazingly, the result is strikingly similar [19]. This is because at the country scale, average income and energy consumption go hand in hand. Chapter 6 discusses this again using both theory and U.S. data.

Using data on the average energy consumption per person for each country of the world, Victor Yakovenko and his students determined that global energy consumption is approaching the same equilibrium distribution (line labeled as "Exponential" in Fig. 4.17), as calculated using statistical physics and that describes incomes in the United States and other countries [19]. To construct Fig. 4.17 you gather data on energy consumption and population for each country. You then sort the data from the lowest to highest per capita energy consumption, and calculate the fraction of energy consumption and population in each country. Starting at the lower left corner with the first country, which is the one with the lowest energy consumption per person, move to the right for the fraction of population in that country and up for the fraction of energy consumption in that country and put a point. For the second point, start at the first point, use data from the country with the second lowest per capita energy consumption, and again move to the right for the fraction of population in that country and up for the fraction of energy consumption in that country and put a point. You do this over and over until you run out of countries. Figure 4.17 repeats this procedure for data in 1980, 1990, 2000, and 2010.

The further the curve is from the diagonal line running from the bottom left to upper right, the less equally distributed is energy across the world and the higher the Gini coefficient. In 1980, the distribution of energy consumption was highly skewed to a small number of rich countries. The distribution was characterized by a Gini coefficient of 0.66. By 2010, energy was distributed much more equally around the world with a Gini coefficient of 0.55. Thus, as global trade increased its pace after 1980, income became more equally distributed across the world because developing countries began manufacturing more products. Because more industrial output means more energy consumption, global energy consumption became more equally distributed as well.

Interestingly, the "exponential" distribution predicted by statistical mechanics via the Boltzmann–Gibbs formula has a Gini coefficient of 0.5. This means that a Gini

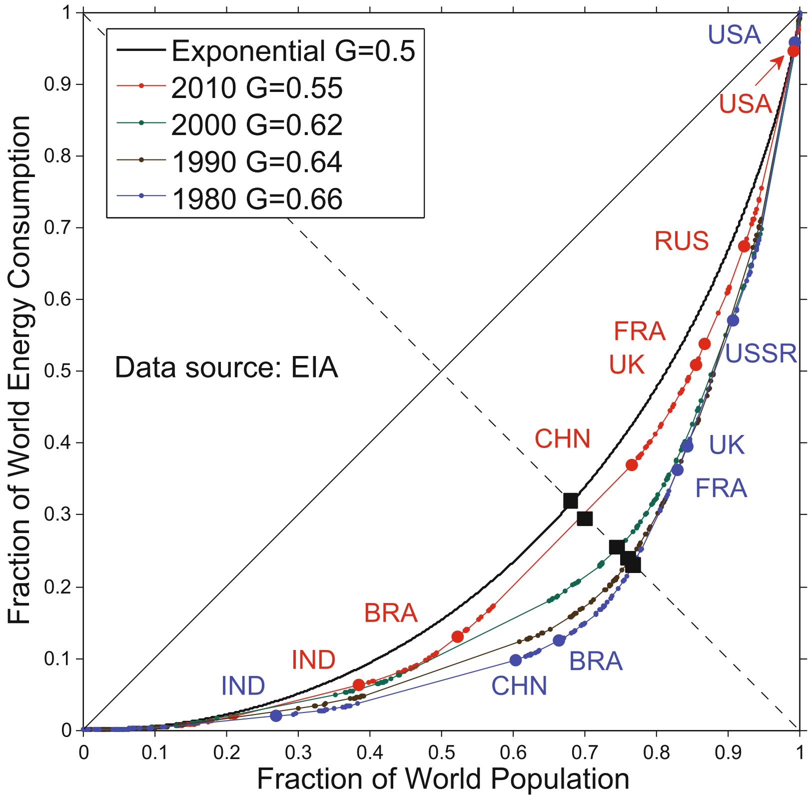

Fig. 4.17 A Lorenz plot of country energy consumption versus population. Over time (from 1980 to 2010) the distribution of each country's average energy consumption per person increasingly approximates that which would be expected by a sequence of random energy exchanges (per Boltzmann–Gibbs equation) among countries as represented by the black line labeled "Exponential" (Figure unmodified from [19] under Creative Commons License 3.0: https://creativecommons.org/licenses/by/3.0/)

coefficient of 0.5 is representative of the distribution in temperatures among a bunch of molecules. Because these molecules are all exactly the same, and none have any advantage over another, an income distribution with a Gini coefficient of 0.5 implies that while *it is an unequal distribution, it represents a fair distribution*.

Wage and Income Distribution: Summary

There are several key takeaways from the wage and income distribution data. First, from the end of World War II until the 1970s, the U.S. and other rich economies increased income equality, but since that time equality has decreased. Second, as income became more concentrated in rich countries, income and energy actually became more equally distributed across the world. From 1980 to the mid-2000s, energy and income were generally shared more equally *between* countries but less so *within* most countries, but income equality actually decreased in some developing countries such as Brazil and China.

Broadly income and energy consumption come together, and thus gains in energy and income that went to Western economies in the 1940s–1970s have since gone to developing countries. From this standpoint, the recent political populism (e.g., the 2016 Brexit vote, the 2016 U.S. presidential election of Donald Trump and popularity of candidate Bernie Sanders) is understandable as a multi-decadal accumulation of citizen resentment. Over the last 100 years, U.S. political polarization has changed in lock step with changes in income inequality: when one went up, so did the other.

But who, if anyone, are the foes of workers in rich countries? Are they low-income workers in developing countries? Are they corporate executives in rich countries who allocate investment to developing countries? Directly and indirectly, people are generally paid to extract resources and turn them into products and services by consuming energy. If we are making things that extract and consume energy, we need the requisite physical machinery, transport systems, and industrial facilities. In short, we need infrastructure.

Infrastructure

Infrastructure As comedian and talk show host John Oliver joked, infrastructure is basically anything that can be destroyed in an action movie.[37]

But on a more serious note, it is important to understand the quantity and age of infrastructure for the same reasons we considered the quantity and age of human population. Just like people, infrastructure accumulates and gets old, and if we slow down the rate of investment in infrastructure, then a higher percentage of infrastructure becomes relatively old. And just like people, if the infrastructure becomes too aged, worn, and feeble, then it can't support economic activities and functions that keep people safe and comfortable in their homes.

It is hard to appreciate all of the economic services that our roads, bridges, railways, ports, pipelines, and electricity grid provide. Even our communications infrastructure—the wires, fiber optic cables, and wireless relay towers—is becoming more critical by the day as it connects more people and devices. This information connectivity is both good (increased access to knowledge) and bad (increased hacking of secure data such a credit card accounts).

[37]Last Week Tonight with John Oliver, March 2, 2015. Video available April 15, 2018 at https://www.youtube.com/watch?v=Wpzvaqypav8.

If infrastructure works properly, we don't notice it. We tend to only hear about infrastructure when it stops working. When very important infrastructure fails, it is nationwide or global news, and people make movies about it. Think hurricane Katrina and the failed levies of New Orleans,[38] the sinking of the *Titanic*,[39] the explosion and sinking of the offshore drilling platform *Deepwater Horizon*,[40] and the destruction of the electric grid of Puerto Rico from hurricane Maria in 2017.[41]

The American Society of Civil Engineers (ASCE) tallies an "infrastructure report card" with the state of the U.S. infrastructure expressed in letter grades such as B+ and D−.[42] The ASCE considers roads, railways, airports, pipelines, water and wastewater, energy, and other infrastructures. The latest grades are generally poor, and the grades have declined since ASCE started providing them in 1988. The overall grade for 2017 was D+. While some are alarmed and see this as a call to invest in our nation, others see a narrative from a group whose members' jobs depend upon building infrastructure itself. That brings up an engineering joke. What is the difference between mechanical and aerospace engineers versus civil engineers? Mechanical and aerospace engineers build weapons; civil engineers build targets.

But seriously, all engineers work for non-destructive purposes when building and operating major types of energy infrastructure such as power plants. Just like we thought of the age of the population, we can think of the age of power plants, and they are getting older.

Figure 4.18 shows the fraction of U.S. power plant capacity that is older than a certain age. The power plant age is the number of years from the date the generator began operation. If the lines in Fig. 4.18 are increasing, it means that power plants are aging faster than we are building new ones. If the lines are decreasing, it means there is an investment boom in power capacity. No physical infrastructure lasts forever, and power plants are no exception. They require maintenance, including the replacement of major components.

The post-World War II U.S. economic boom was characterized by the rapid increase in energy consumption, a "baby boom" in population, and a continuing decline in the cost of energy and food (as in Chap. 2). It was also characterized by the decreasing age of power plants. In 1948, 36% of power capacity was older than 20 years. Due to rapid power plant construction after World War II, only 10% of power capacity was older than 20 years in 1971. The types of power plants built in the 1950s and 60s were hydropower, coal, and natural gas with some also consuming oil-derived fuel. Because the electric grid infrastructure was building

[38]Cinema Katrina: The Top 10 films inspired by the 2005 storm: http://www.nola.com/movies/index.ssf/2015/07/cinema_katrina_10_years_later.html.

[39]Wikipedia list of films about RMS *Titanic*: https://en.wikipedia.org/wiki/List_of_films_about_the_RMS_Titanic.

[40]Deepwater Horizon (2016): http://www.imdb.com/title/tt1860357/.

[41]*After Maria* (2019), https://www.imdb.com/title/tt10136680/.

[42]https://www.infrastructurereportcard.org.

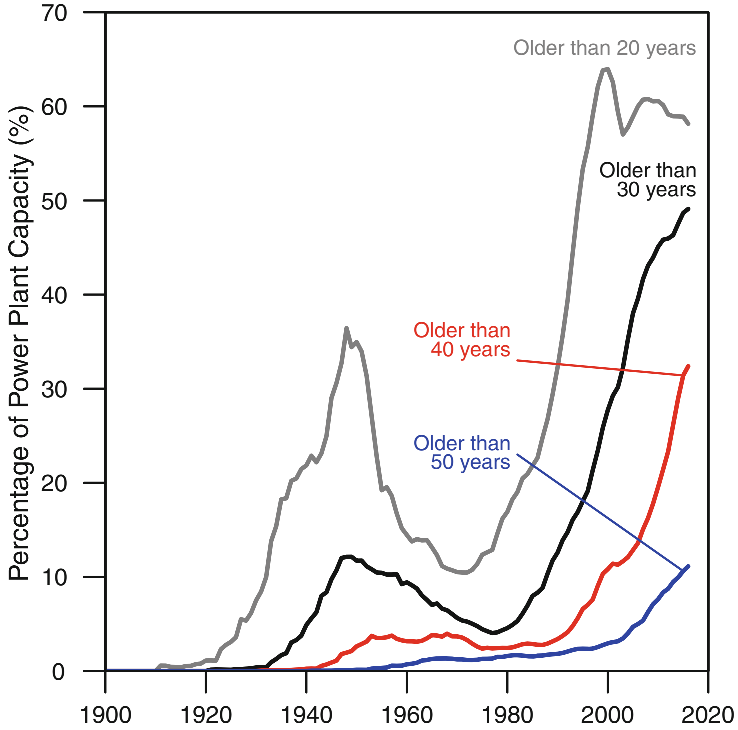

Fig. 4.18 Percentage of U.S. power plant capacity that is older than a certain age. Data are from EIA form 860

from a small base before the war, most of the grid was new. Many home appliances were converted to electricity and purchased for the first time.

The post-World War II wave of power plant installations did not last. As we have seen in so many other economic and energy data, the 1970s are a significant turning point. One U.S. policy response to the oil crises was the Power Plant Fuel Use Act of 1978 that effectively outlawed the use of oil and natural gas as fuels for electric power. This law was repealed in 1987, but the impact on the rate of installed natural gas-fired power plants is evident in Fig. 4.19. This law is one reason for the dominance of coal and nuclear capacity construction in the late 1970s and 1980s.

The U.S. has never had an older fleet of power generation assets than today [15]. In 2016, about 50% of all power capacity was older than 30 years, a higher percentage of power plants of that age than ever before. If we want to have more total generation capacity, we have to install new capacity faster than the existing capacity retires. Increasingly, maintaining and replacing power plants just to keep total capacity at the same level takes resources that have historically been allocated to accumulating more capacity in total [15]. As the total quantity of infrastructure accumulates within the electric grid, at some point, the operation and maintenance

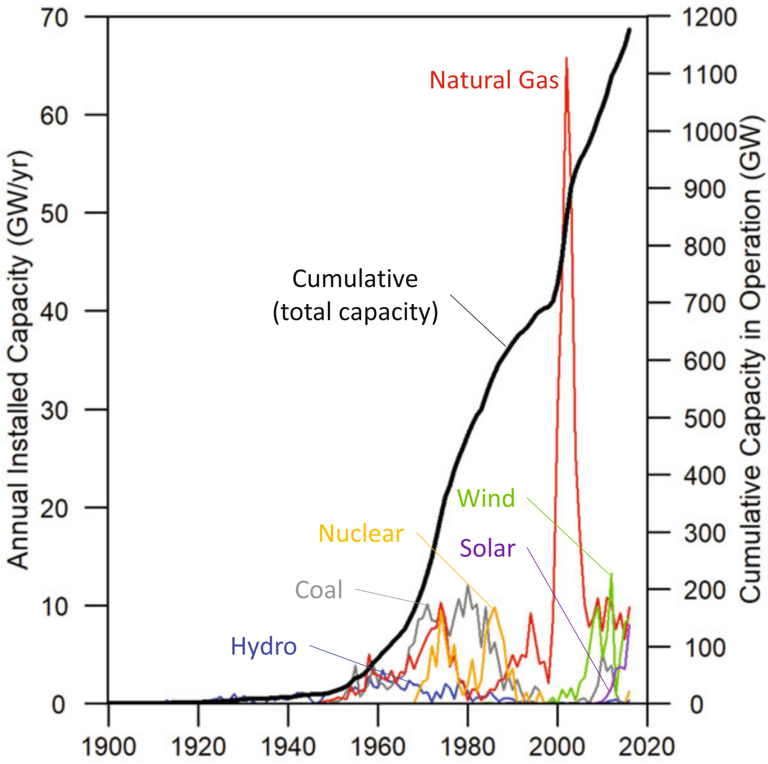

Fig. 4.19 (Left axis) The amount of U.S. power plant capacity installed per year and primary fuel. Solar includes photovoltaics and concentrating solar power. (Right axis) The cumulative amount of U.S. power plant capacity in operation over time. Data are from EIA form 860

costs might become large enough to prevent expansion. We could interpret a non-expanding grid as a response to physical and economic constraints where the costs of maintaining what we have are overwhelming the ability to expand further. Chapter 5 revisits this concept of energy consumption within expanding networks, such as the electric grid.

In addition to having an older power generation fleet, the U.S. no longer consumes more electricity. U.S. electricity generation increased almost continuously from the beginning of the industry until 2007, when it reached about 4000 terawatt-hours just as the Global Financial Crisis hit. Since 2007, annual electricity generation has remained approximately constant (recall Fig. 3.5). Some regions of the country have declining electricity consumption, and some have increasing consumption. Recall from the energy trends in Chap. 2 that U.S. total primary energy consumption has also been flat for over 15 years. Neither of these stagnant consumption trends *have ever been previously experienced in U.S. history*.

Because overall U.S. demand for electricity has been constant for over 15 years, any new power plant must largely be seen as either *replacing* a retiring plant or *displacing* the generation from a power plant with higher operation and maintenance costs. There is little incentive to increase the total installed capacity of power plants. Why make new power investments when people aren't consuming enough power from the existing power plants? In this environment investors lower risk by focusing on smaller rather than larger power plants. Hence recent investments have focused on energy efficiency, demand response, and smaller capacity natural gas, wind, and photovoltaic plants instead of larger coal-fired and nuclear power plants [15]. Figure 4.19 shows this trend in power plant installations. Before the 1990s new power plants were fueled by coal, uranium (nuclear power), natural gas, and water (hydro power). Coal and nuclear plants are more energy efficient, and thus have lower operational costs, when they use relatively large generation units, say more than 600 megawatts (MW) of capacity. Since the late 1990s power plant installations have been dominated by natural gas, wind, and solar that can be installed from 10s to a few 100s of MW at a time.

There are several policy and technological reasons for the post 1990s shift. First, there was a push toward deregulation, or restructuring, of the electricity system in many parts of the country (e.g., Texas, New England, New York). This effort split apart electric monopolies into two separate types of companies. First, the electric poles and wires were still owned by regulated utilities that received a guaranteed rate of return on their investments. Second, the newly classified *independent power producers* now owned the power plants and compete against each other to sell electricity on the grid. These new companies could build power plants to compete with the existing fleet. In the early 2000s, natural gas turbines, derived from the jet engines used in aviation, became affordable and could be combined with traditional steam turbines to make power plants with power efficiency beyond what a coal, nuclear, and existing natural gas plants could achieve. Plus, natural gas was cheap, and these "combined cycle" natural gas power plants had relatively low capital cost. These factors led to the tremendous boom in natural gas-fired generation in the early 2000s. The 6 years from 2000 to 2005 are the only ones in U.S. history with annual installations greater than 15 GW per year for any given type of power plant.

The pulse of new natural gas capacity put pressure on older inefficient power plants. The U.S. witnessed its first major wave of power plant retirements starting in 2001. Amazingly, there were practically no power plant retirements through the year 2000. By 2000 the U.S. had only retired less than 3 GW of capacity. By 2010, 42 GW had retired, and by 2016 it was 133 GW.

Just as discussed with population, the components of the electric grid can grow in number. Just as with population, if we slow the expansion of the grid, then the average age of the grid increases. Just as with population, if the grid is no longer expanding, it is not necessarily representative of a failure in decision making or a lack of investment. Just as we cannot escape the limitations of a finite Earth, the aging grid is also not a problem from which it is possible to escape. It is a reality to embrace, to understand, and within which to adapt.

The U.S. is still feeling the ramifications of the increasing rate of power plant retirements since 2010. Recall from Chap. 3 the bankruptcy of Luminant power. It was representative of companies that owned too much coal power during a time when natural gas became cheap (again after 2008) and wind and solar photovoltaics both benefited from policy and mass manufacturing to make them increasingly affordable. Nuclear power is also struggling to stay economic because the operating cost is often higher than that for natural gas, wind, and solar.

As of 2018, owners of coal and nuclear power plants within the U.S. continue to search for ways to keep them economically viable. A prime example is the lobbying effort of FirstEnergy Solutions, the unregulated arm of FirstEnergy Corporation based in Akron, Ohio. Ohio restructured its electricity system during an extended phase-in period from the mid-2000s to mid-2010s, creating a competitive market to sell wholesale electricity. FirstEnergy Solutions was the unregulated subsidiary created to operate 10 GW of formerly regulated coal and nuclear power plants. In 2018 the company filed for bankruptcy because it was unable to make a profit, and it asked then Secretary of Energy Rick Perry and President Trump to declare a grid emergency for Ohio and provide some type of subsidy that could maintain company profitability.[43]

The reasons cited by FirstEnergy Solutions for its bankruptcy filing? Fracking. Renewables. Pollution control costs for coal plants. Lack of electricity demand since the Great Recession of 2008.

Wow. What a list.

In other words, there appear to be several driving factors for the post-2008 economic difficulties of companies operating coal and nuclear power plants in the U.S. Any one of the aforementioned pressures might have been enough to force bankruptcy. There is not just one isolated pressure on energy companies, like FirstEnergy, that we can blame for their economic trouble.

Summary

This chapter considered five major physical and economic trends that provide data for thinking about ideas within the rest of the book: population, debt, interest rates, wages and income distribution, and infrastructure via the example of power plants. These are not the only data that can inform how energy affects economic and physical growth, but they are informative for that purpose.

Feedbacks from a finite Earth put pressure on the growth and accumulation of population and infrastructure. This pressure eventually slows growth in turn translating to an increasingly older population and infrastructure. After the 1970s

[43] Ari Natter, Trump Says He's Looking at Emergency Aid for Battered Power Plants, Bloomberg News, April 5, 2018, available at https://www.bloomberg.com/news/articles/2018-04-05/trump-says-emergency-aid-sought-by-firstenergy-to-be-examined.

major energy and economic trends changed. The U.S. ratio of total debt and loans to GDP increased much more rapidly following the slowdown in energy consumption during that decade—this ratio peaked at 380% of GDP in 2009, and has remained above 350% of GDP since that time. Global debt-to-GDP ratios now also reside in the same range as that of the U.S. As a consequence, central bank interest rates, as well as rates on government bonds, have rested at low values, sometimes below zero, that are unprecedented in the history of the modern industrialized economy.

Since the 1970s, income distribution in the U.S. and other rich economies (most of those in the OECD) has typically become more unequal while income (or GDP) and energy have become more equally distributed among all countries of the globe. This trend somewhat accelerated after 2000 as China joined the World Trade Organization, thus ramping up its share of an increasingly globalized economy. While policies do matter for influencing income distribution, for example, between those that work for salaries and wages and those that earn money by having money (i.e., from investment), physics-based explanations of income distribution shows that we should not expect income distributions to approach complete equality even within an economy that is completely fair to all individuals. In short, policy and physical principles both matter.

At this point, there is little value in considering another energy and economic trend in isolation. We must move on to the next step that considers how the various trends fit together into a cohesive view. We need to know how each of these trends links and feeds back to each other.

What is the common context for stagnant energy consumption in Western countries, no to low population growth, unprecedented high public and private debt levels relative to GDP, unprecedented low central bank interest rates, and an aging infrastructure? Are these all symptoms of a common cause? Is there some unifying thread? We now turn to Part II of the book, and we start *putting it all together with a systems perspective.*

References

1. Alvaredo, F., Chancel, L., Piketty, T., Saez, E., Zucman, G.: World inequality report 2018. Tech. rep. (2017). http://wir2018.wid.world
2. Angle, J.: The surplus theory of social stratification and the size distribution of personal wealth. Social Forces p. 293–326 (1986)
3. Bettencourt, L.M.A.: The origins of scaling in cities. Science **340**(6139), 1438–1441 (2013). https://doi.org/10.1126/science.1235823. http://science.sciencemag.org/content/340/6139/1438
4. Bivens, J., Mishel, L.: Understanding the historic divergence between productivity and a typical worker's pay: Why it matters and why it's real. https://www.epi.org/files/2015/understanding-productivity-pay-divergence-final.pdf (2015). Online; accessed March 13, 2018
5. CBO: The distribution of household income, 2016 (2019). https://www.cbo.gov/publication/55413
6. De Stercke, S.: Dynamics of energy systems: A useful perspective. Tech. rep., International Institute for Applied Systems Analysis (2014)

7. Dobbs, R., Lund, S., Woetzel, J., Mutafchieva, M.: Debt and (not much) deleveraging: The global credit bubble and its economic consequences. Tech. rep., McKinsey Global Institute (2015)
8. Drăgulescu, A., Yakovenko, V.: Evidence for the exponential distribution of income in the USA. The European Physical Journal B - Condensed Matter and Complex Systems **20**(4), 585–589 (2001). https://doi.org/10.1007/PL00011112
9. Drăgulescu, A., Yakovenko, V.M.: Exponential and power-law probability distributions of wealth and income in the United Kingdom and the united states. Physica A: Statistical Mechanics and its Applications **299**(1–2), 213–221 (2001). http://dx.doi.org/10.1016/S0378-4371(01)00298-9. http://www.sciencedirect.com/science/article/pii/S0378437101002989. Application of Physics in Economic Modelling
10. Fizaine, F., Court, V.: Energy expenditure, economic growth, and the minimum EROI of society. Energy Policy **95**, 172–186 (2016). http://dx.doi.org/10.1016/j.enpol.2016.04.039. http://www.sciencedirect.com/science/article/pii/S0301421516302087
11. Galbraith, J.K.: The End of Normal: The Great Crisis and the Future of Growth. Simon & Schuster, New York (2014)
12. Galbraith, J.K.: Sparse, inconsistent and unreliable: Tax records and the world inequality report 2018. Development and Change **50**(2), 329–346 (2019). https://onlinelibrary.wiley.com/doi/abs/10.1111/dech.12475
13. Graeber, D.: Debt: The first 5,000 Years. Melville House, Brooklyn, NY (2014)
14. ILO, OECD: The labour share in g20 economies. Tech. rep., International Labour Organization and Organization for Economic Co-operation and Development (2015). https://www.oecd.org/g20/topics/employment-and-social-policy/The-Labour-Share-in-G20-Economies.pdf. Report prepared for the G20 Employment Working Group Antalya, Turkey, 26–27 February 2015
15. King, C.W.: The rising cost of resources and global indicators of change. American Scientist **103**, 6 (2015)
16. King, C.W., Holman, A.S., Webber, M.E.: Thirst for energy. Nature Geoscience **1**, 283–286 (2008)
17. Kremer, M.: Population growth and technological change: One million B.C. to 1990. The Quarterly Journal of Economics **108**(3), 681–716 (1993)
18. Lab, W.I.: World inequality data, 1980–2016. Tech. rep., World Inequality Lab (2018). http://wid.world/data/. Data downloaded February 27, 2018.
19. Lawrence, S., Liu, Q., Yakovenko, V.M.: Global inequality in energy consumption from 1980 to 2010. Entropy **15**(12), 5565–5579 (2013). https://doi.org/10.3390/e15125565. http://www.mdpi.com/1099-4300/15/12/5565
20. McLeay, M., Radia, A., Thomas, R.: Money creation in the modern economy. Quarterly Bulletin 2014 Q1 (2014)
21. Nicholas, Shaxson, *The Finance Curse: How Global Finance Is Making Us All Poorer*. Grove Atlantic Press, 2019.
22. Sawyer, S.M., Azzopardi, P.S., Wickremarathne, D., Patton, G.C.: The age of adolescence. The Lancet Child & Adolescent Health (2018). https://doi.org/10.1016/S2352-4642(18)30022-1
23. Silva, A.C., Yakovenko, V.M.: Temporal evolution of the "thermal" and "superthermal" income classes in the USA during 1983–2001. EPL (Europhysics Letters) **69**(2), 304 (2005). http://stacks.iop.org/0295-5075/69/i=2/a=304
24. Smil, V.: Energy and Civilization A History. The MIT Press, Cambridge, Mass. (2017)
25. Stillwell, A.S., King, C.W., Webber, M.E., Duncan, I.J., Hardberger, A.: The energy-water nexus in Texas. Ecology and Society **16**(1) (2011). https://www.ecologyandsociety.org/vol16/iss1/art2/
26. Tainter, J.A.: Energy, complexity, and sustainability: A historical perspective. Environmental Innovation and Societal Transitions **1**, 89–95 (2011)
27. Tainter, J.A., Allen, T.F.H., Little, A., Hoekstra, T.W.: Resource transitions and energy gain: Contexts of organization. Conservation Ecology **7**(3) (2003)
28. Tainter, J.A., Patzek, T.W.: Drilling Down: The Gulf Oil Debacle and Our Energy Dilemma. Springer (2012)

29. Webber, M.E.: Thirst for Power: Energy, Water, and Human Survival. Yale University Press, New Haven and London (2016)
30. West, G.: Scale The Universal Laws of Growth, Innovation, Sustainability, and the Pace of Life in Organisms, Cities, Economies, and Companies. Penguin Press, New York, NY (2017)
31. Yakovenko, V.M., J. Barkley Rosser, J.: Colloquium: Statistical mechanics of money, wealth, and income. Reviews of Modern Physics OCTOBER–DECEMBER 2009 **81**(4), 1703–1725 (2009). https://doi.org/10.1103/RevModPhys.81.1703. http://www.sciencedirect.com/science/article/pii/S0378437101002989