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A Low-Growth World

Implications for the Insurance Industry and Pension Plans

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CONTENTS

A Low-Growth World

Implications for the Insurance Industry and Pension Plans

Background

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I. Executive Summary

This paper introduces the topic of low growth to the actuarial risk management literature. Growth refers to systemic or long-term rates of economic growth, as measured by gross domestic product (GDP), and the paper addresses low growth in both global and national contexts. Sustained compound growth in GDP is an often unstated assumption in the work performed by actuaries in all practice areas.

This paper aims to shine some light on that assumption and the potential asset and liability impacts on the actuary's primary stakeholders, the insurance and pension sectors, if this assumption does not continue to hold. We propose that the implications of a low-growth future are broad enough and substantial enough that it should be considered explicitly in one's enterprise risk management (ERM) program as stress-testing scenarios are developed. We do not propose quantitative methods or solutions to the problem of forecasting growth and quantifying the risk. We do model a method of evaluating the risk, which can also be generalized to other risks.

Following are key takeaways, followed by a summary of the report sections:

1. We are faced with a number of factors that could plausibly limit future growth, and the dominant economic growth models do not capture these factors. These factors might also interact in unexpected ways.
2. Existing long-term projections, developed by various authors, suggest the expected annual global GDP growth rate over the period 2010-2060 might be half that over the period 1960-2010, and a "low-growth" scenario might have average growth rates of 1 percent or less.
3. The standard stimulative monetary and fiscal policy responses to cyclical low growth would be ineffective and could have adverse consequences in a systemic low growth environment. As a result of lower growth, spending more on one thing (e.g., health care, education) crowds out spending on something else. Choices must be made, and some will be painful. Growth allows more options to policymakers.
4. Impact of low growth on insurance and pension assets would include lower real returns on all asset types, with increased asset risk and potential change in the universe of available assets. This would increase the cost of benefits, increase the likelihood of product feature changes, and potentially change how interest-rate guarantees (move from nominal to real rates) on liabilities are determined.
5. Low growth would be expected to adversely affect mortality and morbidity rates, with adverse effects to insurance companies for life/health insurance liabilities and potential benefits to pension and annuity liabilities.
6. Impact of low growth on property risks and other general insurance risks would vary by the drivers of the low-growth scenario.
7. Risk managers should consider low-growth scenarios and the associated risks in their ERM programs. While the level of uncertainty may make risk quantification difficult or inaccurate, risk managers can follow a disciplined process for evaluating these risks, which are modeled in Sections III to V and can be summarized as:
    a. Understand the conventional wisdom.
    b. Evaluate gaps in the conventional wisdom.
    c. Actively seek the wisdom, knowledge and opinions of others (especially those who think differently than you do).

d. Critically evaluate that wisdom.
e. Apply your learnings to the unique risk profile of your business.

Following the Section II introduction, in Section III we begin with an overview of some of the literature related to growth rates, economic theories of growth, empirical history of economic growth and potential drivers of a low-growth future. This review shows that in the long sweep of history, growth is a recent phenomenon that began in the 1700s with the beginning of the industrial revolution. Over more recent history, growth rates peaked in the middle of the 20th century and have declined since then, particularly in what we call the developed world. For the U.S. and other members of the Organization for Economic Cooperation and Development (OECD), growth rates of 4-5 percent in the decades of the 1950s and 1960s have declined to approximately 2 percent since the turn of the millennium.

We review a number of "headwinds to growth"[1] that have been proposed to explain these recent declines, including demographic, environmental, technological, sociopolitical and geopolitical factors. These factors could exhibit an ongoing drag on future growth. The standard economic models of growth, the neoclassical and endogenous models, are simple limited-factor models, which do not consider these headwinds in any direct way. Forecasters who want to include such factors in their economic models must build them in separately, which some have begun to do.

In Section IV, we review a number of long-term (e.g., 50-year) economic forecasts produced by a number of different authors intended to represent not just low-growth conditions but a range of potential growth conditions. We summarize the results of 20 35- to 50-year forecasts with a start date of 2010 for the U.S., China and the world, finding that the median scenario exhibits annual growth rates roughly half of those experienced over the prior 50 years. The lowest growth scenarios generate growth rates low enough to result in negligible compounding effects, and even the highest are low by 20th-century standards.

In Section V, we illustrate the process of analyzing the potential impact of a low-growth scenario on the life/health insurance, property and casualty insurance, and pension sectors from a number of perspectives. We find that significant effects could be expected with respect to asset, liability and strategic risks, and potentially with respect to operational risks. Some effects would be expected to be general to low-growth scenarios, while others would vary depending on the specific drivers contributing to low growth. The effects would depend heavily on government and central bank responses to systemic low growth, with traditional fiscal and monetary policy responses likely to have unintended and potentially adverse consequences. While the effects cannot be predicted with any reasonable degree of numeric certainty, certain consistent themes emerge and serve as a basis to discuss the types of industry responses that would likely occur.

In Section VI, we conclude with a discussion of considerations for incorporating low-growth scenarios into one's ERM program. We recommend that such scenarios should be considered and that they should be developed with careful consideration of the interrelationships among variables. Quantitative scenario analysis tools exist and may be useful, but one should beware of black boxes with a false aura of precision. The most effective near-term ERM responses to

[1] We borrow the term "headwinds to growth" from Robert Gordon (Gordon, 2012). It is synonymous with drivers of low growth and factors contributing to low growth.

the risk of a long-term low-growth scenario are probably driven by qualitative analysis, monitoring processes and developing contingency planning to build resiliency.

Being an actuary means we are destined to become lifelong learners. The exam syllabus provides an excellent base, but risks will evolve in ways that are not foreseeable. Being open to new ideas and then critically deciding how to utilize that information helps a risk manager build scenarios to test the limits of potential outcomes.

II. Introduction

The expectation of perpetual economic growth is perhaps the most consequential and least examined of all long-term forecasting assumptions. Often implicit rather than explicitly stated, the assumption of economic growth permeates all our planning and forecasting. A forecast may consider whether growth will speed up or slow down, whether it will be temporarily interrupted by a recession, but not whether it will continue over the long term. Nowhere is the assumption of growth more deeply embedded than in actuarial science, as the theory of interest, a direct consequence of compound economic growth, is a foundational component of actuarial mathematics.

Economic output contributes to wealth, and wealth is considered synonymous with well-being. Economic activity is considered by many to be the primary, if not the only, measure of a society's well-being. Output can be measured in a number of ways, but the dominant measure is GDP. Some have challenged the orthodox view that GDP is equivalent to well-being, and even the economists who first developed the GDP measure cautioned that it provided a measure of the economic means to well-being rather than a measure of well-being itself. Nonetheless, GDP is the dominant measure of economic activity and, when measured on a per capita basis, is almost universally treated as a proxy for well-being. Therefore, we focus primarily on GDP (on both an aggregate and a per capita basis) as a measure of economic activity and on growth in GDP as a measure of growth.

If GDP measures well-being, then growth in GDP is thought to measure a society's advancement. Growing GDP signals that a society is progressing. Flat GDP signals a stagnant society. Shrinking GDP signals a society in decline. The effect carries far beyond economics. Empirically, the world's affluent societies are freer, better educated, more equal, healthier and more accepting. Growth in GDP correlates with these and other more direct measures of well-being. Interestingly, research finds that beyond a point, increasing wealth does not correlate with increasing happiness (Kahneman, Deaton 2010).

Viewed as the means for achieving many social goods, GDP growth is considered necessary to improving the well-being of society. Growth also creates its own imperative in another way. Governments, businesses and households borrow against the expectation of future growth. Consider this expected growth rate as a hurdle rate—borrowing is cost-effective only if growth exceeds the hurdle rate. Beyond being considered necessary, economic growth is considered to be the natural state of the world. The whole of our economic theory and language would suggest that compound economic growth is, if not a law of nature, God-given.

Over the course of history, however, compound economic growth is a relatively new phenomenon. One person may look at 250-300 years of economic growth since the start of the

industrial revolution and see a remarkably consistent long-term trend. Another may look at all of human history and see this period as a distinct aberration. To be sure, economic growth did occur prior to the industrial revolution. Due to the population and agricultural dynamics described by Thomas Malthus, this growth did not result in broadly improved living standards. Then, as now, growth generally resulted from technological developments, but those developments were too infrequent to generate sustained and recurring improvement in living standards.

Considering compound economic growth as a recent phenomenon might cause one to question whether it is, in fact, a natural state of the world or a temporary phenomenon. As it turns out, increasing numbers of authors are asking just that question. Some study historical growth drivers, concluding that they are unlikely to have the same effect in the future. Some see storm clouds that might impede future growth. Others study the growth models of economic theory, asking if they accurately extrapolate economic behavior in conditions far removed from their initial conditions. Many see a future of reduced growth potential, particularly in the United States and the rest of the developed world. Some see the current level of economic activity as unsustainable, leading to inevitable future declines in GDP. A few see collapse.

This paper does not argue for or against any theory or economic model of future growth. It does not aim to forecast or predict future growth rates. It does not proclaim that the sky is falling. It does aim to introduce actuaries and risk managers in the insurance and pension industries to current literature suggesting that growth rates for the last 50 or 250 years may not be predictive of growth rates over the next 50 or 250 years. It argues that the likelihood of future economic growth rates significantly lower than what is commonly expected is significant and that the concomitant risks to the insurance and pension systems are manifold and significant. Finally, it aims to provide a basis for practitioners to consider these risks in their risk management activities.

Some of the topics to be addressed engender strong opinions, sometimes bordering on religious beliefs. Looking at the same picture, some see black and some see white. As authors, we have our own opinions but have endeavored to color the paper with only one of them—the opinion that these risks are significant enough to write about and should be considered by our industries' risk managers and strategists.

The paper also considers the following basic questions:

- What drivers might cause future growth to fall short of past growth levels, and what literature and evidence exist in support of those drivers?
- What are the drivers of growth in the standard economic growth models, and how do they consider factors that might lead to lower growth?
- What long-term economic growth forecasts exist, and what range of economic growth is anticipated?

We wrap up this introduction with a few comments on the contextual framework of the paper, which the reader will find useful to keep in mind.

We intentionally avoid addressing the question "How low is low?" In the context of the paper, low growth could represent a range of growth expectations. At a minimum, "low" growth is significantly lower than we have experienced over the course of our lifetimes. More broadly, a low-growth scenario could be said to mean a scenario where compound growth is not a

dominant feature of the economic system. It could mean zero growth, it could mean contraction, or it could mean growth at a rate (e.g., less than 1 percent) that does not result in significant compounding effects over the foreseeable future.

The focus of this paper is long-term growth, and we recognize that long-term can have different meanings for different people. As John Maynard Keynes observed, “In the long run, we are all dead.” We consider the long run in the context of sustainability. Our objective should be that our industries and firms should be resilient enough to survive the foreseeable future. A time horizon of 200 years, while valid for many purposes, is too long to be meaningful for building institutional resilience. A typical strategic planning horizon—say three to 10 years—is too short to truly consider sustainability. Through the paper, most of our quantitative growth analysis focuses on a horizon of 35-50 years, though different sections may consider horizons ranging from 30 to 100 years.

Many of the headwinds to growth discussed in the paper can be considered emerging risks, either because they have not been considered significant historically or because as they evolve, their past effects may not be predictive of future effects. However, as we know, new risks are continually emerging or being recognized. It was outside our scope to anticipate the emergence of new and different future risks, but this does not suggest that future emerging risks, with results both positive and negative, will not be important or should not be considered by the practitioner.

While this paper is about economic growth, it is also about an analytic process—a disciplined approach to evaluating “macro” risks and assumptions more generally. It is human nature to focus attention on risks we understand and have methods to quantify. For actuaries, this includes mortality, property losses, interest rates, etc. Even our understanding of these risks is based on historical data that may not extrapolate to an evolving macro environment. In this paper, we do not offer ways to quantify low-growth risks, and we recognize that such quantification may not be possible. However, that does not mean we are helpless. By studying the literature of growth and evaluating potential impacts of low growth, in this paper we model a process for you, the reader, to consider the risk of low growth—and other macro risks—in your own risk management analyses.

III. Survey of Existing Literature

In this section, we will cover a lot of ground addressed in the existing literature of growth—economic growth theories, history of economic growth, potential drivers of low growth, and consequences of low growth. We begin with discussion of several books that inspired the research.

a. Books That Inspired the Research

Several books inspired our interest in the topic of economic growth and in this research. They are discussed here to introduce concepts utilized later in the paper. These include scenario analysis, headwinds to growth and cycles. While each book goes into much greater detail, these introductions provide the reader a base that sets up the rest of the paper.

Limits to Growth: The 30-Year Update (Meadows et al., 2004); *2052: A Global Forecast for the Next Forty Years* (Randers, 2012)

Limits to Growth (*LTG*) is one of the seminal works of the environmental movement, drawing attention to natural resource issues nearly 50 years ago. The original book, published in 1972, was the result of a study commissioned by the Club of Rome.[2] *Limits to Growth* has been updated twice—a 20-year update published in 1992 titled *Beyond the Limits*, and *Limits to Growth: The 30-Year Update*, published in 2004. The *LTG* summary is based on *The 30-Year Update*, the most current edition. The thesis and conclusion of *LTG* in all three volumes is that left unchecked, the paradigm of exponential growth in population and the physical economy will ultimately lead to their very collapse due to the combination of resource depletion and degradation of our physical environment. *2052: A Global Forecast for the Next Forty Years* (*2052*) was written by Jorgen Randers, one of the authors of the *LTG* series, extending and updating the work in several ways.

LTG "used systems dynamics theory and computer modeling to analyze the long-term causes and consequences of growth in the world's population and material economy" (Meadows et al., 2004, p. ix). According to the System Dynamics Society, "System Dynamics is a computer-aided approach to policy analysis and design. It applies to dynamic problems arising in complex social, managerial, economic, or ecological systems—literally any dynamic systems characterized by interdependence, mutual interaction, information feedback, and circular causality. … Mathematically, the basic structure of a formal System Dynamics computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations."[3] The models are characterized by nonlinearity, feedback loops and endogenous drivers, concepts all too familiar to actuarial modelers.

While *LTG* was viewed by many as a forecast, it is more accurately described as a scenario analysis—a what-if analysis based on specific scenario inputs designed to produce a range of results. The original study included 12 scenarios, including a "business as usual scenario," later expanded to 14 scenarios in *The 30-Year Update*. The scenarios included behavioral changes from the business as usual scenario as well as changes in the physical assumptions intended to address "questions such as: are current policies leading to a sustainable future or to collapse? What can be done to create a human economy that provides sufficiently for all?" (Meadows et al., 2004, p. ix). Central to the conclusions is the concept of overshoot and collapse—that humanity overshoots critical limits due to delays in feedback loops and time delays in developing technological solutions. *The 30-Year Update* directly addresses the ability of the market to adapt and sustain growth through technological innovation and market forces along with critiques that the *LTG* model undervalues the impact of technology and markets, specifically modeling scenarios with significantly greater technological benefits. The authors conclude that the market cannot save us because of the delays noted above—but also because markets respond to incentives. Without intervention, the market's incentives do not currently align with sustainability.

LTG was specifically concerned with limits to the physical economy, not the financial economy. The question of whether economic growth could be sustained through growth in nonmaterial

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[2] The Club of Rome, *https://www.clubofrome.org/*.

[3] What Is SD. *System Dynamics Society*, *https://www.systemdynamics.org/what-is-sd* (accessed March 22, 2019).

goods and services was not addressed. The authors concluded that a business as usual scenario would lead to collapse—and that optimistic scenarios regarding resource capacity or technological growth could delay but not avoid collapse—but that systemic efforts to implement sustainability practices could avert such a collapse.

2052 was written in 2012, eight years after the last *LTG* update. Based on the same underlying methods and model dynamics, *2052* differs from *LTG* in several important ways. First, *2052* is a forecast, not a scenario analysis. With the additional years of data on the earth's physical systems and the global response, Randers considered it possible to project a likely future, at least on a broad scale. Second, *2052* broadens the scope of the projections to include nonmaterial elements of the future, including the financial economy, and cultural impacts. Finally, *2052* uses a shorter projection horizon—40 years as compared with 128 years for the original *LTG*, making the forecasting problem relatively easier.

Overall, Randers predicts—optimistically in comparison with some of the *LTG* scenarios—that the world will have avoided collapse by 2052, with inconclusive prospects for avoiding collapse in the second half of the 21st century. The most significant favorable factor predicted by Randers is a slowdown in population growth. He sees the global population peaking in 2040 at about 8.1 billion and then declining due to a significant decline in fertility in an increasingly urbanized world (by contrast, 2017 U.N. population projections forecast a population of 9 billion in 2040, increasing to 11 billion in 2100) (United Nations, 2017). Randers sees this slowdown in population growth as a key to avoid the worst effects of climate change and environmental unsustainability.

With respect to GDP, Randers sees a slowdown in productivity growth partly due to an increasing service share of the economy, where he believes it is more difficult to improve productivity, and partly due to an increasing cost of social strife and international conflict. He sees an increase in investment, from approximately 25 to 35 percent of economic output, as a result of investments to address climate change and environmental degradation—initially forced investment in reaction to disasters and then voluntary investment for environmental mitigation and adaptation. Combined with a slowdown in population growth, he sees GDP growth continuing beyond 2052, but at a significantly reduced rate, with a doubling of global economic output in the 40-year period 2010-2050, compared with a quadrupling over the previous 40 years. With the shift from consumption to investment, he sees global consumption peaking in 2045.

By region, Randers sees an enormous shift of economic power from the developed world to the developing world as the developing economies continue to close the gap in living standards. In the U.S., he projects negligible growth in aggregate and per capita GDP after 2030, with per capita consumption beginning to decline in 2025 and by 2050 reaching a level lower than 2010. The pattern he projects for the OECD excluding the U.S. is similar on a per capita basis but lower on an aggregate basis due to a more aged population. As the developed world matures and begins to decline, Randers sees continued growth in the developing world, primarily China and other rapidly growing economies, with GDP in these regions increasing three- to fourfold, comparable to global growth for the period 1970-2010.

LTG and *2052* are important in their efforts to model complex physical and economic dynamics in a robust way. Any such effort will be flawed, but the issues raised in these books have increasingly gained traction. Detailed review of the models and assumptions was beyond our

scope, but the methods appear consistent with an actuarial approach. One should not rely blindly on the projections from either book, but they are useful to frame the issues and potential impact of an environmentally driven decline.

Rise and Fall of American Growth (Gordon, 2016, and Gordon, 2012)

Soon after the American Civil War, a flurry of invention and change began that lasted for more than 100 years. Americans went from the entire family sharing a large tub in the kitchen for their "regular" bath (after carrying in the water and heating it over a fire) to walk-in showers inside temperature-moderated homes. The times have certainly changed.

Dr. Robert Gordon, a professor at Northwestern University, in his book *The Rise and Fall of American* Growth shares details about the speed with which Americans adopted various items in the century following 1870. Especially interesting were the differences between urban and rural, north and south.

Changes in the Last Century

We enter 2018 worried about dangers such as climate change and overpopulation. At the beginning of the 20th century, prior to antibiotics and antiseptics, our forebears were concerned that cities were becoming unlivable due to a reliance on horses and lack of sanitation. Manure piled up in the streets, mixing with urine and rain to make a goopy and disgusting mess. Cholera and other diseases were unwanted but regular visitors. A quarter of agricultural land was devoted to crops to feed the horses, and humans were paid to clean up after them. The automobile provided a pivot, allowing society to quickly shift in a more sustainable direction. Public waterworks increased life expectancy dramatically by improving sanitation and reducing disease. Development of the germ theory of disease, combined with these public improvements, reduced infant mortality and the risk of childbirth.

Regulations have historically improved our standard of living but generally came about only after an unsavory practice was illuminated. Transparency through regulation and testing (e.g., food testing and environmental protection) enhances living standards, life expectancy and quality of life. This provides an important balance to the purely financial ramifications of capitalism.

It is worth reminding the reader that not all was perfect during this period of growth, with the Great Depression and two world wars dominating in turn, along with many less significant events.

Headwinds

Gordon argues that this period covering the second of three industrial revolutions was an anomaly and that American growth will revert to the 0.2 percent found prior to 1700. He suggests there are six headwinds to growth:

1. Demographic factors, including the baby boom, and the demographic dividend, where females entered the workforce, allowed a one-time growth spurt in the last century.
2. Plateau in educational attainment, as college graduation rates fade from a peak about 20 years ago.
3. Rising inequality as growth in real income has bifurcated between "haves" and "have-nots" leads to the lower 99 percent doing poorly and the median getting worse. Also self-fulfilling as more "haves" marry each other and send their kids to the best schools.

4. Interaction between outsourcing and technology, providing jobs to those who charge the least in a global marketplace.
5. Energy and the environment lead to catch-ups and proactive costs.
6. Consumer and government deficits, already high around the world, have not historically led to happy endings, as higher taxes and lower benefits and services must eventually reverse these imbalances.

Comparing 1870 and 2010 in the United States

Since 1870, the U.S. population has grown by more than eight times and now exceeds 325 million. Average household size has shrunk by 50 percent; we are older and more diverse. Teenage males are much more likely now to be in school than working on a farm, females have entered the workforce in large numbers, and the concept of retirement has been introduced.

Incremental improvements were often followed years later by revolutionary change. The telephone and elevator provide good examples, where the original invention led to secondary advancements in emergency response and urban living. While the technological revolution continues, with tools like artificial intelligence and the internet of things continuing to rapidly evolve, Gordon argues that the information revolution will be much less consequential for economic growth.

Long-Term Cycles: *The Fourth Turning* (Howe and Strauss, 1997)

At a high level, in *The Fourth Turning*, William Strauss and Neil Howe suggest that history cycles, repeating regularly in ways that mirror the human life cycle. A saeculum covers four generations (turnings), or one person's lifetime. Once the generation that survived a period or event is gone, a similar event returns in a new form. History does not repeat itself exactly, but it does rhyme. The fourth (last) turning in each cycle is particularly chaotic, covering 20-25 years where authoritarian leaders are followed, even if they make poor decisions. While it is hard to specify precise dates of turnings as they occur, in recent interviews, Howe believes the 2008 financial crisis kicked off the current fourth turning. The most recent periods defined by a fourth turning in the United States were the Great Depression/World War II, the Civil War and the Revolutionary War. If he is correct, this period could last as late as 2030, with changes enacted late in the era that lead to a blissful generation of growth.

Each saeculum is composed of four successive generations that follow each other through the four turnings.

1. Heroes: born during an unraveling
2. Artists: born during a crisis
3. Prophets: born during a high
4. Nomads: born during an awakening

The four generations repeat similar eras. The first turning is a "high" that leaves a crisis behind and enters a period of prosperity as Heroes enter midlife. The second turning is an "awakening," where artists enter midlife. The third turning is an "unraveling," where prophets enter midlife. Completing the cycle, the fourth turning is a crisis, with nomads entering midlife and taking on the leadership role.

Generations follow regular cycles and have recurring attachments to the other generations. Examples include:

- Strict parents have pampered grandchildren.
- A warrior generation (heroes) encourages children to be peaceful, but the grandchildren think of war as romantic.

In today's era of longer lifespans, up to six generations can be living at any one time. Currently living are the GI (hero, born before 1925, fought during the most recent fourth turning), silent (artist, 1925-42, sheltered children during the most recent fourth turning), boomers (prophet, 1943-60, typically think of war as romantic), 13th (nomad, 1961-81), millennial (hero, 1982-2002) and Generation Z (artist, after 2002). These generations have distinct roles in each turning. In each crisis (fourth turning), prophets (boomers) occupy the role of elders, nomads (13th) are entering midlife and will be expected to get things done when it matters most, heroes (millennial) will be the soldiers as they enter young adulthood, and artists (Gen Z) will be too young to do anything except stay out of the way.

Since the book was written more than 20 years ago and contains predictions, it is safe to say that some were right and others wrong. One they get right is that many boomers will be entering retirement with little hope of independent living.

The authors suggest that a reliance on resiliency, thinking through a variety of scenarios and preparing for each in some way while staying open to surprises, will improve expected results. Considering cycles, together with scenarios, provides the connection between the book and this paper. At any point in time, like a balance sheet, the current economic and geopolitical situations are recorded. Risk managers considering the future must recognize that change is the only constant and that history often repeats itself. It cycles. It could be the balance of power internationally, trade strategies, currency relationships, place in the debt cycle, level of interest rates, generation of insurance and pension products, asset class returns, diseases, or agricultural practices. Everyone is a risk manager and needs to consider where the next pivot may take us. Confidence in knowing the future is always ill-conceived.

b. Theories and Models of Economic Growth

In this section, we provide a brief overview of the history of economic thought related to economic growth, from the classical economists forward. This discussion will provide important context for the remainder of the paper, providing a basis to consider how factors that may limit growth have been considered, or not considered, in the economic models and formulations on which growth assumptions are based. A couple of key points are important to note at the outset.

1. Economic growth theory is concerned with the long-run growth rate of the economy as opposed to short-term cyclicality.
2. These theories address growth in economic output, with underlying equilibrium assumptions that output is fully utilized by demand.

Classical Economics

Classical economic theory arose in the late 1700s and developed through the 1800s, relatively early in the industrial revolution. The classical economists treated growth within the context of

broader macroeconomic theory rather than through separate models or theories. Under classical theories, growth arose from the accumulation and reinvestment of surplus profits. Diminishing returns, largely due to limits of productive resources, would ultimately lead to zero marginal profit and an end to growth. As stated by Adam Smith, "a country which had acquired that full complement of riches which the nature of its soil and climate, and its situation with respect to other countries, allowed it to acquire … could, therefore, advance no further" (Smith, 1776/1952, p. 40). Malthusian population dynamics, whereby "population grows in response to a rise of wages above subsistence" (Harris, 2011), would provide elasticity in the labor pool to support the available capital and would provide a check on wage growth. In a society that was still largely agrarian, limits in arable and otherwise productive land presented the resource limit that would lead to diminishing returns on capital. With some exceptions, the classical economists therefore saw limits both to macroeconomic growth and to wages of laborers. Although the growth limits they envisioned have not been borne out to date—with technological development and shift from an agrarian economy of which they could not have conceived, and with 200 years of population and wage growth that have not followed Malthusian dynamics—some current thinking about the impact of resource limitations harks back to their ideas.

Harrod-Domar Model

In the first half of the 20th century, models of growth under Keynesian economic theory were exemplified by the Harrod-Domar models, developed independently by Roy F. Harrod in 1939 and Evsey Domar in 1946 (Harrod, 1939; Domar, 1946). Under the Harrod-Domar models, growth potential was driven by an equilibrium relationship among four constant exogenous[4] factors: return on capital (v), savings rate (s), rate of growth in labor productivity (m) and growth in the workforce (n). In the Harrod-Domar models, growth in the output capacity of capital (s * v) must equal the growth in the output capacity of labor (m + n). This equilibrium condition, combined with the assumed values for the four factors, drives growth capacity. The Harrod-Domar models marked a movement toward models with fewer factors that could be expressed mathematically. Failure of these models to explain economic developments of the first half of the 20th century led to development of the neoclassical models. Importantly for our purposes, these models also marked a departure from the classical economists' explicit consideration of natural limits.

Neoclassical Growth Theory (Solow-Swan Model)

Neoclassical growth theory was developed in the mid-20th century and is exemplified by models developed independently by Robert Solow and Trevor Swan in 1956 (Solow, 1957; Swan, 1956). Developed in reaction to shortcomings in the Harrod-Domar model, Solow and Swan modeled growth from the same four factors as the Harrod-Domar model, along with explicit treatment of depreciation of capital. Conceptually, the neoclassical framework considers the savings rate and return on capital as endogenous—i.e., "variables determined by normal economic processes" (Solow, 1999 p. 641)—while treating productivity and population growth as exogenous. The depreciation rate is treated as a constant. While the savings rate is

[4] Endogenous factors are assumed to be determined through economic processes and computed within the model. Exogenous factors are assumed to be determined by noneconomic processes and are external inputs to the model.

conceptually endogenous, as a practical matter the Solow-Swan model treats it as a constant, consistent with empirical data.

Neoclassical growth assumes constant returns to scale, with scale measured by the labor force, such that the model can be expressed on a per capita basis. Importantly, it also assumes strictly diminishing returns to capital and labor on a per unit basis. In the absence of exogenous productivity growth through technological improvement, the result is that per capita output approaches a steady state. That is, the labor productivity of each worker plateaus at some limit based on available technology and the return on each additional unit of capital approaches zero on a per capita basis. As such, the two factors that might contribute to indefinite growth are an ever-growing workforce and perpetual increases in labor productivity (through technological innovation). Variants of the basic neoclassical models have been developed to incorporate other factors, but the basic neoclassical framework remains a dominant economic growth model.

Endogenous Growth Theory[5]

Critics have pointed out some critical areas where empirical data are not well explained by neoclassical theory. As noted above, neoclassical models predict a slowdown in growth rates as an economy approaches its steady state, due to the assumption of diminishing returns on capital. For similar reasons, neoclassical theory predicts more rapid growth rates in smaller, less developed economies compared with more developed economies, all other things being equal. Some researchers have found that neither prediction has comported well with historical data, leading to the development in the 1980s of endogenous growth models, where productivity improvement is endogenous rather than exogenous. Under endogenous growth theory, technological innovation is a direct result of capital reinvestment in research and development, generating a virtuous cycle whereby diminishing returns on investment are offset by the productivity gains resulting from this investment. In the basic endogenous model, the offset is perfect, such that the return on capital is constant. The endogenous model does not result in a steady state but predicts indefinite growth based on the savings rate and return on capital. In addition, the endogenous model supports certain government action: “Governments can manipulate the business environment in ways that will increase its pace of knowledge growth. This may support trade liberalization or greater openness; it may warrant investment in education or training; and matters such as intellectual property rights regimes (giving incentives to innovate, yet possibly restricting its speed of transfer) become of great significance” (Perman and Stern, 2001, p. 184).

Optimal Growth Theory and the Ramsey Model[6]

The neoclassical and endogenous growth models described above treat the savings rate as a constant. The optimal growth model was pioneered by Ramsey (1928), not as a model to understand growth in a market economy but to address a central planner’s problem of the optimal pattern of investment to maximize social welfare. Additional development was provided by Cass (1965) and Koopmans (1965), including developments showing that the Ramsey model was also optimal in a dynamic decentralized economy. While the Solow-Swan and endogenous

[5] Taken largely from Perman and Stern, 2001.

[6] Taken largely from Benassy, 2011, and Angeletos, 2013.

growth models assume a fixed savings rate, the optimal growth model is characterized by a savings rate determined through intertemporal dynamic optimization (i.e., consumption versus savings choices that maximize the time value of utility). In the Ramsey model, "households are represented as a single dynasty of infinitely-lived households … [with] a single utility function and a single budget constraint" (Benassy, 2011, p. 145). Other variants of the optimal growth model may include a more complex representation of households, including finite-lived households and households with different utility functions and budget constraints. The Ramsey model was based on a neoclassical framework (i.e., with an exogenous rate of productivity growth), while other variants may utilize an endogenous growth framework.

As with the Solow-Swan model, in the absence of exogenous productivity improvement due to technological development, the basic Ramsey model exhibits diminishing returns that result in convergence to an equilibrium, or steady, state. This equilibrium state is independent of the utility function, depending only on labor productivity, the depreciation rate and the discount rate (often called the social discount rate). Thus, the utility function does not affect the equilibrium state but only the optimal path toward achieving the equilibrium state, while the social discount rate affects both the equilibrium state and the optimal path to achieving it.

Summary of Economic Growth Models and Drivers

To summarize, the treatment of growth as a separate area of economic theory is a post-classical development. The classical economists understood growth within the context of their broader economic thought and saw a country's natural resources as a limiting factor in its growth capacity. The predominant post-classical economic growth theories have sought model growth mathematically using a few key inputs. These theories generally reflect the same factors contributing to growth in economic output:

- Size of the labor force
- Labor productivity and its rate of growth
- Savings or investment rate
- Rate of return on capital
- Capital depreciation rate

The models differ primarily in their treatment of some of these factors—most notably the savings rate and the growth rate in labor productivity—as endogenously or exogenously determined. In all these models, there are two factors that could lead to indefinite economic growth—population growth and growth in labor productivity. Population growth is exogenously determined in all these models. Rate of return on capital and capital depreciation rate are effectively treated as constants. The primary development moving from the neoclassical framework to the endogenous growth framework is the endogenous treatment of labor productivity growth.

Limitations of Economic Growth Models

Before proceeding, it is important to note some key limitations to the dominant economic growth models. These limitations generally relate to the "unknown known" problem whereby historical data is not predictive (not to be confused with Donald Rumsfeld's unknown unknown problem). These unknown knowns relate to implicit assumptions and to model simplifications.

The era of economic growth began with the advent of the industrial revolution, roughly in the mid-1700s. Measured over that period, empirical data generally support the use of these underlying assumptions and simplifications. However, the growth era represents a relatively short portion of recorded human history, and it is not clear that these assumptions can be extrapolated indefinitely. Section III.d will address factors that may limit the future extrapolation of these factors.

Assumption of Constant Returns to Scale

The first key limitation is the assumption of constant returns to scale, which is relevant in two ways. Most notably, it is equivalent to assuming unlimited physical resources. Per capita economic capacity is assumed to be the same at a population of 6 billion, 60 billion or 600 billion. While reasonable people may disagree about the point at which the population level overstresses the capacity of earth's physical systems, few would argue that such a point does not exist. Also related to the assumption of constant returns to scale is the distinction between aggregate growth and per capita growth—and the relative importance of the two. Simplistically, if consumption per capita is viewed as a measure of economic well-being, it seems that per capita economic growth is more important than aggregate growth. However, in a market economy, where future economic capacity is monetized through debt and equity valuations that in turn reflect assumptions of future growth, the relative importance is not as clear.

The Ramsey optimal growth model provides a basis for incorporating environmental factors, and some economists have begun to develop growth models incorporating environmental factors. Henry Thompson (Thompson, 2004, and Thompson, 2012) has extended the two-factor (capital, labor) neoclassical growth model to a three-factor model, with the third factor being a nonrenewable resource. In this model, optimization involves not only balancing savings and investment in each period but also optimizing the depletion pattern of the nonrenewable resource. These models are early in their development and are highly sensitive to assumptions, such as the elasticity of substitution (the ease with which one factor of production can be substituted for another, or with which a scarce resource can be replaced by a more plentiful one). However, they represent clear progress in addressing one of the key limitations of the existing models, which effectively assume an infinite elasticity of substitution.

Assumptions Regarding Productivity Growth Drivers

Second, the models are silent regarding the underlying drivers of productivity growth. Whether in the neoclassical framework or the endogenous growth framework, no link is made to the physical basis of technological development or productivity improvement. Unlimited capacity for technological development and productivity improvement is taken almost as an article of faith. This faith is often grounded in the implicit assumption of a high elasticity of substitution described above, which applies to multiple types of substitution—the substitution of one resource for another, the substitution of capital for labor or the substitution of manufactured capital for a natural resource. With high elasticity of substitution, it is easy to adapt to limits in one or more factors of production; with low elasticity of substitution, such adaptation is not as effective. As discussed in later sections, productivity growth could be slowed by factors such as energy supply, productive resource capacity or a plateau in educational attainment, with limited potential for substitution.

Demand Limits

Third, these growth models address productive capacity (i.e., the supply side of the equation), the economy's capacity to produce goods and services. Economic demand is assumed to be unlimited, or perfectly elastic with production. Each unit of output generates an equivalent unit of income, and households will utilize their full income for either consumption or investment in future productive capacity.

Expectations Theory

Expectations theory typically describes a yield curve and how the term structure of interest rates is likely to change in the future, but expectations are also a psychological feature of the economy. Qualitative statements by influential people can drive the economy in ways that rational expectations do not anticipate. Mario Draghi's "whatever it takes" or Warren Buffett's investments in the wake of the financial crisis were both designed to build confidence and influence the narrative that was very negative at the time. Variables like inflation tend toward momentum; our expectation of next year's inflation rate is whatever it is today. This all leads to growth expectations and is qualitatively based. Business sentiment attempts to capture this as a metric, but often these expectations are not recognized by those who hold them. In the extreme, these lead to fear and greed, with investors often doing the wrong thing. Businesses that recognize these tendencies before their competitors can realize a contrarian advantage.

Complex Adaptive Systems

As an example of the simplifications embedded in the economic models, standard economic theory assumes that everyone is a rational agent acting in their own best interests using probability and expectations theory. Findings from behavioral finance (each agent is unique, with its own cognitive biases), common sense and personal observations make this a difficult hypothesis to validate. When an ecosystem involves interactions and agents acting on their own terms, a model can be built but not optimized. Simulations can show expected results and other statistics, providing information to help make decisions. These types of systems are modeled for weather (remember the butterfly flapping its wings in Japan that caused a weather event in North America), sickness (e.g., a virus would consider the number of contacts, likelihood, severity), transit in cities (e.g., people moving around between jobs, home, activities) and, of course, the financial ecosystem.

In the past, many financial terms were assumed to be linearly related to each other. In complex adaptive systems, the relationships are dynamic and nonlinear, incorporating higher-order interactions. An example designed to convey the basic concept would model cars on a particular stretch of highway, with each driving at a different speed and with a distinct style but not able to change the environment (the highway, weather). One car may be stuck behind a slow driver and stay there for the remainder of their trip, while another may aggressively pass them on the shoulder of the road.

A more sophisticated economic analysis would consider a group of investors who had each bought a specific asset and collectively own it in its entirety. Some used leverage, some were high-net-worth individuals, and some held this asset in a qualified retirement account. Initially, there is ample liquidity, but then the asset falls in value and some investors receive margin calls. The forced sales lead to more selling pressure as potential buyers take a few days to figure out

their plans, while sellers become desperate and lower the price they are willing to accept. The environment has changed and will not stabilize until the market has cleared.

Complex adaptive system based models generally do not have unique solutions, but the distribution of results they supply may better describe the world's economy. Actuaries should continue to develop insurance and pension models using these techniques to learn how they can be used in tandem with deterministic scenario models to better understand the balances between risk and return.

Limitations of GDP as a Measure

While the limitations discussed above apply to the models of economic growth, we must also point out some limitations in GDP as a measure. These limitations encompass shortcomings in our financial accounting systems and shortcomings in the definition of GDP. While this paper does not focus on alternate measures of well-being or economic activity, addressing some of these shortcomings would be beneficial to timely recognition of the effects of some of the headwinds to growth to be discussed in Section III.d.

Externalities and goods versus bads: Externalities are costs or benefits to third parties as a result of a firm's activities. Benefit externalities include the overall increase in knowledge resulting from a firm's research and development activities and are often ultimately reflected in GDP through the earnings of other firms that benefit. Cost externalities are items such as the effect of pollution on public health, which are often not reflected directly in GDP or are reflected in counterintuitive ways. If an industrial pollutant leads to childhood cancers, the damage itself may not reduce GDP, but the resultant costs—the economic activity generated from health care and site cleanup—add to GDP. In this way, it is often said that GDP makes no distinction between goods and bads.

One common suggestion for addressing negative externalities is to design a tax to force the internalization of externalities that otherwise avoid detection by financial statements. To address the cost of climate change (and similarly for pollution), for which the marginal harm is minimal but the aggregate harm is consequential, a carbon tax has been suggested to fund cleanup efforts.

Natural resources as capital: Depletion of a limited resource is another source of concern, with extraction of fossil fuels one of many examples. The cost to extract and use a commodity currently includes no reference to what happens when that runs out. It provides income to someone who removes it, but ignores its irreplaceability as capital. E.F. Schumacher argued that natural resources should be accounted as capital items, rather than income, to address this shortcoming and add transparency (Schumacher, 1973). The farmer who fertilizes the field and cultivates a crop can argue that they are sustainable. One who taps an aquifer for water cannot avoid this controversy.

Depreciation and net domestic product (NDP): The difference between gross domestic product and net domestic product is depreciation. Just as the economic growth models generally treat depreciation as a constant, depreciation is generally assumed to be constant—and therefore ignored—in measuring economic activity. However, climate change and other environmental factors may lead to increases in the rate of depreciation through natural disasters and environmental degradation, making net domestic product a more meaningful measure. Imagine that all of New York City was rebuilt on the mainland as a result of rising sea levels.

The construction effort would result in a tremendous increase to GDP, but the gain in wealth, measured by NDP, would be nil.

Happiness and alternate measures: Attempts have been made to extend the financial system that uses GDP as a primary metric to include nonfinancial items like happiness. Is it more important to have more money or more happiness? The answer is driven by culture. Many with lots of money are not happy, and many are happy with little money. Schumacher coined the term "Buddhist economics" (Schumacher, 1973) to describe an economic system that maximized well-being with a minimum of output, and this thinking is central to the concept of a steady-state economy developed by Herman Daly (Daly, 2008) and others. Examples of proposed alternate measures include green GDP, taking into account climate change and loss of biodiversity, and sustainable GDP, which can be maintained into the future. Other indices are based on inequality, life expectancy or education. The Human Development Index and Happiness Index attempt to combine multiple metrics.

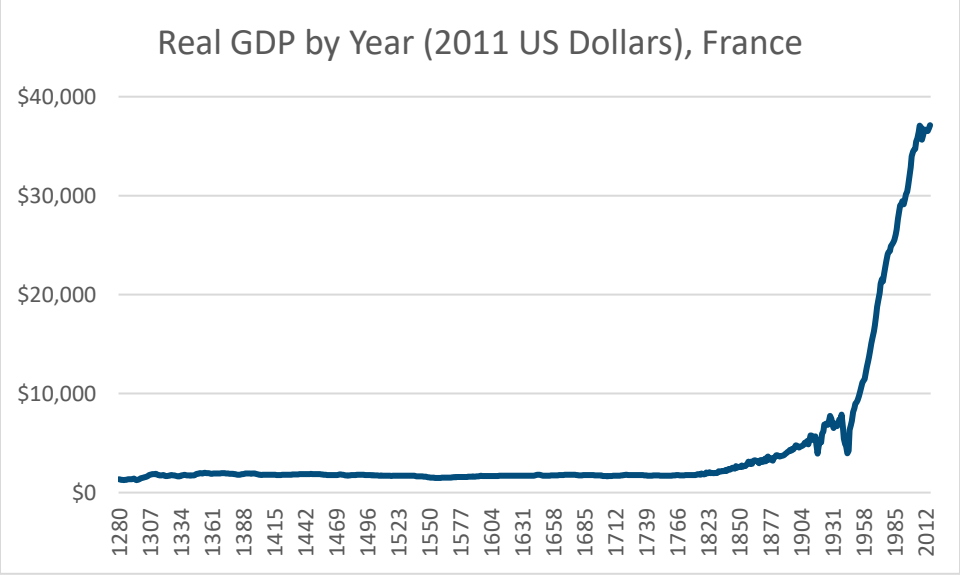
c. Empirical History of Economic Growth

Long-Term History of Growth

The recent advent of the era of economic growth has been noted by numerous authors. Max Roser (Roser, 2018) has written a succinct long-term history of economic growth. Figure 1, using data from the Maddison Project Database, one of Roser's sources, is representative and shows real per capita GDP (2011 U.S. dollars) for France beginning in 1280. For the period 1280-1750, per capita GDP varies between a low of $1,259 occurring in the late 1200s and a high of $2,011 occurring in the middle 1300s, with the start of the period having a value of $1,364 and the end of the period having a value of $1,731. Beginning in the middle of the 18th century, per capita GDP begins to grow and has continued largely uninterrupted until today.

Figure 1

REAL GDP BY YEAR, 1280-2012—FRANCE (2011 U.S. DOLLARS)



Source: Maddison Project Database, version 2018, *https://www.rug.nl/ggdc/historicaldevelopment/maddison/*. See Bolt et al., 2018 for details of development.

This pattern is consistent for other countries with data extending back for similar periods. Before the middle of the 18th century, there are increases in per capita income, but those increases are not sustained. Since then, for the last 250-plus years, sustained growth in per capita GDP has been the norm across the world. As described by Roser, this change results from productivity improvement combined with a fundamental change in population dynamics. Productivity improvement, fueled by technological development, is the engine of economic growth. Prior to the industrial revolution and the era of growth, technological improvements did occur, but these improvements were accompanied by Malthusian population dynamics, whereby productivity improvement was absorbed by population growth. "Improvements in technology had a different effect in the Malthusian pre-growth economy. They raised living standards only temporarily and instead raised the size of the population permanently" (Roser, 2018). Improvements in technology were sporadic rather than continual and self-sustaining. In the 18th century, technological gains began to occur at unprecedented rates, becoming self-reinforcing rather than sporadic. It may be that the pace of technological gains is what finally shifted the population dynamics, ushering in the era of growth.

Recent History of Growth

What about more recent patterns of growth, including regional differences? The following discussion compares GDP growth rates since 1950 in several economic regions of the world (not to be confused with geographic regions). Data are from the Penn World Table database, which includes data for the period 1950-2014. These regions are defined relatively consistently with Randers' 2052 definitions (Randers, 2012), as shown in Table 1.

Table 1

COMPARATIVE ECONOMIC REGIONS

U.S.	United States of America and its territories
China	China and its territories
OECD	2018 members of the OECD, excluding the United States: Australia, Austria, Belgium, Canada, Chile, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland,* Israel, Italy, Japan, South Korea, Luxembourg, Mexico,* Netherlands, Norway, New Zealand, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey,* United Kingdom
BRISE	The largest remaining emerging economies: Brazil, Russia, India, South Africa and others (Argentina, Indonesia, Iran, Saudi Arabia, Thailand, Ukraine, Venezuela, Vietnam)
ROW	The rest of the world, excluding any country not in the Penn World Table database

*Indicates a difference from Randers' definition, due to changes in OECD membership.

Figure 2 shows annualized real GDP growth rates by decade (plus the four-year period ending in 2014), and Figure 3 shows the same comparisons on a per capita basis.

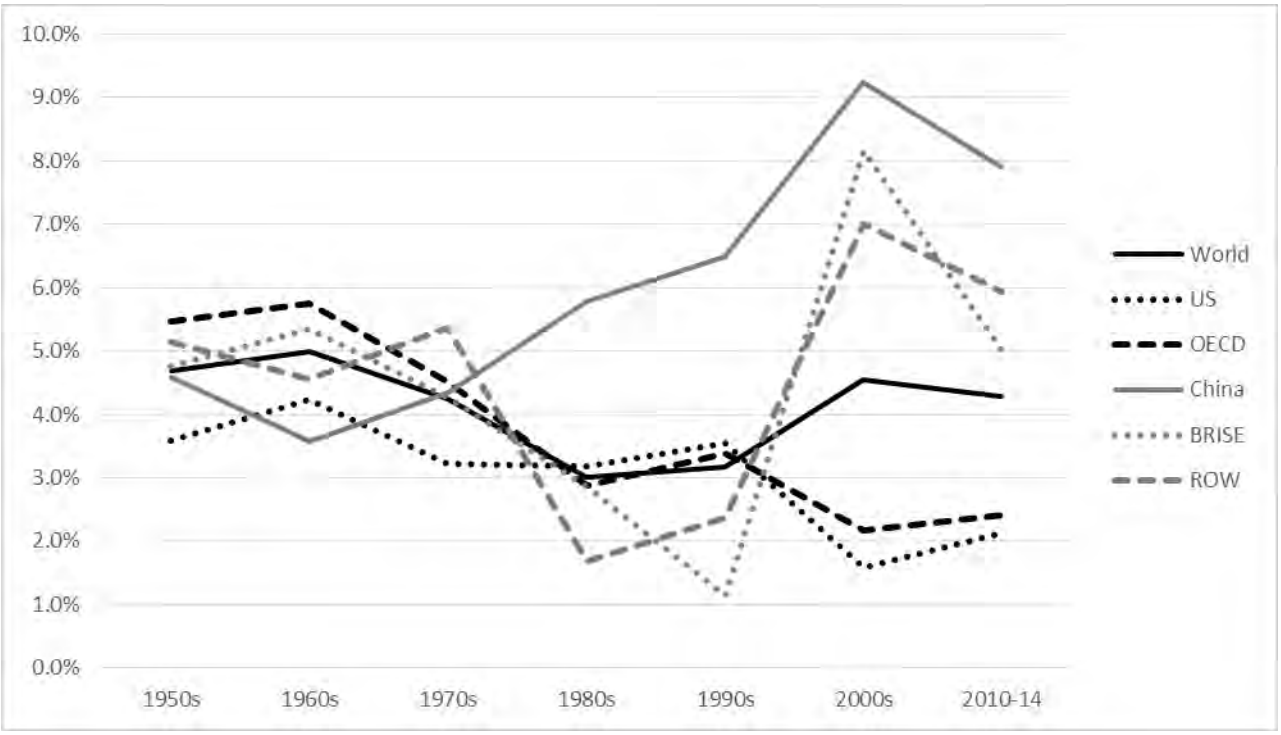
On a worldwide basis, Figure 2 shows growth rates of approximately 5 percent in the 1950s and 1960s, declining to approximately 3 percent in the 1980s and 1990s, and rebounding to 4-4.5 percent in the 2000s and 2010s. The regional data show some interesting patterns. Through 1980, regional growth rates are within a fairly narrow band, with the U.S. toward the bottom of

the band and the other OECD countries toward the top. Since then, China has consistently shown more rapid growth than any other region. The smallest economies, the BRISE and ROW regions, saw significant declines in growth in the 1980s and 1990s but have rebounded strongly since then to significantly outpace growth in the more developed economies. Meanwhile, growth in the U.S. and remaining OECD regions have tracked closely with one another since 1980, with a steady downward trajectory—both very close to the global average of 3 percent through the 1980s and 1990s but declining to about 2 percent, well below the global average—in the 2000s and 2010s.

How have these patterns affected growth in economic well-being, as measured by per capita GDP? Figure 3 shows similar patterns, but with some interesting distinctions. As expected, per capita GDP has grown more slowly than aggregate GDP, with the difference declining as population growth has slowed over the period. On a global basis, population growth contributed about 2 percent to annual growth through 1990, declining to 1.2 percent for the most recent period. As a result, global per capita growth rates are higher in the 2000s and 2010s than they were in the 1950s and 1960s. As we saw with aggregate growth, this rebound is driven by the emerging economies. U.S. and OECD nations show declining per capita growth throughout the period, with growth rates of 1-2 percent since 2000, though the declines are not as precipitous as the aggregate data showed.

Figure 2

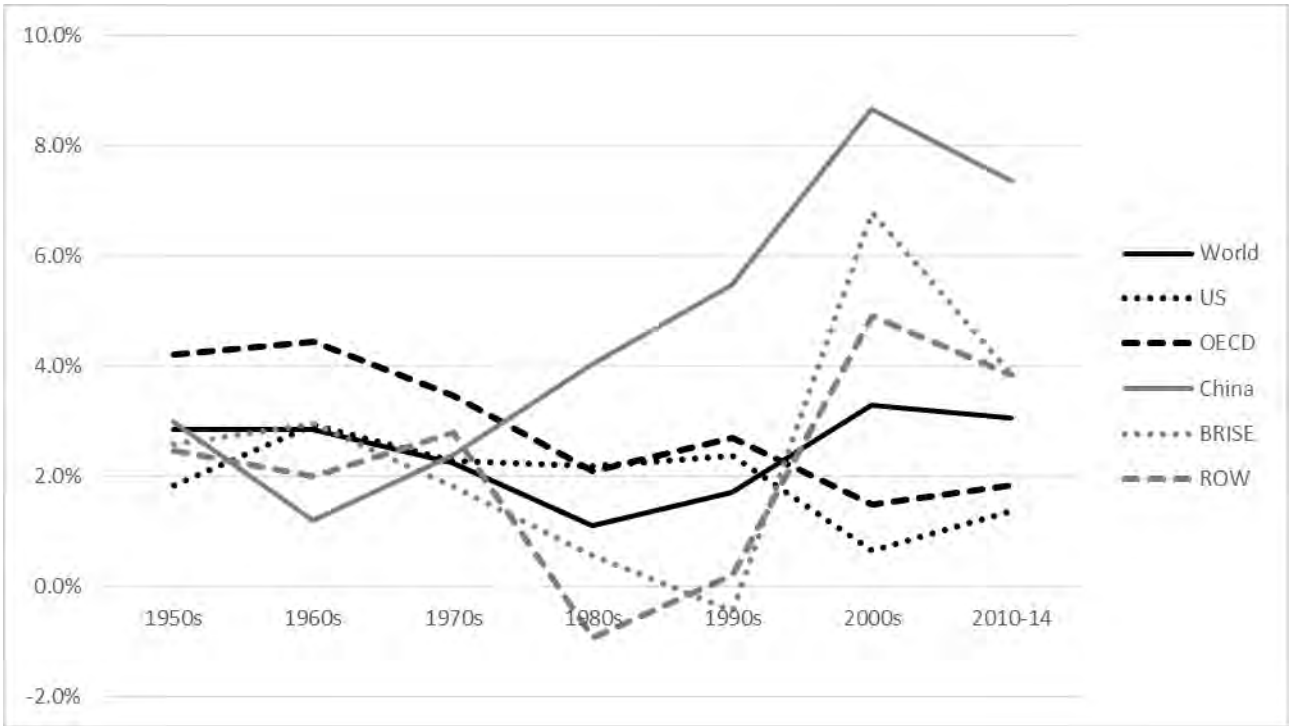
WORLD/REGIONAL REAL GDP ANNUALIZED GROWTH RATES BY DECADE, 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Figure 3

WORLD/REGIONAL REAL PER CAPITA GDP ANNUALIZED GROWTH RATES BY DECADE, 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Some alternate views of the data provide interesting insight into longer-term changes in the distribution of economic activity and development of living standards over the period. Figure 4 shows the percentage distribution of global GDP by region (the regions all sum to 100 percent), and Figure 5 shows per capita GDP of the various regions using the U.S. as a benchmark. These charts show the cumulative impact of these divergent growth patterns and highlight the development in the emerging economies vis-à-vis the developed world. In 1952, the U.S. and OECD regions accounted for nearly 80 percent of the global economy, declining to 46 percent by 2014. The U.S. share has dropped by more than half—from 37 percent to 16 percent. The offsetting gains have been shared among the three emerging regions of China, BRISE and ROW, with each more than doubling its share of the world economy over this period.

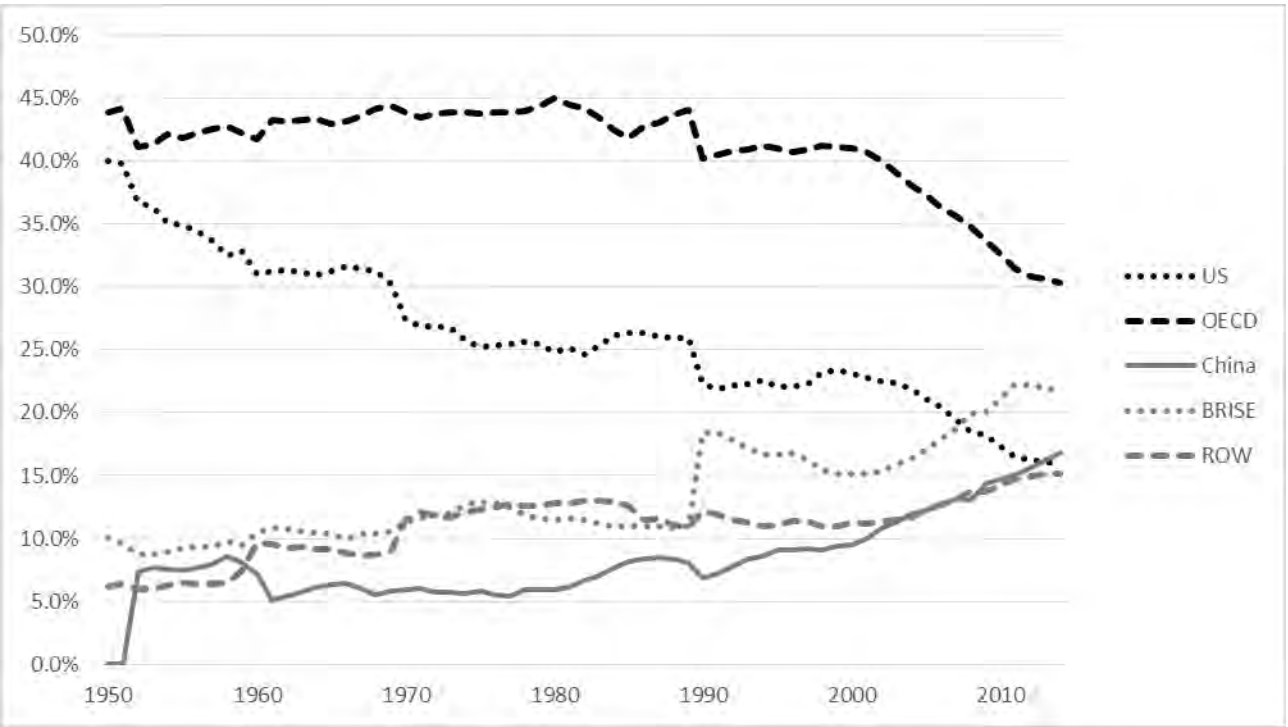
On a per capita basis, using the U.S. as a benchmark, some different patterns emerge. Worldwide average GDP per capita was in a tight range from 20 to 23 percent of the U.S. for the full period 1952-2006, climbing steadily since then to 28 percent. The OECD region grew steadily from less than 40 percent of the U.S. in the early 1950s to approximately 60 percent in the mid-1990s and has been fairly steady since then. Through 2000, the emerging economies as a whole showed little gain in economic well-being relative to the U.S., with per capita GDP levels in the range of 7-10 percent of the U.S., even as their share of global GDP grew from 22 percent to 36 percent. Since then, however, their per capita GDP has risen to 18 percent of the U.S., led by China but with gains in all three regions.

[Notes on Figures 2-5: Data is not available for all countries in all periods. In particular, China enters the database in 1952, a number of countries enter in 1970, and Russia and a number of other Soviet bloc countries enter in 1990. In Figures 2 and 3 showing annualized growth rates,

we have adjusted for these discontinuities. In Figures 4 and 5, similar adjustments were not practical, and the effect of these discontinuities is apparent in 1952, 1960, 1970 and 1990.]

Figure 4

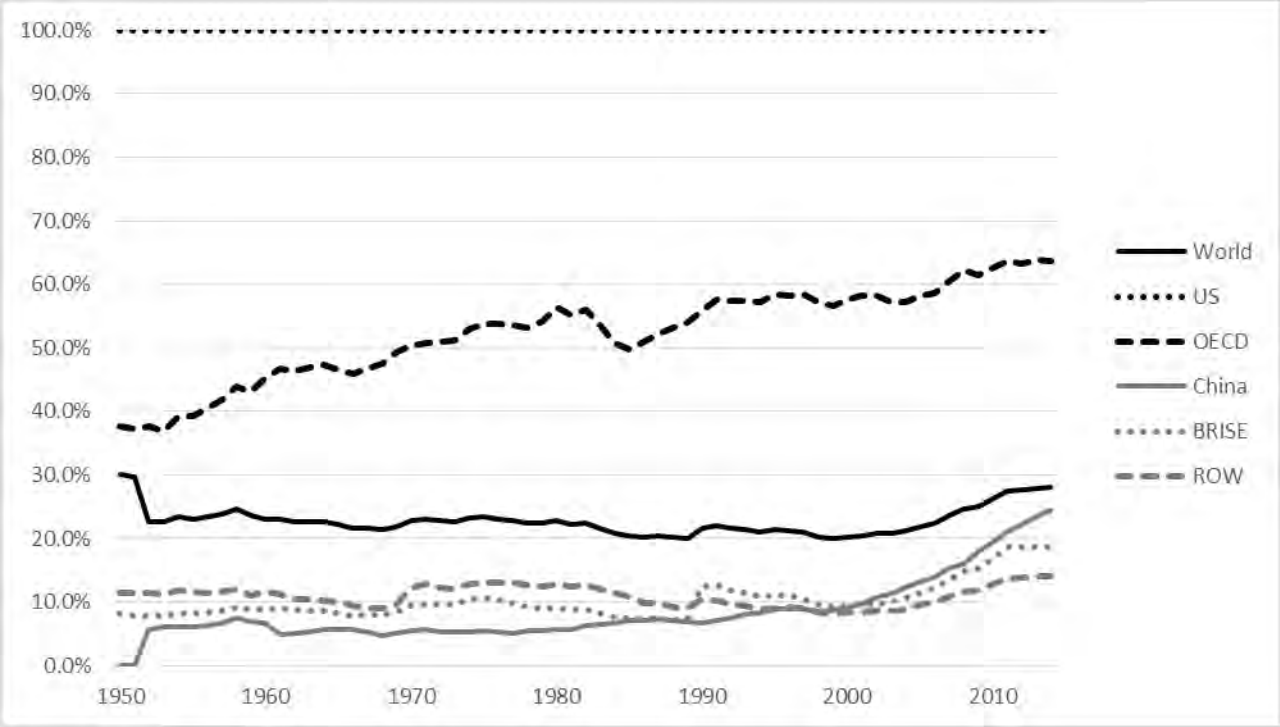
DISTRIBUTION OF WORLD GDP BY REGION, 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Figure 5

WORLD/REGIONAL REAL GDP PER CAPITA AS A PERCENTAGE OF U.S., 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

When considering the economic growth theories discussed above, what does this data suggest about economic growth prospects, both globally and regionally? Here are some observations and opinions:

- Aggregate global growth does not show evidence of a return to the bad old days before the era of growth. While global growth declined in the 1980s and 1990s, it has rebounded in the 2000s and 2010s. Noting that this data ends in 2014, the full decade of the 2010s will be different from what these data show.
- Global economic well-being continues to show strong growth, as measured by per capita GDP. After declining in the 1980s and 1990s, growth rates in the 2000s and 2010s are the highest seen in the period since 1950, exceeding 3 percent.
- Growth rates in the developed regions of the world have fallen steadily over this period, with global growth since 2000 driven by China and other developing nations. The U.S. and OECD shares of global GDP have been in steady decline.

A key difference between neoclassical and endogenous growth theory is that neoclassical models suggest convergence in per capita GDP as diminishing returns take hold in more developed economies, while endogenous growth models suggest continued divergence as prosperity breeds ever-greater productivity gains. These data indicate growth and convergence patterns more consistent with neoclassical theory, more so in the more recent years. These patterns seem to be consistent with an open global economy in which significant variation in economic well-being indicate inefficiency that can be wrung out of the system. During a closing

of the global economic system, one might expect a decrease in the growth rates of all regions—but especially in the less developed regions.

d. Potential Drivers of a Low-Growth Future

We have discussed the economic theories of growth and the history of growth. Now we turn our attention to potential headwinds to growth and how they are treated in the economic models. We begin by returning to our discussion of the drivers of growth within the economic growth models. This will provide a base when evaluating the drivers of low growth vis-à-vis the economic models.

Theoretical Drivers of Growth

Growth is the first derivative of production, so a growth model begins with a production function, and reviewing the production function helps in visualizing the drivers of growth. The following formula illustrates a two-factor production function that follows what is known as the Cobb-Douglas form, a common basis for the growth models:

$$GDP = TFP \times K^{\alpha} \times L^{\beta}$$

In this formula, production (GDP) can be thought of as the weighted average of the two factors of production—the value of capital (K) and the value of labor (L)—multiplied by their combined productivity (total factor productivity, or TFP). The exponents α and β are the geometric weighting factors (so they add up to one) capturing the relative importance of capital and labor, respectively—formally known as output elasticities.

So what does the production function tell us about the drivers of growth? An increase in any of K, L or TFP increases GDP, so growth drivers are the factors that increase these variables. The value of capital is a function of savings and depreciation rates. The value of labor is a function of the size and education of the workforce. TFP drives the return on capital and, depending on the model, may be an exogenous input item or may be a function of the other variables. So growth may be driven by an increase in the savings rate, a decrease in the depreciation rate (although this is assumed to be out of our control), an increase in the workforce or its level of education, or an increase to TFP.

We now move on to discuss potential real-world drivers of low growth, with an eye toward the ways they affect these theoretical drivers of growth.

Demographics

Population, and its component parts, plays an important part in economic growth. The economy, in aggregate, is not a fixed size; larger populations generate a bigger pie, with increased opportunities. Historically, the world has experienced a long period of population growth, with high fertility rates overcoming high mortality due to disease (especially) among children and short (relative to today) lifespans for those making it to adulthood. Life expectancy in 1900 was 46 years at birth for white rural males. This has increased to more than 76 years today, with expectations of a long life changing behaviors. Better sanitation; health care, including antibiotics and vaccines; and education (especially when extended to females) have all played a

role in reduced child mortality, leading to lesser need for large families to ensure some would survive. Tools to manage human reproduction have also allowed family size to be determined by choice. These changes allowed women to enter the workforce during the 20th century. The New Deal, introduced by Franklin Roosevelt during the global depression of the 1930s, created a safety net for Americans that now includes retirement, disability and food security.

The 20th century saw population migrate from rural farmers to urban manufacturers, increasing GDP. Today, the gig economy allows those who do not require personal interaction (e.g., writers, software developers) to operate from a rural platform. This could lead to unanticipated changes in GDP.

The OECD group of developed countries are typically aging, but each is unique. Many are watching Japan, the oldest of the group, to see what incentives and tools are successful, wondering if the economic malaise of the last generation was driven by demographics. So-called third-world countries are entering this phase as Asian and African countries expand their economies and make similar choices.

An aging population implies limited GDP growth, in part because an aging population is typically also a slow-growth population. An aging population may limit workforce growth even more than it limits total population growth, increasing the dependency ratio, as a result of workers retiring and leaving the labor pool, and may cause educational attainment to slow. An aging population may also introduce demand-side limits to growth, as retirees typically reduce consumption.

Aside from aging effects, as noted in Section III.a, 20th-century growth in the developed world was pushed along by the large-scale entry of women into the workforce. This will not recur, so relative to that period, the result will be a slowdown in growth. In developing nations, the labor force (male and female) is generally not fully utilized, so this effect may not constrain growth for some time to come.

Immigration is a wild card in this analysis. Although each immigrant adds to the population in one country while reducing it in another, economic migration allows workers to move to a region where there is more likely to be work, so it grows the world's GDP. Migrants look for economic opportunity and a safe place for their families to live. Some leave their homelands voluntarily, but many are forced out by regional conflicts or resource depletion. Will aging populations welcome them as hard workers, or will they seek to keep out those who are culturally different? Japan seems to be choosing to develop robotic companions rather than allow external service workers. The results will include unintended consequences of the actions chosen.

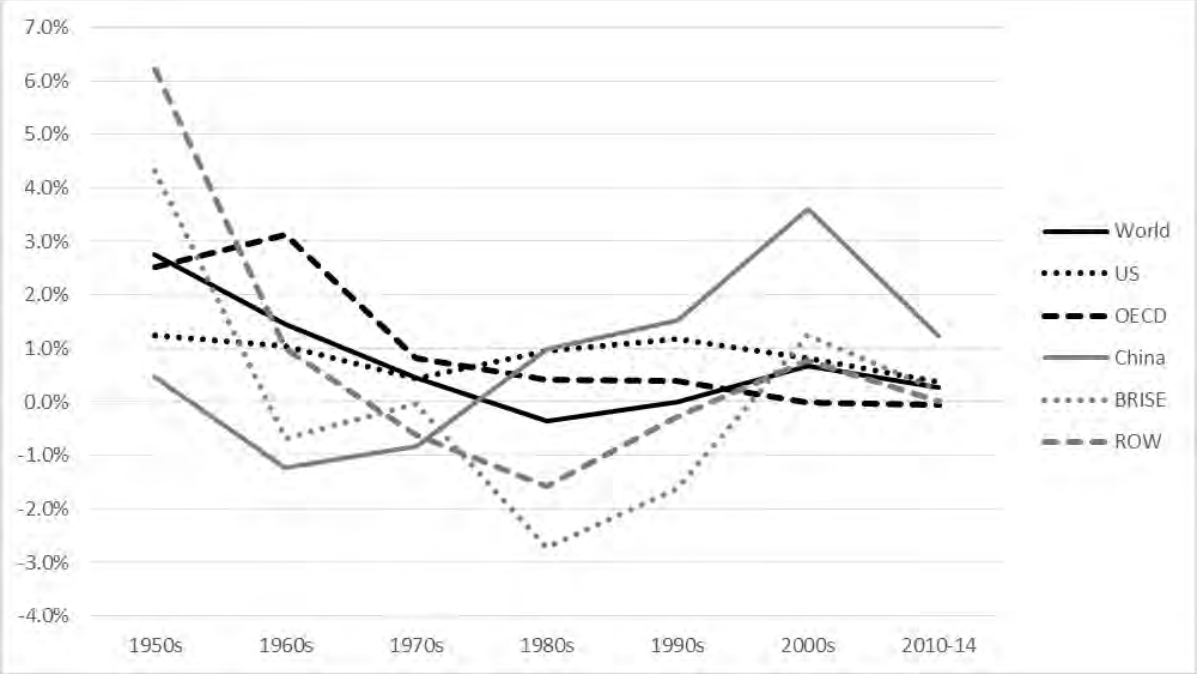
Productivity and Technology

Technology-driven productivity improvement has been considered to be the single most important factor driving growth and is the ultimate determinant of growth in the economic models. TFP cannot be measured directly, and computed values vary due to variations in data sources and construction methods, both temporally and regionally. Figure 6 shows TFP growth rates by region since 1950, based on Penn World Table national accounts TFP data, weighted by GDP presented on the same basis. Although the regions do not demonstrate a stable trend, the worldwide total shows TFP growth rates below 1 percent since the 1970s, including negative growth in the 1980s driven by the BRISE and ROW regions. Only China shows TFP growth above 1 percent in recent years, although only in the 2000s might its TFP growth be called

robust. The data indicate that recent growth in China, BRISE and ROW has been driven much more by population growth, increases in the human capital index and new investment rather than TFP.

Figure 6

WORLD/REGIONAL TFP ANNUALIZED GROWTH BY DECADE, 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Consistent with per capita GDP, a productivity gap exists between the U.S. and the rest of the world. Table 2 shows per capita GDP and TFP as a percentage of the U.S. for the regions of the world. The TFP gap is smaller but has shown less convergence over this period. In particular, China's TFP has declined relative to the U.S. even while its per capita GDP has more than tripled, because its growth has been fueled more by growth in the value of capital (fueled by debt) and growth in human capital. This data suggests that, although the productivity gap between the U.S. and the developing world has not closed substantially, closing this gap could provide a future boost to growth prospects in these regions.

Table 2

REGIONAL/WORLD REAL GDP PER CAPITA AND TFP, PERCENTAGE OF U.S., 1950-1959 AND 2011-2014

	Real GDP per Capita % of U.S.			TFP % of U.S.		
Region	1950-1959	2011-2014	% Chg	1950-1959	2011-2014	% Chg
U.S.	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
OECD	39.7%	63.4%	159.7%	63.6%	80.3%	126.2%
China	6.4%	22.1%	345.0%	48.9%	44.6%	91.4%
BRISE	8.3%	18.3%	221.9%	43.8%	56.1%	128.2%
ROW	11.5%	13.7%	119.1%	32.4%	51.0%	157.5%
World	24.7%	27.4%	111.2%	72.0%	68.3%	94.9%

Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Robert Gordon, discussed in Section III.a, has cited reduced TFP growth as a key headwind to growth in the U.S. As computed by Gordon, TFP growth grew rapidly in the first half of the 20th century, beginning the century below 0.5 percent per year and peaking at nearly 3.5 percent per year in the 1940s, only to decline rapidly to a rate well below 1 percent for each decade since the 1970s (Gordon, 2012, p. 547). In Gordon's analysis, a unique set of circumstances led to the dramatic increases in TFP, and the correspondent increases in economic well-being, in the middle of the century. These circumstances begin with the full integration of transformative inventions from the late 19th and early 20th centuries—the foremost being motor vehicles, electricity and lighting, refrigeration and air conditioning—that Gordon calls the Second Industrial Revolution. However, Gordon also cites key factors related to the Great Depression and World War II. In his analysis, the protectionist trade policies enacted early in the 1930s and sweeping labor reforms later in the 1930s led to significant real wage gains, which incentivized businesses to invest in automation and other innovation. Even more important in Gordon's telling, the war effort in the 1940s set up the prosperous era that followed in several key ways: i) the U.S. government made tremendous investments in private capital for wartime production, which was then available for domestic production after the war; ii) to meet the requirements of wartime production required a previously unheard-of degree of innovation—both technological and organizational—with the same methods applied to domestic production after the war; and iii) consumption rationing resulted in tremendous pent-up demand after the war ended. Wartime conditions and willingness to sacrifice by individuals, companies and unions were key to some of these innovations. Some of these conditions are not always present. The Second Industrial Revolution set up the tremendous growth in TFP through the middle of the century, but the Great Depression and World War II provided real and permanent boosts as well.

We are now in what Gordon calls the Third Industrial Revolution—the information revolution—which can be viewed as beginning in the 1970s. In framing future prospects for TFP growth, a fundamental question is whether the effects of the Third Industrial Revolution will be as great as the effects of the Second Industrial Revolution. Empirically, Gordon's numbers indicate that the reality of the information revolution has been lackluster. Qualitatively, he argues that the information revolution's most important impact to TFP occurred before 2005 and that the ongoing impact will be neither broad enough nor transformational enough to drive TFP growth nearly equal to that achieved over the period 1920-1970. Combine with that the unique contributions he attributes to the Great Depression and World War II, and the picture is of anemic growth in TFP by historical standards. Time will tell whether he is right or wrong.

An additional factor not addressed by Gordon that could limit future productivity growth is the link between TFP and the price and consumption of energy. Broadly, productivity improvement relies on the development and improvement of tools to aid in production. Almost without exception, energy is required for the production and use of these tools (Tverberg, 2016). There is no question that the availability of high-volume, low-cost energy—through fossil fuels—has enabled the historical development and use of tools that increase productivity. At a time when future growth in energy use might be limited either voluntarily by society (in response to climate change) or involuntarily (in response to decreasing supply and increasing extraction costs), an important question is whether economic growth can be decoupled from growth in energy use, as some economists have argued. In 2004, David I. Stern and Cutler J. Cleveland studied the existing literature and found that while the energy intensiveness of production had declined historically, this decline was largely "explained by a shift to higher quality fuels," concluding that "energy use and output are tightly coupled with energy availability playing a key role in enabling growth" and that "prospects for further large reductions in energy intensity seem limited" (Stern and Cleveland, 2004). As stated succinctly by Gail Tverberg, an actuary who has studied resource issues extensively, "a decrease in energy consumption by the business sector can be expected to lead to falling productivity growth" (Tverberg, 2016).

In summary, productivity growth has slowed in recent years, in both the developed and developing worlds. The literature we have reviewed offers two reasons why this slowdown in productivity growth could be permanent. First, we may have reached a point of diminishing returns on technological development, where future innovation—while high in gee-whiz appeal—will be less impactful to GDP than the innovations of the 19th and 20th centuries. Second, any limitations in energy use or increases in energy costs may limit productivity growth or even lead to productivity decline.

We note that many consider these views to be overly pessimistic. The first two industrial revolutions continued to improve productivity decades after the initial inventions (e.g., the first steam engine was created in 1698 to pump water out of coal mines, and it was 200 years later before cars and tractors began to be commonly used). In a similar way, many believe that the most significant impact of the information revolution is yet to come.

In addition, the conventional wisdom is that alternative energy sources like wind or solar that do not pollute the air could provide a pivot that allows economies to grow even as populations stabilize or peak.

Environmental Drivers

Climate change: Climate change will affect growth directly, both through the impact of the changed climate and through actions taken to mitigate and adapt to climate change. Some effects discussed in the literature include the erosion of productivity. Agriculture on average will be less productive in a changed environment, and natural disasters are expected to regularly disrupt production. In addition, consumption and productive investment will be crowded out by investment in nonproductive activities (i.e., activities that do not increase the economy's productive capacity), such as rebuilding capital destroyed by natural disasters and other effects of climate change, replacement of fossil fuel infrastructure with renewable energy infrastructure, other investments in climate adaptation and mitigation, and investment to replace economic services provided by the natural environment. Finally, energy supplies may be constrained if

fossil fuels are scaled back to address climate change and renewable capacity cannot be expanded quickly enough to fill the gap.

As discussed in Section III.b, climate change mitigation and adaptation might generate significant activity, but much of that activity—building floodwalls, relocating cities inundated by rising seas—will stave off declines in well-being rather than increase wealth or well-being. Geoengineering experiments, such as placing mirrors around the planet to deflect sunlight or launching particulates into the atmosphere to replicate the results of a volcanic eruption, would have unexpected consequences and be much more costly than solutions that lower greenhouse gases directly by reducing greenhouse emissions (Mann and Towes, 2016). Mitigation and adaptation techniques that reduce premium increases will allow insurers to provide early warning of climate change effects and align incentives with insurers. Estimates are that an annual investment of less than 1 percent of GDP would be necessary to mitigate the impact of global carbon dioxide, if we began today (Ritchie, 2017).

Resource constraints: We have discussed the historical lack of treatment of natural resources in economic growth models as well as recent efforts to incorporate resources into those models. We have also discussed the link between energy resources and GDP growth. We now turn our attention to resource constraints as a potential driver for reduced growth.

Concerns with limits in natural resources have a long and fraught history. With respect to nonrenewable resources such as fossil fuels and mineral resources, discovery of new sources and technological advances in extraction and processing have generally far outstripped the stress on existing supplies. Indeed, a 2016 report by U.S. Geological Survey staff argues that with respect to mineral resources, “many studies erroneously forecast impending peak production or exhaustion because they confuse reserves with ‘all there is’” (Meinert et al., 2016). This report points out that resources do not suddenly run out, à la Dr. Seuss’ truffula trees but that a decline in a resource would lead to price increases, adjustments in both supply and demand, and ultimately a shift to a substitute. In the view of these authors, “the main resource issue for the future likely will be the development of capacity to discover and produce additional resources,” and “at a global level, it is not clear that society is making the investments in education, research and development to ensure that these mineral resources will be available for future generations.”

In another scenario, global warming allows development of areas previously inaccessible in the far north and south. This creates a spiral where increased carbon dioxide in the atmosphere allows more fossil fuels to be extracted, but also creates dead zones on land around the equator.

Not all authors are as sanguine about the ability to ultimately meet mineral and energy resource needs through new discovery and substitution. Ted Trainer of UNSW (University of New South Wales) Sydney describes the issue thus: “If the 9 billion people we will have on earth within about 50 years were to use resources at the per capita rate of the rich countries, annual resource production would have to be about 8 times as great as it is now” (Trainer, 2011). With respect to energy resources, Trainer argues that “wind, photovoltaic, solar thermal and biomass sources, along with nuclear energy and geo-sequestration of carbon could not be combined to provide sufficient energy to sustain affluent societies while keeping greenhouse gas emissions below safe levels” (Trainer, 2008).

Others, like Tverberg, argue that the cost of developing additional capacity itself has an insidious nature that will limit growth: “What we are experiencing is diminishing marginal returns with respect to oil supply” (Tverberg, 2016). Fossil fuel energy has fueled productivity growth precisely because it was cheap. With increased prices and without cheaper energy alternatives, energy cannot be an engine for continued growth.

Moreover, what of renewable resources like timber or fish stocks? They are renewable only to the extent of their productive capacity. The harvesting of many resources currently exceeds their productive capacity now and will exceed that capacity even more under increased demand. Environmental degradation also tends to reduce the productive capacity of renewable resources.

Environmental degradation and ecosystem destruction: Ecosystems are complex networks, interacting and evolving over time. Stability, when changes are referred to in increments of thousands or even millions of years, is the key to maintaining, and growing, biodiversity. When discontinuities occur, plants and animals are unable to adapt quickly enough to survive. We are in such a period now. Previously, five times in history, mass extinctions have occurred that changed the future of the planet. We now live in the Anthropocene epoch, reflecting human impact on the earth. Climate change—driven primarily by increases in carbon dioxide, spillover effects of expanding the human footprint and the aggregate buildup of pollution like plastics—all could slow economic growth materially. If this happens fast enough, the result could be apocalyptic, leading to scenarios depicted in the *Mad Max* movie franchise. Even if the result is not catastrophic, with biodiversity and food supplies devastated, the cost to develop technologies to substitute for the earth’s resources and for economic services provided by the natural environment could be tremendous.

Steady-state/degrowth economic policies: While not considered mainstream, increasingly there are voices arguing that the only rational responses to environmental limits are steady state or degrowth policies, economic policies intended to restrain rather than promote GDP growth. Steady-state economic policy inverts the standard view of economic growth, arguing that the earth is essentially in a steady state—with inflows and outflows of radiant energy roughly equal and with negligible material inflows and outflows from space—and that economic activity should attempt to maximize welfare within limits of sustainability.

The goal of a steady-state economy is not to maximize production, or even to optimize growth in the sense of optimal growth theory, but to maximize utility or well-being given environmental constraints. As stated by Herman Daly, one of the earliest and most prominent advocates of steady-state policies, a steady-state economy (SSE) is not a static economy but a dynamic economy where development is in the interest of making the most of the economy’s throughput, not in the interest of increasing that throughput. Under this view, the current level of growth in high-income countries is “noneconomic,” resulting in a net decrease in well-being because of its environmental costs (Daly, 2008).

Daly describes the characteristics of an SSE as he sees it—controls on physical inputs (possibly through cap-and-trade arrangements or depletion taxes), poverty reduction through redistribution, elimination of free trade with non-SSE countries, a stable (and, therefore, aging) population, longer-lived goods, increased information sharing (and reduced intellectual property rights), low interest rates (and a reduction in debt and the associated financial infrastructure) and an environmental tax system—to name several. According to Daly, growth should continue

in poor countries to increase the welfare of their populations and rich countries should reduce their growth to free up resources.

The prospects for widespread adoption of steady-state policies appear remote at the current time. Without exception, leaders and policymakers embrace the conventional wisdom as embodied by the following: “Historically nothing has worked better than economic growth in enabling societies to improve the life chances of their members, including those at the very bottom” (Rodrik, 2007). While opinions could change in response to climate change and other environmental issues, it appears more likely that leaders and policymakers will continue to strive for growth, whether or not that striving is fruitful. This is especially true in democracies, where voters often have a short-term focus.

The 20th century saw progress in addressing several environmental issues that could be unwound in the 21st by biological evolution.

Antimicrobial “solutions” have extended lifespans and allowed elective surgeries to grow GDP. Bacteria are evolving, building up resistance to currently available antibiotics. Many facets of everyday life (e.g., youth sports, working or going to school while sick) would be impacted.

The Green Revolution industrialized agriculture while limiting biodiversity through monofarming, with each region utilizing high-yielding varieties to optimize results. Agricultural diseases continue to evolve, and a misstep could lead to widespread famine (Mann, 2018).

Debt Constraints

The International Monetary Fund (IMF) has reported that global debt reached a historic peak of $164 trillion in 2016 (latest available data), or 225 percent of global GDP and 12 percent higher than the debt load leading up to the 2008 financial crisis (IMF Fiscal Monitor: Capitalizing on Good Times, 2018). This includes nonfinancial private debt at approximately 150 percent of GDP and government debt at approximately 75 percent, continuing an upward trend in debt/GDP extending back to at least the early 1950s, interrupted only by the financial crisis. Putting aside the risk of a debt crisis to be discussed later, increasing debt/GDP could constrain growth in two significant ways. First, if the net cost of debt service rises faster than GDP, investment and consumption may be crowded out by the cost of debt service. Second, both borrowers and lenders consider economic growth prospects in determining borrowing capacity, and increased borrowing that does not result in commensurate growth will eventually lead to constraints in future borrowing capacity and, therefore, investment.

Debt cuts both ways, and unproductive borrowing must ultimately result in some constraint on economic growth. Reinhart and Rogoff, in a paper following up their 2009 book *This Time Is Different*, have discussed the reduced benefit of additional borrowing on GDP growth once the debt to GDP ratio exceeds 90 percent (Reinhart and Rogoff, 2011).

Consumer Optimism and Demand

As noted in Section III.b, economic growth models are production-side models that assume limitless demand. Consumers drive the economy, and they are not the rational beings of the economic models. Sometimes they are confident, and sometimes they are depressed. This is inconsistent with monetary policy.

The velocity of money (VM) reflects how often money is used to buy something, so a high value is consistent with lots of spending and a low value reveals consumers who are holding on to their money for a rainy day. One interpretation is that a low velocity of money occurs when consumers fear for their own financial situation, while a high velocity of money occurs when consumers fear for the currency's financial situation and are anxious to buy material goods before high inflation or devaluation reduces the value of their money. As can be seen from the formula, a low velocity of money implies low economic growth.

$P \times Y = VM \times M$

Where

P is the price level

Y is real GDP

VM is the velocity of money constant

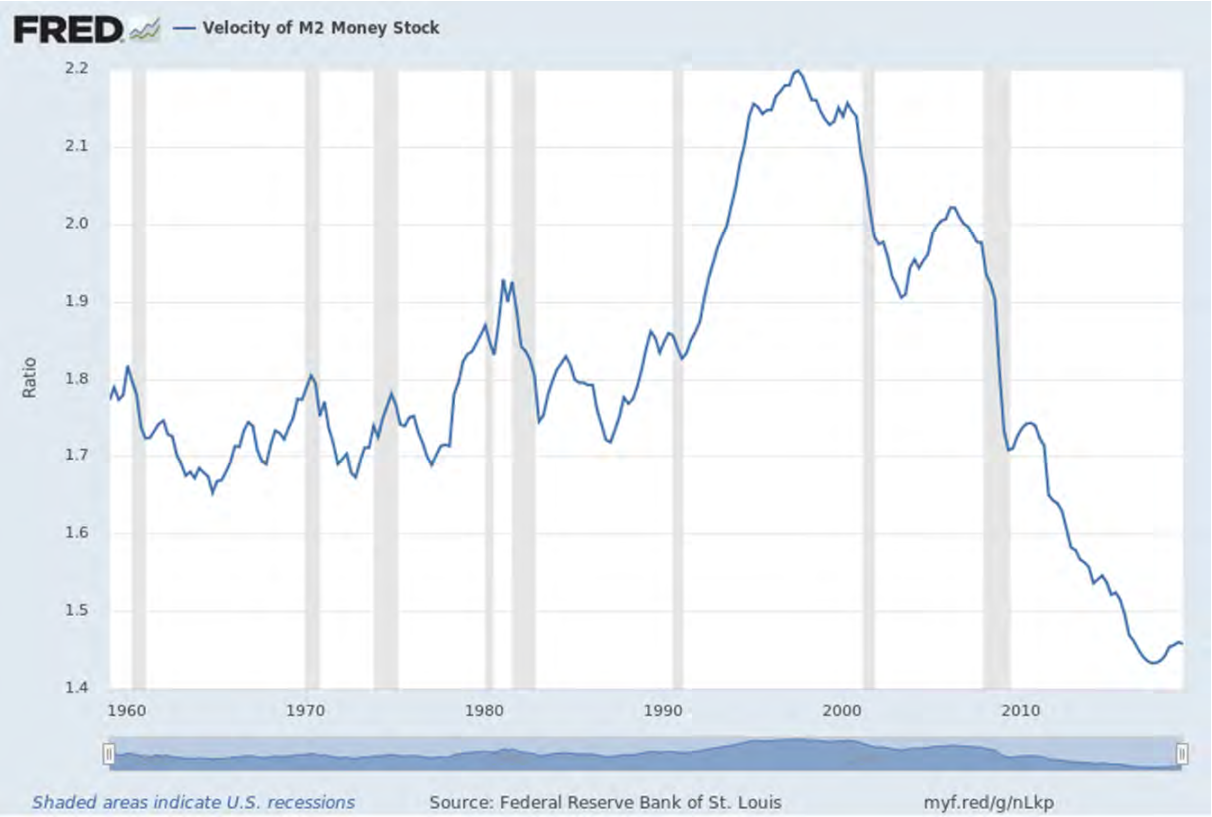
M is the supply of money

The theory behind the velocity of money assumes that it is constant. If this assumption is incorrect, such that increases in the money supply are offset by decreases in the velocity of money, the effectiveness of monetary stimulus suffers. This has been referred to as "pushing on a string" since neither inflation (price level) nor real GDP increases if money "dropped from helicopters" is not spent.

Monetarists believe that increasing the money supply will automatically lead to either inflation or growth in real GDP. However, the velocity of money has not been constant, as shown in Figure 7, which charts U.S. velocity of money since 1959. After decades of holding generally in a range from 1.7 to 1.9, it has since been as high as 2.2 and as low as 1.4. The high readings were in the mid-1990s, and only recently did the velocity of money bounce off its low of 1.426.

Figure 7

U.S. VELOCITY OF MONEY, 1959-2018



Source: Federal Reserve Bank of St. Louis, Velocity of M2 Money Stock [M2V], retrieved from FRED, Federal Reserve Bank of St. Louis, *https://fred.stlouisfed.org/series/M2V*, April 29, 2019.

While consumer optimism is cyclical, long-term shifts in the velocity of money are possible as well. Such shifts could relate to longer-term changes in opinions regarding economic prospects. They could also relate to a values-based move away from consumerism, a possible response to environmental factors.

Helping grow consumer optimism during the 20th century were increasing levels of credit granted for middle-income earners to purchase homes, especially returning veterans following World War II (Rothstein, 2017). Most of the population now has access to credit, at least in the U.S., and this spur to growth is not repeatable.

Cultural Factors

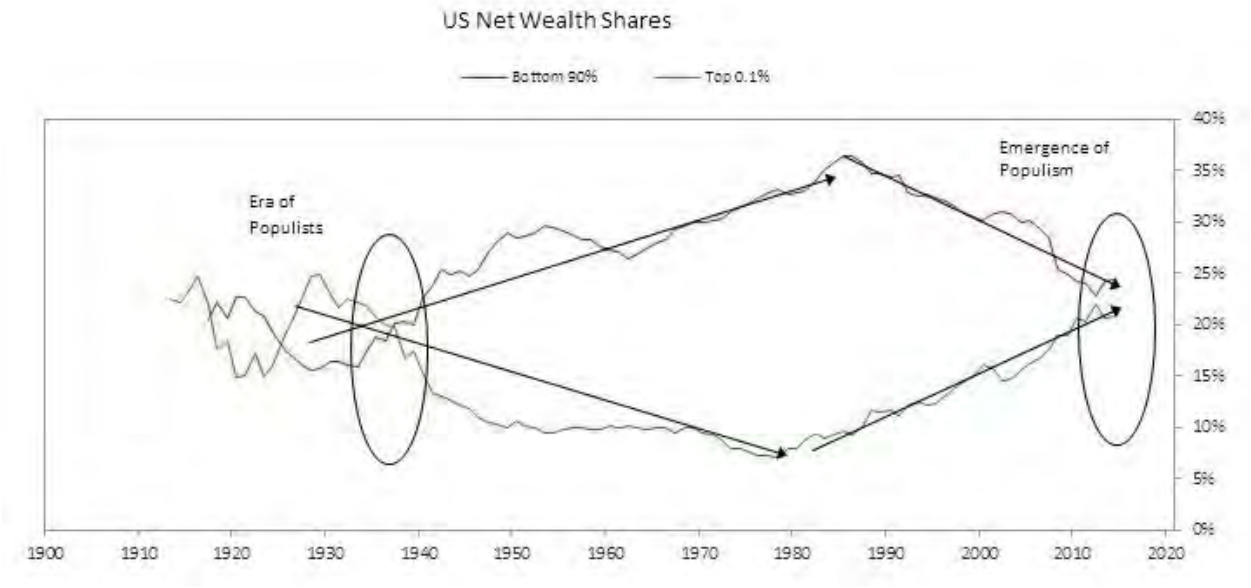
Several other cultural factors could influence future growth in a negative way, either regionally or globally. Two factors highlighted here were cited by Gordon as headwinds to U.S. growth: inequality and education.

The rise in inequality has received a great deal of attention of late, including in the widely praised and widely criticized *Capital in the 21st Century* by Thomas A. Piketty. Gordon's treatment is based on analysis performed by Piketty and Emmanuel Saez. Gordon shows that for the period 1917-1948, U.S. real income per capita grew much more rapidly for the bottom 90

percent than for the top 10 percent—1.5 percent/year versus 0.6 percent, for an average of 1.1 percent/year over the period. Gordon calls this “the great compression,” arguing that it set the stage for broad rapid growth in the period 1948-1972—2.6 percent/year and nearly equal for the two groups. For the period 1972-2013, Gordon measures a 0.2 percent decline in real income for the bottom 90 percent compared with a 1.4 percent increase for the top 10 percent, for an average of 0.5 percent, setting the stage for the reverse of the rapid growth of the 1948-1972 period. This cycle is readily apparent in Figure 8, a chart developed by Ray Dalio to describe the phenomenon.

Figure 8

U.S. NET WEALTH SHARES, 1910-2018 (DALIO, 2017)

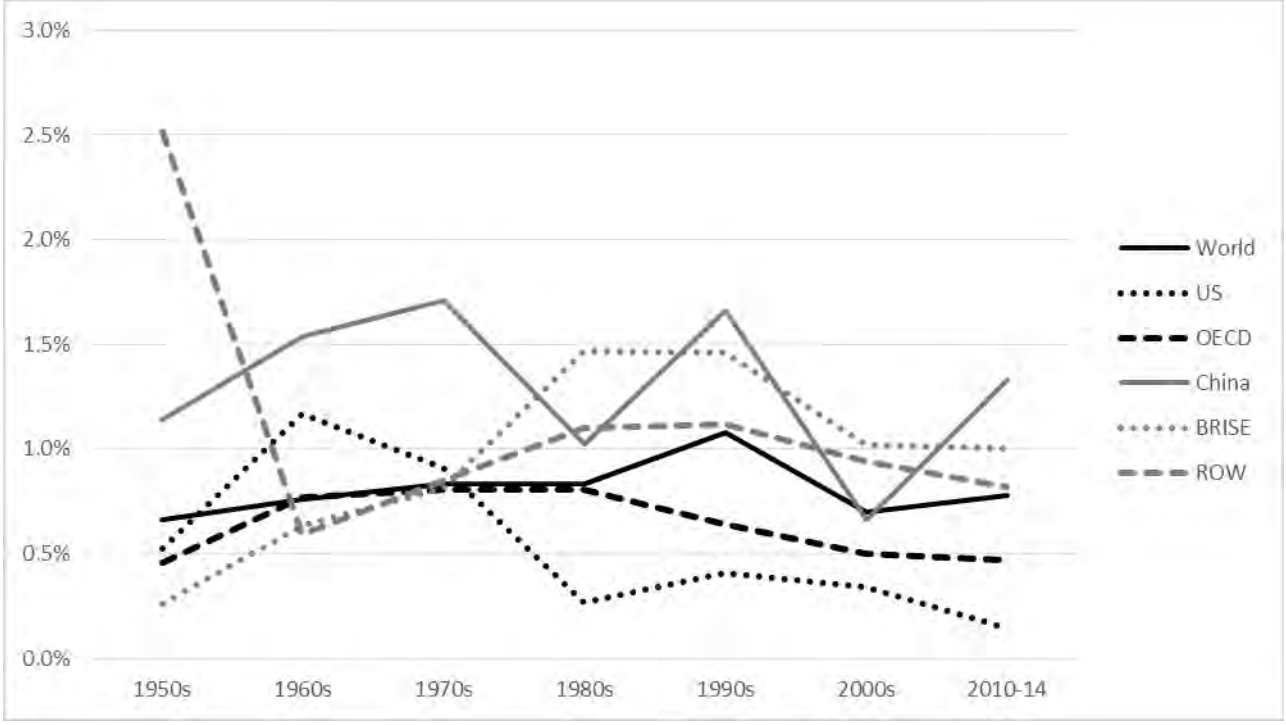


How might inequality lead to reduced growth? Numerous studies have investigated the relationship between inequality and economic growth, generally finding that inequality negatively influences growth. Numerous causal factors have been proposed, including increased social and political instability (Temple, 1999), reduced workforce productivity (Baumol, 2007) and reduced aggregate demand (Stiglitz, 2009). Less conclusive have been studies of the impact of growth on inequality.

With respect to education, Figure 9 shows the trend of growth rates in human capital in the regions of the world. Worldwide, the rate of change has remained stable. By region, we see a pattern of declining growth in the developed world and higher growth rates in the developing world than in the developed world. As human capital is expected to contribute directly to GDP through worker productivity, this pattern would be expected to contribute to declining growth rates in the developed world and a narrowing of the gap between the developed and developing worlds.

Figure 9

WORLD/REGIONAL HUMAN CAPITAL GROWTH BY DECADE, 1950-2014



Source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

Interaction of Drivers

In this part of the paper, we have discussed drivers individually, operating in silos, but despite mostly being independent of each other, many or all could occur simultaneously. One aspect of interaction is how their combined effects relate to their individual effects. Another is causal effects of one driver on another. While a fascinating topic, analyzing these interactions in any level of detail is outside the scope of this paper.

Risks do not occur in a vacuum, and they interact in ways that are unexpected, quick and with high impact. A low-growth scenario could interact with demographics, regional conflicts or climate change. An already-bad scenario could spiral out of control due to feedback loops. Many risks interact using nonlinear and dynamic functions. Higher-order interactions that are not always apparent in advance will tend to have unintended consequences. Geopolitical, societal, environmental and technological risks all end up impacting the financial ecosystem, sometimes directly but often in indirect ways.

Many higher-order interactions between risks are Boolean. They either happen or not; there is no probabilistic distribution of potential outcomes. This can seem to accelerate the severity and velocity (how quickly they develop) of concurrent and sequential events. Some may be systemic, using leverage, liquidity needs and the layers of a complex adaptive system to inflict damage on the financial system.

Much of the outsized GDP growth since World War II has been driven by increased trade and letting down barriers. Movement toward free trade has made it easier to develop supply chains

around the world and increased educational opportunities for many, especially women and minorities. A change to that trend will unwind the gains made over the past 70 years since the Marshall Plan was enacted. In addition to the factors we have discussed, cyberwarfare could contribute to that trend, with fears of technological damage to infrastructure resembling the nuclear threat of the Cold War. Other surprises could result from changing assumption trends, such as potential changes to mortality improvement trends, which will be discussed in Section V.

e. Government/Public Policy Cause and Effect

Government fiscal and monetary policies are generally intended to be countercyclical to growth, aiming to maintain growth in a just-right Goldilocks range. In theory, this just-right range is a long-run growth target corresponding to the optimal growth rate discussed earlier. Variations in the growth rate are supposed to represent business cycle deviation from the long-run rate, and fiscal and monetary policy responses are designed for cyclical low growth, stimulating growth to return to its long-term rate. A problem comes if the government growth target differs significantly from the optimal long-term growth rate, or even the possible long-term growth rate. This paper posits reasons why either the optimal long-term future growth rate or the possible long-term growth is lower than policymakers have supposed.

Among the group of developed countries that belong to the OECD, all have positive government debt to GDP ratios, and many of the larger countries (e.g., United States, Japan, Canada, United Kingdom and many members of the European Union) had ratios above 100 percent in 2015 (Irwin, 2016). Governments seem to believe that fiscal policies are painless and that monetary policy can manage the economy all by itself. This leaves elected politicians free to promise, and unelected central bankers accountable for the results. This is ineffective, as monetary policy works best when budgets are close to breakeven. This data includes only (federal) government debt, so it does not include state and municipal debt; private debt; or off-balance sheet debt, like defined benefit pension plans and Social Security. Politicians recognize that the least painful way to reduce debt is to grow your way out of it, leaving debt steady but increasing GDP. This is very hard in a low-growth environment that may coincide with low nominal interest rates.

Fiscal Policy

Several fiscal policy tools are available to encourage or discourage GDP growth. They provide cash flow to the economy when it is needed and pull it back during prosperous times. Some are built in and are countercyclical stabilizers, such as unemployment benefits and tax revenue. Intentional fiscal policy measures, often based on Keynesian economic theory, rely on changes in government net payments, spending increases or tax reductions to stimulate growth. Infrastructure spending, valued for its ability to be a future growth multiplier, is often targeted. While there are limits to its effectiveness, Keynesian spending creates jobs directly through projects and indirectly through supporting them. When practiced to excess, stimulus leads to inflation or currency devaluation and possibly to a banking crisis.

The limitations come in as aggregate public debt grows. Each dollar of debt is less effective than the one preceding it. As debt levels grow, some suggest that austerity measures that move toward balanced budgets help clear the system of excesses and allow the capitalistic forces of

creative destruction to work. Both of these approaches differ from the Austrian School of Economics, which would rely on individual incentives to manage an economic ecosystem with hands off.

Sovereign wealth funds can also be used in a stimulus role, investing in infrastructure or supporting important industries.

Many governments have backed themselves into a corner with respect to fiscal and monetary policy. Their attempts to stimulate, and reluctance to slow down, have left their economies susceptible to disruptions. The solutions that balance social welfare with fiscal sustainability are becoming tougher to implement, especially for politicians who face elections. Nevertheless, tough choices are necessary. A key choice involves entitlement spending, which—while not necessarily used as a tool for fiscal stimulus—is a key element of fiscal sustainability through creation of a safety net.

A prosperous society can afford to support those less fortunate. Incentives that balance entitlements so they do not come to dominate, and negatively influence, the economy are hard to build. Off-balance sheet debt from Social Security and Medicare are no less real, but these benefits are created legislatively. There are no legal guarantees to them, and they have been altered in the past. Each year that no change is made will make the ultimate modifications more stressful to those impacted. The American Academy of Actuaries developed a game to estimate the impact of increasing the retirement age, reducing cost-of-living adjustments, reducing benefits (for some or all), raising payroll taxes (for some or all), taxing benefits or taxing health care premiums. While most of the discussion revolves around raising the retirement age, according to the website, 88 percent of the shortfall could be accomplished by removing the cap from the earnings subject to tax.[7] Enacting such changes would stabilize the future economy and lessen fiscal pressures.

Monetary Policy

Monetary policy, generally set by central banks, aims to affect the money supply by guiding the cost of borrowing. The classic tool of monetary policy is short-term interest rates, and the typical response to low growth is to reduce interest rates and stimulate borrowing. This leads to increased business investment and consumer spending, which leads to growth in GDP.

Internationally, the monetary policies of different countries interact through currency markets. Exchange rates are flexible, subject to the laws of supply and demand. A low-growth environment may influence these markets, although it is a relative game. For one currency to weaken, another must strengthen. Lower relative growth reduces demand for the currency.

Central banks from many countries have evolved new methods of monetary policy over the past 20 years, adding tools to their arsenal. As they lowered rates to zero, and sometimes beyond zero, alternative methods included buying assets in an effort to stimulate their economies. Initially these were troubled assets, then government-issued securities, and now some central banks hold publicly traded securities of private companies as passive investors. By increasing

[7] The Social Security Game. *American Academy of Actuaries*, http://socialsecuritygame.actuary.org/ (accessed March 22, 2019).

demand for debt securities, the banks sought to further reduce interest rates and stimulate borrowing.

The central banks' investment activity can be viewed as passive from the standpoint of market forces, because their buying and selling does not respond to market prices. Concerns have arisen about the reaction of markets to these actions. Supply and demand are impacted, so when passive investors—as price takers—are buying, one would expect the price of the asset to increase due to increased demand and stagnant supply. This has likely helped fuel the rise in asset prices during the recent, long, bull rally. The opposite should occur when passive investors are selling, leaving it unclear who the marginal buyer is and whether a feedback loop could lead to increased volatility and market drops. When a passive investor needs to sell, who provides the liquidity (Rudolph, 2018)? A possible result is discontinuities in market prices. While unrelated to monetary policy, we note that the same concern has been raised with respect to index investing, especially as higher percentages of total assets are managed in this way.

Our discussion of government policy so far has focused on fiscal economic theory, associated with John Maynard Keynes, and standard monetary policy, associated with Milton Friedman. Modern Monetary Theory (MMT) is not new but has recently received favorable publicity from a few economists and a variety of politicians. It argues that deficits do not matter to a sovereign government and that unlimited debt does not run the risk of bankruptcy. It is obvious why politicians would like this theory, as it absolves them of blame for anything they do. How a currency would maintain the confidence of its users, even if its focus is on inflation and unemployment, is unclear. Proponents argue that taxation will keep inflation in check through incentives, but it is unclear that politicians controlling the purse strings would view this as a constraint. As discussed above, Reinhart and Rogoff have found reduced benefits of additional borrowing on GDP growth once the debt to GDP ratio exceeds 90 percent (Reinhart and Rogoff, 2011). Common among economists is the thought that higher debt loads increase an entity's credit risk and make it more likely to default.

MMT has been embraced by some U.S. Democratic politicians from the progressive left who think it is a magic bullet that will allow them to implement new programs (e.g., addressing health care, inequality, climate change) with no fiscal accountability. Republicans have also overseen growing deficits in the U.S. and act at times as if they believe either MMT or an abdication philosophy that managing the economy is the responsibility of the Federal Reserve. While these positions and policies may be popular in the short term, if such policies have unintended adverse effects, voters are unlikely to support the party that brings them hyperinflation. At some point, debt needs to rebalance, or control of the currency will be lost. As the world reserve currency, the United States has been able to continue deficit spending, but just as in the 1960s, spending on both guns and butter cannot continue without repercussions.

Feedback Loops and Unintended Consequences

As stated above, the standard stimulative fiscal and monetary policy responses are intended to address cyclical low growth. So what might their impact be if low growth is not cyclical but structural? Asked another way, what might be the impact if the policymakers' growth target is too high? Both fiscal and monetary policy tools for managing growth operate through the management of debt. Monetary policy attempts to adjust the cost and supply of private debt, while fiscal policy adjusts the accumulation of government debt, encouraging the accumulation

of debt when growth is too low and discouraging it when growth is too high. Through this lens, it is clear that if the long-term growth target is wrong, these policies will ultimately become pro-cyclical rather than countercyclical (mitigating). If policymakers target a growth rate that is too high, the result will instead be an unsustainable debt load that causes reduced growth. Debt levels build in response to the stimulus measures, but the economy does not grow enough to pay the debt costs. Growth targets that are a little bit too high might lead to stagnation, while growth targets that are a lot too high may lead to increased growth for a while, followed by a crash—a debt or inflation crisis. Reinhart and Rogoff (2009) have written extensively about the role of debt in financial crises of various types.

If recent experience is a guide, the failure of stimulus policies in the face of persistent low growth would likely cause policymakers to double down on those policies—creative central bank stimulus programs, tax cuts and spending programs increasing government deficits—further exacerbating the debt load. Governments appear to have many tools they can use to manage the economy centrally, but only as long as the confidence in their management endures. Once confidence is shattered, the systemic risk becomes obvious.

If, as we argue below, structural low growth forced a consequential reduction in debt, a significant portion would likely occur through default. For government debt, default can be direct, or indirect, through inflation/currency devaluation. Although not always the case, it is typical for governments to default on external debt and inflate away domestic debt (Reinhart, Rogoff, 2009). It is likely that inflation crises, including inflation resulting from intentional currency devaluation, would be characteristic of a low-growth world. The combination of inflation and low growth defines stagflation.

Countries may also consciously devalue their currency for trade advantage, usually supporting this by strategically increasing supply (effectively printing money). There are times when many countries attempt to stimulate exports by lowering rates or reducing their currency's value, but this works only on a relative basis. A currency war erupts during a fight to have the least valuable currency. There are no winners (Rickards 2011). Currency wars could be a common feature of a low-growth world, with the currency devaluation simultaneously devaluing debt and providing trading advantages. Winning a currency war, however, could be difficult. As governments attempt to stimulate their economies, they could go too far and lose control of their currency. If demand for a currency falls far enough, this is reflected by a rise in interest rates. If a country loses control of its currency, it results in inflation or hyperinflation. It could also have a banking crisis, with similar results.

Businesses and individuals do not have the option to inflate away their debt, although one side effect of an inflationary spiral is that it would directly inflate away business and personal debt as well as government debt. Absent an inflation crisis, a banking crisis might result as businesses and individuals default on their unsustainable debt loads.

It is critical for policymakers to understand all the drivers of growth, including those not captured in the standard economic models, and to set growth targets and expectations accordingly. If a low-growth future is on the horizon, these targets, and the policies put in place to achieve them, may well determine whether society collapses or is able to adapt to that future. To date, it appears that attention to many of these factors has been relegated to the fringes, with institutions and policymakers not seriously considering their risks. The most significant risk, to insurance risk managers and to the world as a whole, is the risk of willful ignorance. Risks tend

to grow during stable, prosperous times and become transparent only during a crisis. As Warren Buffett says, “You only know who is swimming naked when the tide goes out.”

f. Potential Consequences of Low Growth

Having discussed the factors that could contribute to a low-growth future, we now turn to the potential consequences of low growth.

Key Economic Variables

Components of Economic Output

GDP is made up of four components: personal consumption spending, business investment, net exports (exports less imports) and government spending. A change in growth patterns may impact these components differently, with varying effects on well-being. In addition, changes in per capita and aggregate GDP can have different implications. In this section, we discuss the impact of a long-term, systemic reduction in growth on these dimensions of output, including possible differences in impact, depending on the driver of low growth. We focus on two drivers: demographic shift and environmental degradation, including climate change.

Economic well-being is measured by the utility of consumption, not production. Therefore, personal consumption spending is the component of GDP most closely linked with well-being, and a change in GDP impacts well-being only to the extent it accrues to personal consumption. Business investment reflects spending to invest in future production, which—if spent productively—will result in higher future personal consumption. Government spending reflects the amounts spent by governments to provide their services, including salaries and benefits for government workers and goods and services purchased from the private sector. Government spending does not include transfer payments to individuals, such as Social Security or other benefit payments. The consumer spending resulting from these payments is part of personal consumption spending. Net exports is the balancing item between GDP and national income and can be viewed as a measure of net savings (or net borrowing)—i.e., the excess (or shortfall) of income over spending. Crowding effects are important, because a unit of production cannot simultaneously be used for more than one component.

A good model for a demographically driven slowdown is provided by Japan. Over the period 1995-2015, Japan’s total population has increased by a cumulative 1.3 percent (less than 0.1 percent per year), the age 70-plus share of the population has doubled from 9.3 percent to 18.6 percent, and the working age share of the population has declined from 67.7 percent to 63.8 percent. Over roughly the same period, real GDP has experienced an average annual growth rate of 0.8 percent over the period 1994-2014, with per capita GDP growing at essentially the same rate. Over this period, the consumption share of the economy has grown from 51 percent to 60 percent and the government share has grown from 13 percent to 21 percent, offset by an investment decline from 33 percent to 22 percent and a drop in net exports from +4 percent to -3 percent. The impact of this shift on well-being is dramatic, as per capita consumption has grown by 1.7 percent, reasonably close to the other developed nations. During this entire period, Japan has attempted to stimulate its economy using fiscal and monetary tools. Capacity shifted as investment was scaled down to the growth capacity of the economy, and exports were scaled back to support consumer and government spending. This is the pattern one might

expect in an economy that has the capacity to respond accordingly. By contrast, in 2014, the investment and net export shares of the U.S. GDP were comparable to Japan's 2014 share—21 percent and -5 percent, respectively—while consumption was 12 percent higher, at 72 percent. If a demographic slowdown on the scale of Japan's were imminent in the U.S., it would be in a much weaker position to maintain growth in consumption. Its best option might be to raise the retirement age or otherwise incent delayed retirement.[8]

As the most significant effects of climate change and other forms of environmental degradation are yet to come, an empirical case study is hard to come by. Randers' forecast (Randers, 2012) reflects a number of drivers, but a significant one is the impact of climate change. This discussion is based on his arguments. Over his projection horizon, he does not find a significant role for climate change in the rate of GDP growth (the same would not be the case if his forecast included the second half of the 21st century), but he does find a significant role in the components of GDP. He envisions that responses to climate change will lead to significant increases in investment. Initially this would be forced investment to rebuild after disaster, followed by voluntary investment in mitigation and adaptation as the long-term problem becomes real to policymakers and the public. He also sees increased costs to address the effects of environmental degradation, which will take the form of investment. Using several estimates of the total investment required to address climate change, and considering the effect of delayed investments, he estimates a 10 percent increase in the investment share of the world economy by 2052—from 25 percent to 35 percent. Converse to the pattern seen in Japan's demographic slowdown, such a shift would provide a drag on improvement in living standards, already constrained by the slowdown in growth. Randers predicts that because of continued productivity improvement in the developing world, per capita GDP would not fall for the world as a whole but likely would in the developed regions.

Finally, we will briefly discuss per capita versus aggregate growth, irrespective of driver. Which one matters? The obvious answer is both. As a measure of economic well-being, per capita GDP, output per person, is more meaningful. Per capita consumption is even more meaningful, because it measures the portion of GDP available to meet personal needs and wants. Median per capita consumption is yet more meaningful because it captures what is available for the average person's consumption. Median personal income may be even more meaningful because it provides a measure of what the average person can afford to consume, as opposed to what the average person does consume. Per capita measures are critical for understanding economic welfare, and as noted above for the case of Japan, aggregate measures can be very misleading in this regard. Decomposing the data into component factors can be very helpful in determining the impact drivers.

However, it is a mistake to focus on per capita measures to the exclusion of aggregate measures. Business owners demand earnings growth on an aggregate basis. Tax revenues depend on the aggregate tax base, and government spending may or may not vary on a per capita basis. However, the most significant reason aggregate growth matters is business and government debt. As will be discussed in Section III.f, a debt-based economy may be said to

[8] Data source: Penn World Tables, *https://www.rug.nl/ggdc/productivity/pwt/*.

have a growth imperative. In the absence of growth—aggregate growth—debt is an increasing drag on well-being.

This section is not intended to provide a comprehensive discussion of the varying ways that slowing growth can affect the composition of economic output, but to highlight that a low-growth future can mean many different things. In managing against the risks of a low-growth future, it is critical to consider which low-growth future you are managing. Unexpected results and unintended consequences of actions are difficult to anticipate.

Inflation

Inflation is usually driven by the market forces of supply and demand. High growth can lead to resource shortages, including labor (lower unemployment requires higher wages), raising the price and leading to inflation. If increases in productivity are the driver of growth, then inflation will be minimal. This encourages future growth through stability.

Demand Pull

Increased wages provide a feedback loop with higher purchases and more demand. Eventually, the market begins to expect inflation, so employees anticipate periodic increases and manufacturers build inflation into their bids. Once this self-fulfilling spiral begins, it can be hard to reverse course. This is known as demand-pull inflation.

The impact of inflation on businesses varies based on how much of the higher cost can be passed along to consumers. If consumers accept all of the cost increase, then profits will not decrease and may even go up if based on a percentage of the larger pile of cash.

Cost Push and Stagflation

Cost-push inflation is driven by expenses that deflect alternative purchases. It slows growth as the higher-cost item crowds out spending for other items. Higher prices could also be caused by food shortages, devaluation of currency, rising taxes or increasing regulation. High inflation combined with low growth is called stagflation.[9]

The period most associated with stagflation is the 1970s, set up by government spending in the 1960s for both defense spending (e.g., Vietnam War) and social programs (e.g., Medicare) and triggered by oil embargoes (due to OPEC monopsony). This required Paul Volcker's tightening of monetary policy as Federal Reserve chairman, leading to a strong recession, to reduce inflationary expectations. Other examples of stagflation are generally referred to as hyperinflation, since the inflation rate dominates. Examples include 1920s Weimar Republic, 2008 Zimbabwe and currently in Venezuela.

Interest Rates

Low nominal interest rates and low growth often go hand in hand, but which is the driver? They seem to be correlated, but it is not a guarantee. If low growth develops from structural factors like demographics and productivity that are slow moving, this can lead to low interest rates and

[9] Pettinger, Tejvan. Conflict between economic growth and inflation. *EconomicsHelp.org*, November 15, 2017, *https://www.economicshelp.org/blog/458/economics/conflict-between-economic-growth-and-inflation/* (accessed March 22, 2019).

flatter yield curves (IMF Fiscal Monitor: Capitalizing on Good Times, 2018). An aging population with higher longevity may save more and push rates down. Credit demand is likely to reduce, and demand for liquid deposits goes up. Since the level of interest rate volatility generally correlates to the level of interest rates, measured interest rate volatility may be low. The public may be reminded of the risk for deposits to default, as they were in Cyprus in 2012 (O'Brien, 2013), with regulators moving toward regulating banks like utilities, with low returns and low risk. Savers may be tempted to reach for yield by accepting additional risks, while those managing assets for others are challenged as expenses become more transparent when nominal rates are low. Real interest rates may not be impacted.

Nominal interest rates, particularly on business and personal borrowing, may be a different matter entirely. A stagflation scenario will result in low real interest rates but high nominal rates, as compensation for inflation risk. In addition, if low growth increased the risk of default, credit spreads would increase, resulting in higher nominal rates for all sorts of business and personal debt and even government debt.

Asset Returns

The impact on asset returns of a low-growth environment is more challenging, as lower demand leads to lower profitability for companies, but low discount rates increase asset values. If a reduction in a firm's expected growth in profits coincided with the reduction in interest rates, the immediate impact on its stock price might be small. After recognition of the change in these assumptions, the expected return would be lower, corresponding with the lower discount rate. Even in the absence of GDP growth, individual firms would still seek to grow and investors would still seek firms with growth potential. But without systemic growth, these growth opportunities would be more limited and would be at the expense of other firms, resulting in increased competition and volatility of stock returns.

In the long run, the impact of low growth on asset returns can be analyzed by considering the national income, which equals GDP less depreciation and indirect business taxes. National income grows at effectively the same rate as GDP. If growth in net income slows, then growth in business income or investment income can be maintained only at the expense of personal incomes. Ultimately, reduced growth must result in reduced asset returns.

Financial System

Impact of Debt

In our financial system, GDP growth and debt are inextricably linked. Bank lending under the fractional reserve banking system is the primary means of money creation. Although money creation is not a factor in the growth models discussed above, in the Keynesian tradition money creation is a necessary condition for investment and, therefore, economic growth. It has been argued that this results in a growth imperative for a capitalist economy: The economy must grow, because without growth, firms cannot profit while banks simultaneously accumulate capital against their increased lending. The implication is that any long-term growth rate below some threshold is incompatible with our debt-based monetary system. Under zero growth, firms will fail, leading to a downward spiral (Binswanger, 2009; Sorrell, 2010). This argument is consistent with our intuition. Lenders must be compensated, and borrowing firms must be able to profit after lenders are compensated. Some level of growth is necessary to provide for both.

This suggests that for zero growth (or growth below some threshold) to be viable, the fractional reserve banking system could not continue to serve the role of money creation.

Whether or not these arguments are correct, economic growth increases borrowers' repayment capacity, so that debt capacity would decline in the absence of a growth assumption. All other things being equal, default risk would increase for the same reason, increasing the cost of debt. Faced with reduced profit potential, increased debt cost and reduced debt availability, businesses would see a tremendous reduction in the viability of debt financing. Governments would face similar constraints. Government borrowing would be limited by current GDP, not the promise of increased future GDP. Debt as a dominant feature of our financial landscape would decline, with spiraling and unexpected consequences.

Alternative Financial Ecosystems

So if debt were not a dominant mode of financing in a low-growth world, what would replace it? After all, businesses would still require a means to finance investment. Some who argue that capitalism itself has a growth imperative (see the next section) provide one possible answer: a pivot away from the capitalist system. The recent advent of the sharing economy may provide a different answer. This description has not been sourced from our research and should be considered a speculation on the part of the authors.

Historically, firms have largely owned their capital—ownership of factories and equipment, indirect ownership of their human capital through the employee/employer relationship, etc.—and have issued stock and debt to finance their capital investments. The risks borne by debtholders and shareholders are manifold, and their compensation reflects these manifold risks. Imagine instead a system where firms leased capital without owning it—the "Uberification" of production, if you will. Such a system could be viewed as an extension of outsourcing and the decentralized supply chain in the current economy; currently, end-product producers outsource various components of the production process to suppliers, but the key difference is that the firms at each point along the supply chain own their capital. This imagined system would separate production from the ownership of capital. This system might result in some form of common ownership, but what is more likely in a capitalist economy is that investors would invest directly in capital, leasing that capital to the firms that produce goods and services, rather than invest in the firms that own the capital. It appears likely that the net risk to investors would decline—their primary risks would relate directly to the capital that they owned—and so would their compensation. Assets would still be pooled or securitized, as they are today, but the pooling would generally resemble a real estate investment trust more than a mortgage-backed security. Small businesses would potentially be owned by sponsors, separating the management from capital ownership of the firm. This could make the American dream of building from nothing into being rich an infrequent happening.

While this imagined system may or may not be a practical possibility, in order for a financial system to viably meet the investment needs of a low-growth economy, it would need to eliminate any real or perceived growth imperative. Through better alignment—and control—of risks and returns, a system such as this might reduce the cost of investment sufficiently that growth would not be required to pay the cost of capital.

Noneconomic Consequences

The range of views on the cultural impacts of a potential low-growth future could not be wider, with more optimistic views frequently, but not always, coming from those who believe an end to growth is inevitable. Some have argued an end to growth would spell the end for capitalism—that capitalism requires growth to survive and that "it has to be largely scrapped and remade along quite different lines" (Trainer, 2011). Others have argued that modern civilization itself could not survive without growth and would revert to the pre-growth "conflict and conquest" model, closer to a localized barter scenario (Porter, 2015). On the contrary, some see the possibility of a widespread embrace of nonmaterialist values enabled by technology (Park, 2015). The sustainable development movement embodied in the United Nation's Sustainable Development Goals combines an optimism that the rich world will seriously address development in the poor countries of the world, with the explicit view that growth is the only mechanism to achieve that development. Other major global institutions share the view that growth is the only real path forward to end poverty and improve equality (Growth: Building Jobs and Prosperity in Developing Countries, 2007). For his part, Randers sees a zero-sum world leading to increased conflict, both within and among countries, as the rich try to maintain their advantage and the poor try to get their share.

The view that conflict and division would increase in a low-growth future seems to be supported by the recent rise of nationalist anti-trade and anti-immigrant movements around the world. It seems naive to believe that this development will naturally give way to a more cooperative attitude. As World War II was necessary to set the stage for European cooperation and, ultimately, the European Union, so it is possible that low growth will continue to drive division and defense of self-interest, yielding only to increased cooperation after a major war or catastrophe.

Geopolitical Ramifications

Developed Versus Developing Nations

There is nothing inherent in humans that causes GDP per capita to be higher in some countries than others. As discussed so well by Jared Diamond in the Pulitzer Prize-winning *Guns, Germs, and Steel* (Diamond, 1997), regional variations due to available resources allowed some cultures to grow modern economies faster than others. That some countries have higher GDP and GDP per capita today might mean only that they would be expected to grow more slowly than countries where those metrics currently lag. That said, persistent factors such as literacy, freedom, governance and birth/death rates are also used to differentiate between developed and developing countries and contribute to their potential GDP. The United Nations classifies countries into developed economies, economies in transition and developing economies, using similarly subjective conditions.

Recently, a new categorization was developed by Hans Rosling in his book *Factfulness* (Rosling, 2018). Of the 8 billion people currently alive on the earth, he splits them into four levels. They are defined in Table 3.

Table 3
GLOBAL LEVELS OF DEVELOPMENT

	Level 1 (1 billion)	Level 2 (4 billion)	Level 3 (2 billion)	Level 4 (1 billion)
Drinking water/education	Walk to fetch	Ride bike/kids go to school but don't graduate	Running water/kids go to high school/stable electricity	Hot and cold water indoors / more than 12 years' education
Transportation	Walk barefoot	Shoes/bike	Motorbike	Car
Cooking	Open fire	Gas stove	Multipot gas stove	Stove/oven
Eating	Porridge made from crops you grew	Sell surplus for eggs	Fridge allows variety	Occasionally eat out
Sleeping	Dirt floor	Mattress	Mattress	Mattress
Income ($/day)	<$2	<$8	<$32	>$64

It is hard, but important, for those of us who live in Level 4 to think about how a low-growth scenario would apply to someone living in Levels 1, 2 and 3. For those in Level 1, spending their whole day collecting enough water to drink from a dirty mudhole an hour away, collecting firewood on the way back to their village to cook their porridge, the impact of a low-growth scenario is its effect on basic health and welfare. Control of diseases (like malaria), clean water and sanitation have the greatest impact on improving results and may suffer in the absence of growth. Exogenous factors (like climate change) that impact water supplies and temperature can impact the basic essentials of life and could cause regression to lower levels for all countries. Those living below Level 4, who did not cause climate change as we currently understand it, will often pay the heaviest price if a worst-case scenario plays out. They have built up little resiliency, so have no flexibility. If they can't live where they currently are and maintain their current society, they have few options.

Using Rosling's categories, Levels 2 and 3 are expected to "catch up" to GDP levels of the top group over time. These are the economies whose growth has recently outstripped that of the U.S. and OECD countries, as shown in Section III.c, a pattern that many forecasters project will continue, as will be discussed in Section IV. These are closer to the U.N. economies in transition that are adding to education, productivity, and gender and economic equality—and that have a younger population to start with. While NGOs (nongovernmental organizations) can help with exogenous factors, these internal improvements can also spur growth.

A country that is considered developed, generally Level 4, would be more likely to have a strong legal system and low poverty rates. GDP is higher, and technology is readily available. A low-growth scenario would start from a fairly high level, often with safety nets in place. A developing country starts at a lower level, so it may not notice the change in growth unless the scenario driver influences its environment. Under normal conditions, it would still move toward the

metrics achieved by the developed countries as infrastructure improves. This development relies on open economies, and often aid from Level 4 countries, that may not be forthcoming in some low-growth scenarios.

Private insurance and pension plans are the norm in Level 4 countries and common in Level 3 countries. Those living in Levels 1 and 2 may participate in some local pooling arrangements, and some may have access to microinsurance protection, but they are largely uncovered by the insurance and pension sectors.

Environmental Effects

Developing countries tend to be more susceptible to environmental effects since they do not have formalized safety nets and rely on family. Furthermore, geographic constraints have often created conditions that led to regions being left behind economically, and these are often the same conditions that are susceptible to environmental changes. When everyone in a region is negatively impacted at the same time, there is no one to support those in need. This type of low-growth scenario will be disastrous to many developing countries, while developed countries will try to buy their way out of the predicament. Those responsible for an environmentally driven low-growth scenario will have reaped the benefits economically and have more options. Those previously living below Level 3 will be challenged to survive in such a scenario, especially if they live near the equator, in places where fresh water is in short supply or below sea level.

Of course, there is overlap between these low-growth conditions whose effects may vary among Levels 1, 2, 3 and 4. Each could occur simultaneously, and some could exacerbate the other drivers. This could occur through events such as spillover of a disease from the mammalian population to humans that results in massive fatalities, regional conflicts over fresh water, scarce minerals or energy, a warming climate that floods coastal areas and lowers monoculture crop yields, or a failure of the existing “just in time” science to adapt quickly enough to overcome evolving mutations of insects and diseases around pesticides and antibiotics (pollinating insects, in particular, are at risk today). The earth’s ecosystem evolves smoothly if conditions change slowly, but discontinuities have surprising and unintended consequences. The second-order effects tend to be unanticipated and will change the future in unexpected ways. Historical data may not be predictive.

Regional Winners and Losers

A low-growth scenario that is not environmentally driven will have regional winners and losers, but it is not as clear who they would be. Developing countries would generally be expected to “narrow the gap” to developed country GDP levels, but this will vary based on relative political and economic conditions.

An environmentally driven low-growth scenario would have regional winners and losers who are easier to identify in advance. Areas near the equator, low-lying areas adjoining the ocean and areas where fresh water is already in short supply would be expected to do poorly. In the United States, someone near the Great Lakes would expect to do better than someone in Miami or Phoenix. Hurricanes, wildfires and drought would also intensify, making some areas inhospitable. Canada, Russia and Scandinavia would have frozen tundra become potential farmland and livable space, with lengthening growing seasons, but the soil may not be as conducive to crops as current farming regions, and areas near the equator would see yields

decimated. The ocean currents will change and pH levels will move toward higher acidity levels, changing areas hospitable to life.

Countries in the Middle East will struggle to remain populated as higher temperatures make agriculture nearly impossible and reduced insect and fish biodiversity eliminates protein alternatives. Low-lying countries like Bangladesh have little defense against rising oceans, with hundreds of millions of citizens at risk.

The United States has unique considerations. The dollar has been the world's reserve currency since the Bretton Woods Conference in 1944 and has solidified its role, as oil—until recently—has been traded exclusively in the U.S. currency. There are signs that this could change in the near future, especially as the Chinese economy has grown in influence. Several holders of U.S. Treasury bonds, including Russia and China, have reduced their exposure. Whether currency trading moves to alternatives, like the yuan or euro, uses a basket of currencies or uses Special Drawing Rights issued by the IMF, a move away from the dollar as the dominant currency would have repercussions for U.S. trade and the domestic economy. The stability it provides allows government flexibility to influence markets beyond what it could do otherwise, as other countries are willing to hold dollars and Treasuries. Losing this role would force fiscal policy in particular to be much more balanced, with debt having direct impact on borrowing rates.

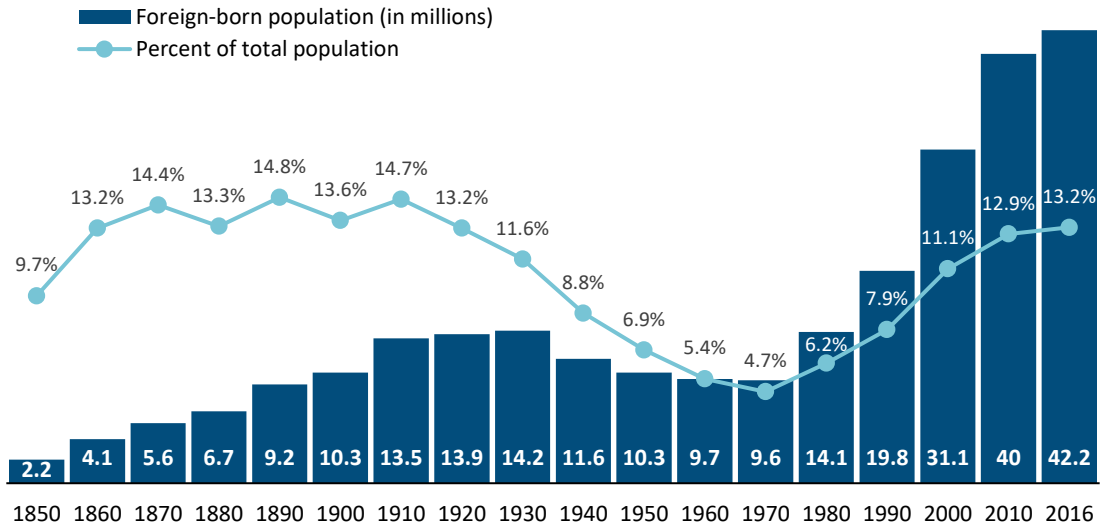
Demographics and Immigration

Demographics will shift GDP toward developing countries as they are younger and growing in both size and economic complexity. While Japan is the initial country to materially age due to low fertility rates, longer life spans and a limited immigration policy, this is a problem for virtually all the developed countries. Developing countries, on the other hand, have higher fertility rates and so a younger population with a lower dependency ratio that provides a potential safety net for the elderly. Over time, if educational progress continues and child death rates improve due to disease and sanitation improvements, the fertility rates in these countries will reduce. It will take at least a generation to adjust to these changes, so developing countries will initially grow quickly before slowing. Developed countries will require immigration to maintain population growth, so if the timing aligns correctly, both groups may benefit.

Immigration is often viewed fearfully by people already living in a region, and this fear historically dissipates as generations pass and recent immigrants assimilate. As an example, laws were passed in the 1920s limiting immigration in the United States due to concerns about Eastern Europeans and Asians, groups that have now been absorbed by American society. Immigrants have been shown to form 25 percent of new U.S. businesses (Kerr and Kerr, 2018), with second-generation immigrants starting about 6 percent of new firms. There is a disconnect between the facts and rumor, but this has been true throughout history (see discussion of *The Fourth Turning* in Section III.a). As shown in Figure 10, the percentage of foreign-born population peaked between 1890 and 1910 at just under 15 percent and then fell to under 5 percent by 1970 before rising to 13 percent by 2016.

Figure 10

U.S. FOREIGN-BORN POPULATION, 1850-2016



Source: U.S. Census Bureau, Census of Population, 1850 to 2000, and the American Community Survey, 2010, 2016.

Not all immigration is the same. Someone moving to upstate New York from Ontario, Canada, will be viewed differently by many from someone escaping war-torn Syria or Venezuela. Regional conflicts make it important to screen refugees, but most who are forced to move are eager to start over and willing to work hard so their children receive opportunities. Treating these immigrants poorly at the border may create, rather than eradicate, the security issues that policymakers worry about.

Immigration should be considered from both perspectives, the country accepting the immigrants as well as the country that allows them to leave. Historically, many countries have allowed many of their best and brightest to leave, often for educational purposes, with the hope that some would return to share their knowledge. This favors personal choice. Others leave due to poor economic situations or are war refugees hoping for a better life. Receiving countries can manage the influx using the visa process and often set limits due to previous geographic location. Immigration has become a politically charged subject.

In a low-growth scenario, fewer jobs are being created, so immigration is likely to slow. Academic immigration, with students enrolled in universities, would be more likely to continue than those immigrating for job prospects at the lower end of the wage scale.

Although a closing of borders may be a predictable response to low growth, the opposite might be a more rational response to a demographically driven slowdown. Immigrants escaping a war-torn country to an aging country that welcomed them would see growth beyond the initial group of immigrants, as children of the original workers tend to move up the earnings ladder from their parents.

By stabilizing countries that are aging, developed countries would use migration to maintain their status as a meaningful trade partner in the world economy, using the law of comparative

advantage to expand the production "pie." There would be a relative improvement in GDP versus inaction, but if productivity growth falls to zero, then population growth would be left to drive any aggregate GDP growth.

If a strategy of open borders were adopted by the world's developed countries, namely those who are OECD members, initially growth would be driven by movement of population to areas of sustainability, but the productivity growth would come later as education of children turns into productivity growth rather than a wasted resource. Economic success and interactions between countries makes regional conflict and other types of war less likely. If a region is overpopulated but sustainable at lower levels, a movement out of the area will improve the local economy and right-size the infrastructure so those who remain have better services, including schooling. This will also pay dividends down the road as an educated workforce expands the local economy.

Unanticipated Consequences of Low Growth

Change always brings surprises and unanticipated consequences. The most significant consequences of any event or decision are often not anticipated by the conventional wisdom or forecasts. Such consequences may be driven by nonlinear tipping points, by unappreciated correlation among variables or by behavioral and psychological factors. It is beyond our scope to attempt to analyze or suggest the myriad unexpected ways in which a low-growth scenario might play out. However, just as continued growth is not inevitable, our socioeconomic systems and institutions are not immutable, and we will suggest some ways that low growth could contribute to fundamental changes in those systems. These may all have low probability and should be considered hypotheticals, not predictions. However, the world is driven by events that you think can never happen—until they do.

The currency system and cryptocurrency: One response to concerns about government debt and potential default, as well as a desire for some to use currency not backed by the full faith and credit of a public entity, has been blockchain alternatives like bitcoin. These cryptocurrencies are digital currencies with the advantage of not being backed by any government while being anonymous. Early attempts have struggled to maintain a stable value and have been subject to theft, leaving the concept yet to be proven as a stable store of value. However, as these cryptocurrencies evolve, they may become viable stores of value for those seeking protection from currency devaluation due to the whimsy of fiscal and monetary policymakers. A low-growth environment with exploding debt levels might be ripe for such developments. If widely adopted, they might overturn the existing national currency system.

The debt-based financial system: In Section III.f we discussed research, arguing that the debt-based financial system has a growth imperative and is incompatible with systemic low growth. While not a consensus position, it is not beyond the realm of possibility.

The capitalist economic system: As with the debt-based financial system, Section III.f discussed research, arguing that capitalism has a growth imperative. When faced with systemic low growth, could capitalism be replaced?

Western liberal democracy: After the fall of the Soviet Union, with the U.S. as the world's sole superpower, the ascendance of Western-style liberal democracy appeared ensured. More recently, the norms of liberal democracy are under assault from both within (the rise of autocratic nationalist movements) and without (the rise of China). Fear and uncertainty, which

could result from long-term low growth, push people from the political center to the extremes. Some might move toward libertarianism or, at a greater extreme, toward anarchic philosophy. By reducing large governments and leaving individual choice instead, libertarians believe that reduced central government decision-making would leave everyone better off. It is unclear if this could be accomplished without destroying a culture that respects property and human rights. As we see when businesses set up competitions to host their next expansions, local decisions are not always best for the country. Climate change is an issue where centralized control may be the only way to avoid large downsides shared globally.

Others might move in the other direction, supporting greater government control under populist policies or autocratic systems of one kind or another. Recalling the prior discussion of *The Fourth Turning*, there is a cyclical nature to populism; about once per century, it seems to come back in vogue. Stemming from a desire to clean up the political bureaucracy, the goals of the people are often overridden by far-left- or far-right-leaning leaders, leading to poor outcomes in the past.

Another alternative is socialism, and some have embraced this ideology. This group attaches to issues like universal health care and sees value in centralized control over other issues (e.g., climate change, human rights) and develops policies accordingly.

Each of these groups believes they have the best interests of their country at heart, and each will react to the current political environment to best achieve their goals. There will be some odd bedfellows as coalitions are formed.

Conflict: Broadly speaking, an increase in conflict in the wake of systemic low growth is, though not inevitable, not difficult to predict and, so, cannot be called “unanticipated.” Evidence can be seen in our current political situation, with increasing class and political divisions within a country, increasing distrust of outsiders and increasing trade tensions. Increased struggle for pieces of a pie that is growing more slowly, or not at all, would not be unexpected. Interactions with other emerging risks, such as climate change and a reduced supply of fresh water, could exacerbate this concern.

However, a broad return to a bygone era of conflict and violence could result from an extended period of low growth and would be hugely consequential. Steven Pinker (Pinker, 2011) has argued that the human species has experienced a tremendous decline in violence of all forms over the course of history and that we live in the least violent time in the history of humankind, attributing the decline to five “historical forces”: The Leviathan (the rise of the modern nation/state), Commerce, Feminization, Cosmopolitanism and The Escalator of Reason (application of knowledge and reason in governing human affairs). Pinker warns that this trend is not guaranteed to continue, and we observe that consequences of a world without growth could counter these historical forces. Indeed, as discussed in Section III.f, many fear that a world without growth would unwind that progress. “Zero growth gave us Genghis Khan and the Middle Ages, conquest and subjugation. It fostered an order in which the only mechanism to get ahead was to plunder one’s neighbor.” (Porter, 2015)

These potential unanticipated consequences may sound extreme, and they are. They may sound impossible, but they are not. In Section III.e, we discussed potential feedback loops with respect to fiscal and monetary policies and how a failure to recognize the growth limitations that may exist could cause these policies to exacerbate the problems they are intended to solve. The same concern applies here. We cannot say definitively whether growth can or should be

sustained. We can say that a government (or a firm) that has studied and planned for the potential risk will be much better positioned to respond than one that has not.

g. Section Conclusion: Summary of Plausible Low-Growth Scenarios

We will conclude Section III with a summary of some plausible low-growth scenarios. These descriptions are focused on a single driver or type of driver.

Demographic Stagnation

A scenario where the driver is demographic stagnation is very challenging, not because it is difficult to foresee but because it is hard to identify the evolution along the way. Many drivers will interact, leading sometimes to unintended consequences. The range of outcomes could go anywhere in a country that is both aging and shrinking its population. Fewer workers generate lower GDP in aggregate.

While many OECD member countries are entering a demographic bust period, Japan is the first to experience such an aging scenario. Some of Japan's specific characteristics will make it easier, but some will make it harder, to navigate the environment. Thirty years ago, Japan enjoyed a sizeable trade surplus, low consumer and government spending (so high savings), and low debt levels. No OECD country enjoys this starting point today.

Japan has had low growth and low interest rates for more than 25 years, has a low fertility rate, and has government debt levels more than 250 percent of GDP. The debt is mostly owed to the Bank of Japan and its own citizens, although a small amount (7 percent) (Pettinger, 2017) is owed to foreign nationals. The Japanese culture has not been inviting of immigrants historically, and citizenship requires renunciation of prior nationality. Service workers are needed. So far, there has been a push to develop robotic nursemaids who will keep the aged company, but recently the Japanese government has encouraged limited immigration visas. As the number of workers per retiree goes down, this will put pressure on the financial system at the same time that debt needs to be repaid. A growth scenario that follows population shrinkage is possible, but without productivity growth, it eventually would collapse either from lack of workers or from conflict.

Japan, and other countries that do not address the issues that come with a shrinking population, may be susceptible to a regional conflict due to fewer, older, residents. With few internal natural resources, if Japan's industrial complex is not firing on all cylinders during hostilities, it becomes susceptible to blockades and combative trade policies. An influx of immigrants working in a free-market environment, allowed to marry the local population, over time could lead the population to a sustainable place. A closed-society scenario would likely exhibit negative growth, while one that encourages immigration could show solid growth over time. Choices will need to be made, and they will be difficult.

The tendency in this, or any, low-growth scenario, might be to close borders and turn inward. As discussed in Section III.f, opening borders might maintain growth and improve the dependency ratio in developed countries, provide opportunities for those from developing nations.

Environmentally Driven Scenario

An environmentally driven low-growth scenario appears increasingly likely and may combine with other low-growth drivers. Scientific and economic research continues to point toward greater economic risk from climate change. Investment in climate mitigation and adaptation efforts will also likely limit growth by diverting investment from other productive activities.

However, climate change is not the only environmental risk that could limit growth going forward. Regardless of the impact of climate change, the supply of cheap fossil fuel resources will eventually run low, slowing growth through price increases and the investment required to profitably exploit less accessible and lower-quality supplies. Degradation in the quality of agricultural land is offset by use of fertilizers and pesticides, which are often petroleum-based and whose ongoing supply and efficacy are not ensured. Pollution and environmental toxins contribute to the extinction of species and compromise the economic benefits provided by the natural environment. Limits to other natural resource supplies, ranging from fishery stocks to rare-earth metals, could plausibly constrain growth.

Most economic projections of the effects of climate change and other environmental risks project growth to slow. These projections generally attempt to capture an expected path of results, not the tail risk. They do not capture the tipping points or cliff effects that are possible as conditions quickly move beyond the range of our historical experience.

Environmental factors could drive a low-growth scenario but also could drive one that is much more catastrophic. Which result ultimately prevails will depend on actions taken by all of us, but vast uncertainty remains as to what level of action is needed to ensure the former and prevent the latter.

Debt Crisis Scenario

A debt crisis scenario interacts directly with other low-growth scenario drivers. It would likely not occur on its own but would exacerbate a low-growth scenario.

Determination of debt capacity is either implicitly or explicitly conditioned on expectations of growth. Individuals buy and borrow on the expectation of increases in wages and housing prices. Businesses borrow on the expectation of earnings growth, and lenders include growth expectations in their determination of debt capacity. Governments borrow on the expectation of growing GDP and growing tax receipts. Each decision is suboptimal if expectations are wrong.

Of course, in the case of governments and businesses, leverage is expected to drive that growth. When growth is slow, fiscal policy attempts to stimulate the economy through government deficit spending. Monetary policy induces borrowing by business and individuals to stimulate growth from both the supply and demand sides.

But what if the old thinking does not apply and the growth headwinds prevent expected responses? Debt grows, but GDP does not. Debt levels are already at dangerously high levels worldwide. Governments and central banks continue to make strong bets that continued borrowing will generate continued growth. The margin for error in these bets is small. Past debt crises have frequently been limited to individual countries. The risk of a global debt crisis in a low-growth scenario cannot be dismissed.

IV. Review of Scenarios

a. Section Introduction

Scenario analysis for an insurance company or pension fund can be said to involve three elements:

1. **Macro scenario:** Scenario of the external, or exogenous, environment. This environment includes, but is not limited to, the macroeconomic elements (GDP and its drivers), the financial system (e.g., interest rates, equity values) and population elements (e.g., mortality rates, human health).
2. **Sector-specific factors:** Includes the specific ways the macro scenario impacts the sector or industry (e.g., how does a change in population mortality rates flow through to insured or annuitant populations?).
3. **Firm-specific factors:** Includes the specific ways the macro scenario and sector-specific factors impact an individual entity, given its strategies, position within the sector and risk profile.

A robust long-term scenario analysis needs to capture all three elements and can be described by a series of simple questions: What is the environment that causes risk to my firm? How does that environment impact my industry or sector? Given my firm's specific strategies, market position and risk profile, what is the relative impact of those sector impacts on my firm? Finally, are there actions that can be taken to mitigate the negative impacts and exploit the positive impacts?

A meaningful and robust analysis requires internal consistency among these three scenario elements (e.g., pension asset returns consistent with interest rate and equity returns) and among the variables making up one scenario element (e.g., equity returns and interest rates consistent with GDP growth and inflation rates), with appropriate recognition of causal and correlative factors. Too often, an analysis may consider a small number of factors in a vacuum, without consideration of either the necessary conditions for that combination of factors or the logical consequences of those factors. For instance, in the cash flow testing exercises used to test reserve adequacy for U.S. life insurers, it is common to test an inverted interest rate scenario. However, these scenarios often miss the real risk of an inversion, which is not the mechanical effect of the inversion on asset values but the increased risk of recession—with all its concomitant effects—signaled by the inversion.

A low-growth future as envisioned in this paper is a macro scenario—a description of the external environment. Every entity faces the same financial ecosystem, but with a unique risk profile. The scenario analysis exercise is about: i) effectively selecting and robustly articulating the macro scenarios, including an assessment of their likelihood; and ii) assessing the sector-specific and firm-specific effects consistent with the macro scenarios. In Section IV, we introduce the reader to several existing macro scenarios developed by other authors, with a focus on the range of GDP growth rates in those scenarios. We then select a single low-growth scenario, and in Section V will discuss the development of assumptions for sector-specific and firm-specific effects for that scenario. Some effects may be considered general across low-growth macro scenarios, while others may vary depending on the driver of low growth. While

focusing on a single scenario, this discussion will attempt to point out areas where the effects may vary depending on the drivers of low growth.

It has been said that all models are wrong, but some are useful (translation: "right enough" for the modeling purpose). A key assumption in the scenario-development process described above is that the relationships among scenario variables can be accurately predicted (i.e., the assumptions regarding these relationships are "right enough"). In fact, most of these relationships are uncertain, and one cannot be sure that one's assumptions are right enough. For instance, both real and nominal interest rates are generally thought to correlate with GDP growth. However, as the 1970s-1980s period of stagflation showed, low growth does not necessarily imply low inflation. As noted in Section III.f, some authors have questioned the correlation between real interest rates and GDP growth. To the extent possible, our analysis in Section IV relies on our sources for the key assumptions regarding such interrelationships, as they have generally studied them deeply and we found them reasonable. At the same time, it is critical to remember that assumptions about such relationships are invariably developed in a backward-looking way and may not hold on a forward-looking basis. We attempt to point out areas of uncertainty in their assumptions that may materially affect their results. Where we have made our own assumptions, we endeavor to be explicit about the basis of our assumptions so that the reader can make an individual judgment.

b. Overview of Existing Macro Scenarios

We will now discuss some long-term economic scenarios and forecasts that have been developed by others to provide a context for the term "low-growth" and to provide a sense of where low-growth scenarios fall in the range of historical results and growth scenarios in the existing literature. The scenarios discussed are not intended to be exhaustive but are reasonably representative.

A number of authors have generated long-term economic forecasts or scenarios. Hillebrand and Closson (2015, 6-22) provide a good survey of existing long-term forecasting literature. Many of these forecasts are more qualitative than quantitative; many have not been developed in a robust, comprehensive way; and many can be construed as biased, reflecting the viewpoints and concerns of the authors. Our objective in reviewing scenarios by others was severalfold: i) to provide insight on the range of long-term economic growth forecasts compared with historical results; ii) to provide insight on what constitutes "low growth" within the range of existing scenarios; iii) to focus on scenarios developed in a robust, unbiased way; and iv) to select a scenario to serve as the basis for our analysis of impacts on the insurance and pension systems in Section V.

We identified several sources of long-term scenarios that met these objectives relatively well and are discussed further in this section. These sources include five scenarios developed at the Frederick Pardee Center for International Futures at the University of Denver, modeled quantitatively using the International Futures (IFs) model, an open-access modeling platform developed and maintained at the Pardee Center (the IFs base scenario is discussed further in the next section); four scenarios developed for the United Nations Environment Programme's *Global Environment Outlook 4* report (Global Environmental Outlook GEO-4, 2007); Shared Socioeconomic Pathway (SSP) reference scenarios developed as part of the scenario framework in use by the International Panel on Climate Change (IPCC) for evaluating climate

risk; and eight scenarios developed by Evan Hillebrand and Stacy Closson for their book *Energy, Economic Growth, and Geopolitical Futures: Eight Long-Range Scenarios* (Hillebrand and Closson, 2015), which the authors modeled using the Pardee Center's IFs platform. These scenario sets were all particularly useful in presenting a range of outcomes that included both low-growth and high-growth scenarios. In addition, we considered the Randers forecast discussed in Section III.a (Randers, 2012) to be useful as a model reflecting environmental factors in a dynamic way. We also considered a 2018 scenario published by the OECD to be useful as a mainstream economic, middle-of-the-road viewpoint. In total, we reviewed 20 scenarios.

Usefulness of a model depends in part on understanding its inherent limitations. The scenario sets discussed below, and the modeling processes underlying them, are long-term trend scenarios. This does not mean that they are simple linear models or that they ignore feedback loops and relationships among variables. It does mean that they are not intended to capture discontinuities or short-term variability (Dalio, 2018). Trends, while not unidirectional, change gradually. Business cycles are not modeled, so there are no recessions or depressions. Political conflict and instability manifest gradually in these scenarios, with no specific wars or regime changes. Environmental effects develop gradually, without tipping points that might result from, for instance, collapsing of polar ice sheets or species extinction. This is appropriate; these models are not intended to predict which countries will experience a depression or when. However, it is important to keep this in mind, because in a long-term low-growth scenario, business cycles and discontinuities of various types would continue and might be exacerbated.

In the remainder of this section, we discuss these various scenario sets as well as the IFs modeling platform. Then we summarize the output of the various scenarios. Finally, we discuss the scenario selected for detailed analysis in Section V.

c. Review of IFs Base Scenario and Rationale

This discussion is based on Hughes (2004). Our discussion draws on Hughes' discussion of his original source material, and we have not cited Hughes' original sources.

First, we turn our attention to the IFs modeling platform and base scenario. This is a useful starting place, as the IFs model platform is very robust, well documented and available freely to all users at http://pardee.du.edu/access-ifs—and also because several of the scenario sets we analyzed were projected using the IFs platform. Pardee Center staff maintain the modeling platform, and the center's researchers also publish research utilizing scenarios they have modeled in IFs. The open-access nature of the IFs platform means that independent researchers also generate and publish forecasts and scenario analyses using IFs. Many of the projections developed by both the center's researchers and independent researchers begin with the IFs base scenario, a scenario developed by Pardee Center staff, modifying base scenario parameters as appropriate to generate the desired scenario. Although it was outside our scope to develop or run our own scenarios for this project, doing so would be possible for us or for the reader. The formulaic structures of IFs, as well as the assumptions and parameters used in the base scenario, are generally based on prior research by other authors, and the sources are extensively documented in the model documentation and Pardee Center publications. The following discussion describes both the structure of the IFs platform and the assumptions and results of the IFs base scenario.

The IFs model covers 186 geographic units (mostly countries), extends over a long period (until 2100) and considers interactions between variables. This means it is an integrated global modeling system, taking input from exogenous variables and projecting future values of endogenous variables related to GDP, population, food, energy, human welfare, governance and international war.

The amount of information available on the platform can seem intimidating but is well worth the time spent either looking at preloaded scenarios or building your own alternative scenarios.

The model incorporates demographic, economic, energy, agricultural, sociopolitical and environmental subsystems. Rather than issuing predictive forecasts, its goal is to help analysts think about evolving economic and social relationships within and between countries. The base scenario provides a good place to start.

There are many uncertainties involved with forecasting out multiple generations. Who could have predicted that the previous 100 years would have included an influenza pandemic, a worldwide depression, a world war only 20 years following the war to end all wars, many regional conflicts, an economic boom that lasted for 50 years, independence of former European colonies, the rise of technology and recognition that carbon dioxide released in the ecosystem was not sustainable? Just as many surprises will occur in the next century, but it is important to have a base case scenario to compare against. There are lots of choices, but the IFs scenario has gone beyond GDP and population projections by country to look at specific input and output variables. It is a central tendency scenario, attempting to position it as one that, on average, is reasonable. It is not meant to be predictive. Think about potential variations in a forecast 80 years from now as fluid variables like life expectancy and technological advancements adjust to current conditions. A base scenario can then be used for sensitivity testing or stress testing certain events or assumptions. It is neither a best estimate nor simple extrapolation of the present, but a starting point for analysis and thought.

For those trying to manage real assets and liabilities, a range of scenarios is key to making decisions and helps modelers and decision makers alike understand the lack of precision and drivers of results.

The IFs model is integrated across issue areas, a major improvement over most single-area expertise models that might focus entirely on GDP and population. Whether you are interested in short-term or long-term implications, considering both helps the reviewer understand the nuances that drive the results. These drivers can be considered in turn.

Population

The number of people alive at any one time seems like a simple model, moving through time driven by mortality and fertility rates. As anyone who has studied demographics in sub-Saharan Africa knows only too well, numerous complexities and interactions among a variety of variables occur. The fertility rate drops as higher education levels are completed by women (note that replacement rate fertility, necessary to sustain population levels, is 2.1 live births per woman). Nongovernmental organizations and governments have tried to address malaria, sanitation and education in this region, led by the Bill & Melinda Gates Foundation. As youth mortality drops, so does the fertility rate, but only after a lag during which families gain confidence that it is sustainable. The impact of HIV/AIDS in this region has also lessened as medicine has evolved.

Interactions between them make exact forecasts difficult, while providing estimates that carry positive momentum.

The developed world is expected to age due to lower fertility rates and increasing life expectancy. A region that combines Europe and Russia is expected to fall from 13 percent to 7.5 percent of the world's population in the first 50 years of the 21st century. As the developed world ages, its dependency ratio, the ratio of nonworking (children and elderly) to working population will rise. The senior safety net, represented by Social Security and Medicare in the United States, has not been around long enough to be tested in such a scenario. The unfunded status of such schemes makes it hard to understand the ramifications. Many look to Japan, as a developed country already enduring a shrinking and aging population, as a case study to see which economic and immigration policies work and which do not. China will be another test case, as it rapidly transitions from a country with a demographic dividend to one with an aged population. The ongoing effects of the former one-child policy will also have unintended consequences that are hard to anticipate.

Migration and urbanization are issues that cut across regions and impact many variables. Aging countries seem a natural fit for immigrants.

Events that could cause disruption of these assumptions include cures for cancer and other medical breakthroughs, agricultural collapse, wars and depressions. A major influenza pandemic occurring while large percentages of the population are receiving pension payments could have a material impact on fiscal results of a country, and wars may be considered more winnable against an aging population or one battling health issues like HIV/AIDS.

Economy

It is difficult to accurately forecast the economy for 10 years, let alone 80, especially for individual countries. One of the biggest challenges is to identify short-term trends that are about to turn. Some guidance in methods and assumptions can be found in forecasts of energy and the environment, as these modelers are accustomed to using a longer time horizon. IFs builds GDP projections using inputs of labor force size, capital stock and multifactor productivity (equivalent to total factor productivity discussed in Section III). Structurally, IFs models the economy on a real basis, without consideration of inflation or the monetary sector, limiting its usefulness when considering inflation risk or nominal interest rates.

The IFs base scenario assumptions tend to narrow gaps between the haves and the have-nots, with developing countries growing GDP faster than OECD countries in general. While GDP growth drops over time in the IFs base scenario, it is not to the low levels contemplated by Gordon and it is driven primarily by slowing population growth rates rather than a reversal of productivity growth.

China and India are the fast-growing behemoths during the 21st century, with China GDP growth slowing continuously, stabilizing in about 2075, and India continuing to grow beyond that. The drivers are population growth, population age structures, multifactor productivity growth and technology adoption rate.

Energy

In the last 50 years, the United States has gone from being a large importer of oil, at the whims of OPEC, to being a net exporter as extraction and refining technologies have improved. The dollar has been the reserve currency, and oil has been traded in dollars for a half-century, but China and Russia are driving pressure for that to change. Demand is modeled in IFs as a function of GDP and population, but the direct relationship between economic growth and energy use will evolve as renewables become more prevalent and services replace manufacturing.

In the IFs base scenario, coal is assumed to rebound after 2030 as cleaner uses are developed. Oil and gas reduce, and by 2050 coal and renewables make strange bedfellows as they become the leading energies. The cost of renewables is assumed to continue a decreasing cost pattern. No assumption is made of oil discoveries in the warming north or south.

Food and Agriculture

The world currently produces enough food to feed the population. Today, malnutrition is primarily due to poverty and the inability to pay for the food, along with food waste and supply chain problems. This part of the model makes clear how difficult higher-order impacts are to integrate. For example, if the earth warms by 3 Celsius degrees, as is forecast, many unexpected interactions will occur. Areas farther north will enjoy increased crop yields, but areas near the equator will become less able to sustain life. Pollution makes the air less healthy to breathe. On a warmer planet, GDP growth is expected to slow, and malnutrition to increase, as crop failures become more common. Biodiversity goes down, with unknown but negative consequences. The base scenario assumes an environment that implicitly includes pivots to increase crop yields and maintain something close to the status quo of food production relative to population. Overall, resiliency is reduced making the world susceptible to shocks like volcanic eruptions and pandemics.

Much has been written about interactions among global meat consumption, rising economic fortunes and global warming. Developing countries are expected to eat more beef as they create a middle class, but the strains on the planet are encouraging developed country populations to switch to protein sources that do not require as much water (grain production), fertilizer and deforestation. The carbon footprint is large, and byproduct waste creates other environmental issues. A feedback loop surrounding climate change, with more extreme weather patterns, creates additional downside pressure. Advances in biotechnology are expected to provide boosts to production. China creates a risk through price pressures and environmental concerns as its large population enters the middle class, and India will create similar risks and opportunities.

Environment

The environmental risks interact with each of the components of the IFs model. One can think of inputs to other systems as either depletion of a nonrenewable resource or overuse of a renewable one to unsustainable levels. This is demonstrated by water, timber or fossil fuel use. An alternative concern is outputs from other systems that accumulate in air, water or land systems, like carbon emissions or pollution. Environmental forecasts are heavily driven by

agricultural and energy systems but are also impacted by demographic and economic systems. They may lead to dislocation and climate refugees.

Water stress seems particularly important as fresh water access is at risk. Higher population levels lead to higher water use for agricultural needs, and as global warming continues, this impacts many sources of fresh water. A feasible solution to desalination would avoid many of these concerns and create discontinuities in a positive direction.

In addition to fossil fuel use, net deforestation is the primary driver of an environmental forecast. The base scenario assumes that deforestation slows and is eventually reversed.

Species loss is a concern directly due to exploitation (e.g., unsustainable fishing) or indirectly through collateral damage. Biodiversity loss and spillover of disease due to habitat encroachment reduce ecosystem resilience.

The IPCC forecasts carbon dioxide, sulfur dioxide, methane and other greenhouse gases across several scenario sets. If these gases inflict pain on the population at large, this will create a natural incentive to pursue renewable energy, reducing their use. The global response to ozone depletion could serve as a model policy and coordinated response. Moving past peak petroleum levels, such factors as the potential reversal of deforestation may reduce greenhouse gas impact, while other factors like the lag effects of carbon accumulation may have the opposite effect, leading to even more uncertainty. As temperatures increase, positive feedback loops may make it harder to change direction. The contrarian view, as has always previously occurred, is that scientists will find a way to figure it out. Unfortunately, positive environmental forecasts are hard to find and analyze. Someone arguing against a negative forecast should be compelled to spell out specific concerns and provide an alternative. The current hostile environment for scientists seems to pose a problem for those putting their faith in technology and market forces to provide pivots.

Max Roser's Our World in Data website[10] tracks many variables and finds that life has improved without most in the general population realizing it. Life expectancy has increased, large health improvements have been achieved by regions in the poorest health, extreme poverty has been reduced, more have safe drinking water and electricity, and internet access is expanding rapidly. Analysts may find it easy to discover forecasts that agree with either gloomy or rosy predictions, and it is important to consider contrarian opinions.

Sociopolitical Systems

The IFs model uses four key elements:

1. Cultural foundations: human values, beliefs and behavioral orientations, which all change as they interact with other cultures
2. Life conditions of individuals: variables such as literacy rates and life expectancy
3. Social and political structures: similar to culture, formally includes governance structures and level of democratization, while informally includes family structure and civil society

[10] Our World in Data, *https://ourworldindata.org*.

4. Social and political processes: level of conflict and cooperation, both domestic and international

The IFs base scenario assumes that the world on average will progressively move toward rationality and democracy. This may be overly optimistic, ignoring any countries moving in the opposite direction, or a better option may present itself. It is unclear how a scenario referencing historical cyclical periods, introducing volatility, would present itself, and is very hard to argue that a discontinuity due to a factor like populism will occur in a specific year. Other variables, like the literacy rate, would be expected to change smoothly over time. Alternative scenarios can provide what-if analysis that leads researchers to better understand the long-term implications of an event or assumption change.

The possibility that a state will fail is easy to document historically but hard to anticipate. There are similarities to climate change in these discussions, as future state failures due to abrupt regime change, revolutionary wars, ethnic wars and genocides/politicides are all likely to occur somewhere, but there is pressure against creating a scenario that picks out a particular country to fail. Systemic risks like climate change are easier to build a scenario around since it impacts everyone. In an African-specific study, democracies are more likely to fail than autocracies, and governments are challenged by features like low trade openness, ethnic discrimination, new or entrenched leaders, and unbalanced growth (high urbanization and low GDP/capita). Factors like the HIV/AIDS epidemic also interact with internal war probabilities. Global leadership and increased tensions show a dangerous period for global conflict when transition occurs to a new global leader. State power can be defined using demographics, economics and military capabilities. Many worry about the rising Chinese presence and whether a two-country power leadership with the United States can peacefully co-exist. Later in the century, the rise of India could generate similar discussions, especially if it aligns itself with one of the other two powers.

Advice to Modelers

The future is unlikely to resemble the past. Historical data may not be predictive, especially when considered along with interactions between risks and events. This makes accurate modeling extremely challenging. Models can extrapolate, using historical data to predict the future, but this has perils as well. Building a base scenario and being transparent about what is and what is not included allows alternative scenarios to be developed that test specific future outcomes. The goal of a modeler is to build an analytical tool, not a predictive one. Encouraging discussion about the future will allow improved decision-making.

Modelers and those who are end users of these tools should keep in mind that there are many uncertainties that could cause changes to the results of the base scenario—or any scenario, for that matter. The formulaic relationships among variables, generally extrapolated from historical studies, may not hold in the future; and even if the formulas hold, the assumptions may not. These uncertainties include:

- Pace of technological change and/or economic growth
- Level of globalization and cultural differences
- Income distribution
- Demographic patterns
- Level of international cooperation
- Governance success

- Material intensity of economy and character of the energy system
- Global power configurations
- Nationalism and other isms
- Wild cards (both positive and negative—e.g., plagues, meteors, volcanic eruptions, technological breakthroughs)

In addition to considering uncertainty in model results, the modeler must carefully validate model results to gain comfort that the model does not contain material errors. Such validation includes what actuaries often call dynamic validation, ensuring that results for early projection years are consistent with recent history. This validation also includes testing the projected relationships among variables to ensure that they are consistent with expectations. A significant difference between the modeled relationships and the expected relationships may mean that the modeler's expectations need to be updated for some previously unrecognized dynamic, or it may mean that the model has an error.

Such validation should be performed for any model, whether internally or externally developed, whether simple or complex. It is particularly important in using a modeling platform like IFs, which is highly complex and dynamic. The richness of the model is its strength, but the complexity also makes it more subject to error.

As we began to consider using the IFs model output to quantitatively assess the impact of a low-growth scenario on the insurance and pension industries, the subject of Section V, we performed just such a validation. We reviewed model documentation to understand as much as possible the formulas and relationships underlying the model mechanics. We exported and graphed the projected values of many output variables and their relationships to one another: relative growth in the components of GDP; GDP growth versus government revenue, spending, deficits and debt; GDP versus government, personal, business and total debt; health care spending versus mortality and morbidity; aggregate versus per capita results; regional versus global results; differences in results between two scenarios; and many others.

In performing this validation, we did flag instances where modeled results did not match our expectations, and in most cases were able to conclude that the differences were explainable by the chosen assumptions or model parameters. But in one particular case, we were unable to reconcile the model's accumulation of government debt. After communication with staff of the Pardee Center, which developed and maintains the IFs platform, they concluded that interest was not being applied to government debt, a model error that they have added to their system development list. Debt versus GDP relationships, particularly government debt, are key elements of our Section V analysis, so this finding greatly limited our ability to use the IFs model results in this analysis. As a result, the Section V analysis is not as valuable as it might otherwise have been, but is an illustration of the importance of good model validation. Given that our objective is focused more on process than results, we do not believe that a correction to the IFs model would significantly change our conclusions.

d. Pardee Center Global Environmental Outlook Four (GEO-4) Scenarios

This discussion is based on IFs Working Paper 2006.07.18 (Hughes, 2006). Our discussion of the GEO-3 narratives draws from the working paper, and we have not cited Hughes' original sources.

Since 1997, the United Nations Environment Programme (UNEP) has published a periodic Global Environmental Outlook (GEO) report. In its third such report, GEO-3 (Global Environmental Outlook 3, 2002), UNEP developed narratives for four possible global futures. For the 2007 GEO-4 report, Barry Hughes of the Pardee Center was asked to create IFs socioeconomic models corresponding to these four narrative scenarios. The development of these socioeconomic scenarios is described in the Pardee Center's working paper, using IFs modeling results to provide scenario projections in UNEP's GEO-4 report (Global Environmental Outlook GEO-4, 2007).

Modeling of these scenarios started with the IFs base case scenario, with various parameters adjusted to be consistent with the scenario narrative, to the extent possible. The working paper describes in detail the model adjustments made for each of these scenarios. Below, we have reproduced the scenario narratives from GEO-3 (UNEP, 2002), and have summarized the key elements of the scenario implementation in IFs, described as changes relative to the base case scenario (Hughes, 2006, pp. 2-9):

Markets First

GEO-3 narrative: Most of the world adopts the values and expectations prevailing in today's industrialized countries. The wealth of nations and the optimal play of market forces dominate social and political agendas. Trust is placed in further globalization and liberalization to enhance corporate wealth, create new enterprises and livelihoods, and so help people and communities afford to insure against—or pay to fix—social and environmental problems. Ethical investors, together with citizen and consumer groups, try to exercise growing corrective influence but are undermined by economic imperatives. The powers of state officials, planners and lawmakers to regulate society, economy and the environment continue to be overwhelmed by expanding demands.

IFs implementation: Reduction in cost of traded goods and services, increase in economic freedom and political freedom parameters, to reflect globalization and liberalization. Increases in migration and foreign investment parameters. Increased oil and gas production and discovery rates. Increased productivity gains, except for the U.S. (because U.S. is the technological leader and globalization primarily helps the rest of the world to catch up) and sub-Saharan Africa (because it is less likely to benefit than other regions).

Policy First

GEO-3 narrative: Decisive initiatives are taken by governments in an attempt to reach specific social and environmental goals. A coordinated pro-environment and anti-poverty drive balances the momentum for economic development at any cost. Environmental and social costs and gains are factored into policy measures, regulatory frameworks and planning processes. All these are reinforced by fiscal levers or incentives, such as carbon taxes and tax breaks. International "soft law" treaties and binding instruments affecting environment and development are integrated into unified blueprints, and their status in law is upgraded, though fresh provision is made for open consultation processes to allow for regional and local variants.

IFs implementation: More rapid cost reduction for renewable energy, reduced energy demand and introduction of carbon taxes to reflect attention to environmental sustainability. Increased agricultural yields to reflect attention to food needs. Reduced fertility rates. Increased

educational spending, health care spending, foreign aid, R&D spending and electronic connectivity to reflect attention to Millennium Development Goals (a set of eight international development goals established in 2000 by the United Nations Millennium Declaration, which all United Nations member countries committed to help achieve by 2015).

Security First

GEO-3 narrative: This scenario assumes a world of striking disparities where inequality and conflict prevail. Socioeconomic and environmental stresses give rise to waves of protest and counteraction. As such troubles become increasingly prevalent, the more powerful and wealthy groups focus on self-protection, creating enclaves akin to the present-day "gated communities." Such islands of advantage provide a degree of enhanced security and economic benefits for dependent communities in their immediate surroundings, but they exclude the disadvantaged mass of outsiders. Welfare and regulatory services fall into disuse, but market forces continue to operate outside the walls.

IFs implementation: Increase in cost of traded goods and services, increase in economic freedom and political freedom parameters. Increases in military spending. Increased fertility (or slowdown in fertility reduction trend). Lower productivity gains, slower cost reduction for renewable energy. Increases in infectious disease burdens and mortality rates.

Sustainability First

GEO-3 narrative: A new environment and development paradigm emerges in response to the challenge of sustainability, supported by new, more equitable values and institutions. A more visionary state of affairs prevails, where radical shifts in the way people interact with one another and with the world around them stimulate and support sustainable policy measures and accountable corporate behavior. There is much fuller collaboration among governments, citizens and other stakeholder groups in decision-making on issues of close common concern. A consensus is reached on what needs to be done to satisfy basic needs and realize personal goals without beggaring others or spoiling the outlook for posterity.

IFs implementation: Policy changes similar to the policy first scenario. In addition, changes reflect values and lifestyles moving away from material consumption and toward other quality-of-life measures, including reduced working lives, reduced productivity rates and further reduction in fertility rates.

As IFs has been updated to newer versions, the Pardee Center has continued to run these scenarios and make the results available to users. Table 4 shows the projections of global aggregate and per capita GDP under the four GEO scenarios and the base case, which we generated in version 7.31 of IFs. On a per capita basis, only the security first scenario shows a significant variation from the base case through 2060. The markets first and policy first scenarios generate almost identical world per capita GDP paths and are only slightly higher than the IFs base case and sustainability first scenarios, which are also almost indistinguishable from each other. On an aggregate GDP basis, we see more variation, driven primarily by the differences in fertility rates, with markets first generating slightly higher GDP and sustainability first generating slightly lower GDP. The differences among these scenarios are more significant on a regional basis than on a global basis, as demonstrated by the results for the U.S. and China. For instance, the sustainability first scenario, while not significantly different from the IFs

base scenario on a global basis, slows U.S. growth almost to a standstill as investment is focused on development in lower-income regions.

Table 4

HISTORICAL GDP GROWTH, 1960-2010; PROJECTED GROWTH, 2010-2060; IFS BASE AND GEO-4 SCENARIOS—U.S., CHINA, THE WORLD

	Annualized GDP Growth						50-year Cumulative GDP Growth					
	Aggregate GDP			Per capita GDP			Aggregate GDP			Per capita GDP		
	US	China	World	US	China	World	US	China	World	US	China	World
Historical 1960-2010	3.2%	8.1%	3.8%	2.1%	6.5%	2.1%	374%	4713%	543%	187%	2229%	180%
IFs Base	1.5%	3.2%	2.3%	1.0%	3.4%	1.5%	108%	391%	210%	67%	423%	115%
GEO-4, Markets first	1.7%	3.4%	2.4%	1.2%	3.5%	1.7%	129%	430%	233%	78%	464%	130%
GEO-4, Policy first	1.5%	3.3%	2.3%	1.0%	3.4%	1.7%	109%	407%	217%	68%	438%	129%
GEO-4 Security first	1.3%	2.0%	1.8%	0.9%	2.1%	0.8%	90%	173%	138%	57%	176%	53%
GEO-4, Sustainability first	0.7%	3.2%	2.1%	0.5%	3.4%	1.6%	42%	390%	181%	26%	432%	116%

Source: Data generated from International Futures Model, version 7.31. Downloaded from *http://pardee.du.edu/access-ifs*.

e. Shared Socioeconomic Pathway Reference Scenario Set

The SSPs are a key component of the scenario development framework currently in use by the IPCC and the climate research communities for evaluating climate risk and climate policy. The scenario development framework was agreed upon at a 2007 IPCC Expert Meeting (Moss et al., 2008) and replaced the prior sequential scenario development framework with a parallel process. The framework is intended to capture global and local effects, with most projections available at the country level.

Scenario development began with a set of five greenhouse gas concentration scenarios (the Representative Concentration Pathways, or RCPs) representing a wide range of potential concentration and radiative forcing futures from the existing scientific literature, which were comprehensive enough to provide full inputs into the climate models. Next, in parallel, the climate modeling community developed a set of climate change projections for each of the five RFPs, and the Integrated Assessment Modeling (IAM) community developed the SSPs as a set of five reference socioeconomic scenarios representing five plausible global socioeconomic futures and including projections of greenhouse gas concentrations, but absent the effects of climate change or associated mitigation and adaptation responses. The RCPs and the climate projections based on the RCPs were then combined with the SSPs to generate full IAM projections for each of the SSPs, both with and without mitigation measures.

The SSP reference scenarios themselves were initiated qualitatively, as a set of narrative scenarios developed in a 2011 meeting at the National Center for Atmospheric Research (O'Neill et al., 2012) describing a range of potential socioeconomic futures. Then, various groups were tasked with developing quantitative projections of various socioeconomic elements—population, urbanization and GDP—consistent with these narratives.

Brief descriptions of the five SSP storylines follow:

SSP1, sustainability: Reasonably good progress toward sustainability. Declining resource intensity and fossil fuel dependency driven by rapid environmentally friendly technological development and increasing awareness of environmental damage. Low-income countries develop rapidly through open economies, improved governance and global institutions focused

on the Millennium Development Goals, resulting in reduced poverty and inequality. Low population growth and significant investment in education.

SSP2, middle of the road: Continuation of recent trends. Slow progress in reducing resource intensity and fossil fuel dependence. Development in low-income countries is uneven, with partially connected markets and relatively weak global institutions. Medium growth in per capita income with slow convergence. Educational improvement is slow, and population growth continues to be relatively high.

SSP3, regional rivalry: Globalization is reversed, resulting in a number of closed regions with widely divergent paths ranging from moderate wealth to extreme poverty. There is little progress in meeting Millennium Development Goals, reducing resource intensity or reducing fossil fuel dependence. Global institutions are weak, economies are closed, and adaptive capacity to address climate change and other challenges is low.

SSP4, inequality: The world is highly unequal, both within and among countries. A small, rich elite controls wealth and resources. Emissions are relatively low because the poor majority lacks sufficient wealth to generate significant emissions, and the elites can relatively easily invest in mitigation technology for their emissions. Global institutions work effectively only for the elite who control them, but adaptation barriers are high for the vast majority of the population affected by climate change.

SSP 5, conventional development: World is focused on economic growth as the solution to all socioeconomic problems, with conventional development fueled by fossil fuels and high resource utilization. Climate mitigation is difficult due to high emission levels, but the benefits of strong economic growth support strong progress toward Millennium Development Goals and reduced challenges to climate change adaptation.

Three independent research teams, reflecting independent and distinct thoughts that could be contrasted, developed GDP projections under the SSPs: a team from the OECD, a team from the Potsdam Institute for Climate Impact Research (PIK) and a team from International Institute for Applied Systems Analysis (IIASA). Each of the three teams generated a GDP model under the five SSPs and published a paper describing its model: Chateau et al. (2012) for OECD, Leimbach et al. (2017) for PIK and Cuaresma (2017) for IIASA. As reference scenarios, these SSP GDP projections provide a useful range of possible socioeconomic futures but, as described above, explicitly exclude any impact of climate change or climate change mitigation efforts. Integrated assessment models, combining the SSPs with projected climate impacts, have been developed, but the comparisons presented here are the reference scenarios without climate impacts. The models developed by the three modeling teams yielded results that in most cases were similar. Note that unlike the scenario sets discussed above, none of these research teams utilized IFs in developing their scenarios.

Tables 5 and 6 compare the 2010-2060 GDP growth and GDP per capita growth under the three sets of SSP scenarios for the world, the United States and China to the historical period 1960-2010. PIK did not explicitly separate results for China. Some observations are:

- On a global basis, the IIASA model generally produces the lowest growth rates, the OECD model produces the widest range among scenarios, and the PIK model produces the narrowest range among scenarios.

- Projected GDP growth is lower than historical growth in virtually all scenarios, globally and for the U.S. and China individually.
- On a per capita basis, global growth is projected to compare favorably with historical growth in all scenarios except SSP3, the regional rivalry scenario. This highlights the impact of slowing population growth on aggregate global GDP.
- For both the U.S. and China, per capita GDP growth is projected to significantly lag historical results. In the U.S., per capita GDP nearly tripled over the 50 years 1960-2010 but is projected to less than double in almost all scenarios. In China, growth is still projected to significantly outstrip the global average but is not projected to maintain its historical pace. This highlights the degree to which future global growth potential is concentrated in the developing world under these scenarios.

Table 5

SSP SCENARIO COMPARISON, ANNUALIZED AND CUMULATIVE GDP GROWTH FOR THE WORLD AND SELECTED COUNTRIES, 1960-2010 VERSUS 2010-2060

	Annualized Real GDP Growth Rate, SSP Scenarios 2010-2060 Versus Actual 1960-2010			Cumulative Real GDP Growth, SSP Scenarios 2010-2060 Versus Actual 1960-2010		
	IIASA	OECD	PIK	IIASA	OECD	PIK
World						
Actual 1960-2010	3.8%	3.8%	3.8%	543%	543%	543%
SSP1	3.0%	3.4%	3.2%	337%	424%	372%
SSP2	2.8%	2.9%	3.0%	305%	317%	348%
SSP3	2.2%	2.2%	2.3%	201%	191%	215%
SSP4	2.2%	2.7%	3.0%	198%	277%	330%
SSP5	3.5%	4.0%	3.5%	467%	608%	462%
U.S.						
Actual 1960-2010	3.2%	3.2%	3.2%	374%	374%	374%
SSP1	1.9%	2.0%	1.6%	157%	168%	124%
SSP2	1.8%	1.7%	1.7%	142%	131%	130%
SSP3	1.1%	1.1%	0.8%	74%	76%	51%
SSP4	1.7%	1.9%	1.7%	127%	150%	128%
SSP5	2.6%	2.7%	2.4%	267%	287%	221%
China						
Actual 1960-2010	8.1%	8.1%	8.1%	4713%	4713%	4713%
SSP1	3.7%	4.3%	NA	504%	702%	NA
SSP2	3.6%	3.7%	NA	472%	504%	NA
SSP3	3.3%	2.9%	NA	416%	322%	NA
SSP4	2.8%	3.6%	NA	299%	483%	NA
SSP5	4.1%	4.8%	NA	662%	937%	NA

Sources:

SSP public database (version 1.1), *https://tntcat.iiasa.ac.at/SspDb*, generated Sept. 5, 2018.

IFs version 7.31, *https://pardee.du.edu/access-ifs*.

Table 6

SSP SCENARIO COMPARISON, ANNUALIZED AND CUMULATIVE GDP PER CAPITA GROWTH FOR THE WORLD AND SELECTED COUNTRIES, 1960-2010 VERSUS 2010-2060

	Annualized Real GDP/Capita Growth Rate, SSP Scenarios 2010-2060 Versus Actual 1960-2010			Cumulative Real GDP/Capita Growth, SSP Scenarios 2010-2060 Versus Actual 1960-2010		
	IIASA	OECD	PIK	IIASA	OECD	PIK
World						
Actual 1960-2010	2.1%	2.1%	2.1%	180%	180%	180%
SSP1	2.6%	2.9%	2.7%	257%	326%	285%
SSP2	2.2%	2.3%	2.4%	198%	205%	229%
SSP3	1.4%	1.3%	1.4%	97%	88%	105%
SSP4	1.6%	2.0%	2.3%	121%	176%	217%
SSP5	3.1%	3.5%	3.1%	356%	466%	351%
U.S.						
Actual 1960-2010	2.1%	2.1%	2.1%	187%	187%	187%
SSP1	1.2%	1.3%	1.0%	85%	92%	62%
SSP2	1.2%	1.1%	1.1%	78%	70%	71%
SSP3	1.0%	1.0%	0.7%	65%	68%	43%
SSP4	1.2%	1.4%	1.2%	83%	101%	84%
SSP5	1.6%	1.7%	1.3%	116%	128%	90%
China						
Actual 1960-2010	6.5%	6.5%	6.5%	2229%	2229%	2229%
SSP1	4.0%	4.6%	NA	625%	863%	NA
SSP2	3.8%	4.0%	NA	560%	597%	NA
SSP3	3.5%	3.1%	NA	462%	360%	NA
SSP4	3.3%	4.1%	NA	407%	641%	NA
SSP5	4.5%	5.2%	NA	814%	1144%	NA

Sources:

SSP public database (version 1.1), *https://tntcat.iiasa.ac.at/SspDb*, generated Sept. 5, 2018.

IFs version 7.31, *https://pardee.du.edu/access-ifs*.

f. Hillebrand and Closson Scenario Set

Evan Hillebrand and Stacy Closson (2015) have developed a set of eight global scenarios for the period 2010-2050 that are valuable in their own right but also useful in terms of the scenario development framework used by the authors. Three factors are identified that they believe are most pertinent to a state of the world scenario: economic growth, energy prices and geopolitical relationships. They set out to develop a scenario for each combination of low/high global GDP growth, low/high energy prices, and low/high political harmony. For each scenario (e.g., low growth with high energy prices and high harmony), they articulate a broader set of conditions

that might cause that scenario to develop and sustain over the projection period (e.g., low growth implies relatively weak energy demand, so high energy prices might result from aggressive policies to shift to renewable energy sources and a slow pace of renewable energy innovation).

They then express in a broad way the logical consequences of these scenarios over time (e.g., if a more harmonious world were to develop under conditions of low growth and high energy prices, what sorts of policies, international agreements and institutions might individual state actors logically put in place to allow for that harmony?). Their process was both qualitative and quantitative, with a great deal of qualitative thought on the conditions and consequences, but also with the development of quantitative projections using the IFs model described in Section IV.c to allow for more robust analysis. Their scenario input files are available on an open-access basis when the IFs model is downloaded from the Pardee Center, allowing the user to project the Hillebrand and Closson scenarios. Results are described in greater detail below.

Finally, the authors evaluated the likelihood of each scenario. The scenario development itself was agnostic to likelihood, and the scenarios were not intended to be equally likely. Said another way, the low-growth/high-energy price/global harmony scenario, for instance, was based on conditions that were intended to be logically consistent but not necessarily likely. After the scenarios had been fully developed, the authors evaluated their likelihood. Table 7 includes a brief description of the scenarios, along with their likelihood as determined by the authors:

Table 7

HILLEBRAND AND CLOSSON SCENARIO DESCRIPTIONS

Scenario	Probability	Energy Prices	Economic Growth	Geopolitics
1: Catching up to America	Low	Low	Strong	Global harmony (Chinese hegemony)
2: Global backtracking	Medium	Low	Weak	Global disharmony (multipolarity)
3: Peaceful power transition	Medium	High	Strong	Global harmony (Chinese hegemony)
4: Regional mercantilism	Medium	High	Weak	Global disharmony (multipolarity)
5: A new bipolarity	High	High	Strong	Global disharmony (bipolarity)
6: Eco world	Low	High	Weak	Global harmony (U.S. hegemony)
7: Ambition fuels rivalry	High	Low	Strong	Global disharmony (multipolarity)
8: Natural disasters promote unity	Low	Low	Weak	Global harmony (multipolarity)

Source: Hillebrand and Closson, 2015, p 183

In each of these scenarios, growth is relatively low in the developed world. In the high-growth scenarios, growth is driven by China and the developing world, and China's power grows as U.S. power shrinks. Energy prices in each scenario correspond with the net effect of the assumed rate of innovation and the demand due to GDP growth. The authors generally view a world with a single power as more harmonious than a bipolar or multipolar power structure. The

authors generally view high-growth scenarios as more likely than low-growth scenarios, with Scenarios 5 and 7 assuming high probability and Scenario 3 having medium probability. Meanwhile, for the low-growth scenarios, they assign medium probability to Scenarios 2 and 4 and low probability to Scenarios 6 and 8. However, it is notable that the low-growth scenarios they consider more likely are generally the ones generating the weakest growth: Scenario 2, with medium probability, generates the weakest GDP growth of any scenario, with average 2010-2060 per capita GDP growth of 0.3 percent worldwide, 0.2 percent in the U.S. and 1.7 percent in China. The 50-year growth projections for these scenarios are summarized in Table 8.

Table 8

HISTORICAL GDP GROWTH, 1960-2010; PROJECTED GROWTH, 2010-2060; IFS BASE AND HILLEBRAND AND CLOSSON SCENARIOS—U.S., CHINA, THE WORLD

	Annualized GDP Growth						50-year Cumulative GDP Growth					
	Aggregate GDP			Per capita GDP			Aggregate GDP			Per capita GDP		
	US	China	World	US	China	World	US	China	World	US	China	World
Historical 1960-2010	3.2%	8.1%	3.8%	2.1%	6.5%	2.1%	374%	4713%	543%	187%	2229%	180%
IFs Base	1.5%	3.2%	2.3%	1.0%	3.4%	1.5%	108%	391%	210%	67%	423%	115%
HC1 - Catching America	2.1%	3.9%	2.9%	1.7%	4.1%	2.2%	189%	591%	328%	131%	628%	196%
HC2 - Global backtracking	0.6%	1.5%	1.0%	0.2%	1.7%	0.3%	36%	109%	64%	11%	128%	13%
HC3 - Peaceful transition	2.0%	2.5%	2.5%	1.5%	2.7%	1.8%	166%	247%	248%	113%	273%	141%
HC4 - Regional mercantilism	1.1%	1.4%	1.3%	0.7%	1.6%	0.6%	75%	105%	92%	41%	123%	33%
HC5 - New bipolarity	2.2%	2.3%	2.3%	1.7%	2.5%	1.5%	191%	219%	209%	133%	244%	113%
HC6 - Ecoworld	1.0%	1.4%	1.4%	0.5%	1.5%	0.9%	61%	97%	104%	31%	115%	53%
HC7 - Ambition fuels rivalry	2.1%	2.1%	2.2%	1.6%	2.3%	1.4%	178%	186%	197%	123%	209%	104%
HC8 - Disasters promote unity	1.1%	2.9%	1.7%	0.6%	2.8%	0.7%	73%	315%	133%	33%	294%	43%

Source: Data generated from International Futures model, version 7.31. Downloaded from *http://pardee.du.edu/access-ifs*.

g. The Long View: Scenarios for the World Economy to 2060

This discussion is based on Guillemete and Turner (2018), with additional thoughts by the researchers.

This paper, which extends the two-year horizon of the OECD Economic Outlook series, outlines the current orthodox view of long-term GDP scenarios. Other measures reflecting quality of life and income inequality are not considered. It also highlights how volatile actual results can be; things change quickly. Throughout the paper, Turkey is considered an emerging market very likely to close the gap with the United States due to expected reforms and demographics. Turkey entered a currency crisis only a month post publication.

Noticeably missing is any discussion of the environment or resource limitations. This is consistent with much of the conventional wisdom, which assumes that any such limitations can be addressed through markets and technology. Despite not considering any climate change scenarios, the OECD baseline and alternatives provide a good qualitative discussion of what drives GDP growth.

A number of sensitivity tests are considered,[11] in most cases representing policy, governance or structural reforms that the authors believe would improve GDP growth. In the base case, global GDP growth drops from approximately 3.5 percent annually to 2 percent by 2060 as aging demographics in developed countries shift GDP toward Asia and away from North America and Europe. The negative scenario seems to be driven by recent events, assuming that tariffs would revert to 1990 levels.

The OECD assumes that public debt to GDP ratios will stabilize at current levels despite aging populations requiring greater health spending with fewer workers. This seems unrealistic, and taxes at some point will need to rise to offset these issues.

Countries are grouped into four broad categories: high-growth emerging markets, low-growth emerging markets, high-growth Eastern European economies and all other advanced economies. The goal is to model global GDP, so there will be volatility between countries.

There are several factors that could narrow the gap between those countries with high GDP per capita today and those that trail behind. Some are preordained, like having a younger population that ages later than in developed countries, with younger female workers continuing higher employment rates as they age. Improving governance through the rule of law and property rights (someone interested in more detail could review the World Bank's rule of law index, which uses six governance indicators and has been published for more than 200 countries since 1996), educational attainment for both genders, fiscal sustainability through interest rates on debt, openness to trade, retirement age, research and development spending, infrastructure spending, and structural reforms all serve to improve living standards materially in many countries.

The OECD scenarios assume that interest rates on government debt increased by two basis points (0.02 percent) for each percentage point the debt to GDP ratio rises above 75 percent, increasing to four basis points when the ratio exceeds 125 percent.

Although several sensitivity tests were included in this OECD paper, we were able to download model output for the baseline scenario only. Table 9 summarizes the projected 2010-2060 growth rates for the OECD baseline scenario compared with actual growth for 1960-2010 and with the IFs base scenario. We have also included, as an additional comparative scenario, Randers' 2052 projections (Randers, 2012), as discussed in Section III.a. The OECD projections show growth rates modestly higher than the IFs base scenario and toward the high end of the scenarios we reviewed but still lower than 1960-2010 actual growth for the most part. Randers generally projects U.S. growth lower than the IFs base scenario but comparable to the IFs base scenario for China and the world as a whole.

[11] Scenarios include baseline, governance reform, product market liberalization, labor market reforms, increase retirement ages, R&D spending boost, public investment boost, stabilize public debt ratios, rising trade protectionism.

Table 9

HISTORICAL GDP GROWTH, 1960-2010; PROJECTED GROWTH, 2010-2060; IFS BASE, OECD AND JORGEN RANDERS SCENARIOS—U.S., CHINA, THE WORLD

	Annualized GDP Growth						50-year Cumulative GDP Growth					
	Aggregate GDP			Per capita GDP			Aggregate GDP			Per capita GDP		
	US	China	World	US	China	World	US	China	World	US	China	World
Historical 1960-2010	3.2%	8.1%	3.8%	2.1%	6.5%	2.1%	374%	4713%	543%	187%	2229%	180%
IFs Base	1.5%	3.2%	2.3%	1.0%	3.4%	1.5%	108%	391%	210%	67%	423%	115%
Randers 2052	0.6%	3.6%	2.0%	0.4%	4.0%	1.6%	34%	490%	164%	21%	609%	121%
OECD 2018 base	1.9%	3.3%	2.6%	1.4%	3.4%	2.3%	160%	402%	270%	99%	430%	216%

Sources: IFs base from IFs version 7.31, *https://pardee.du.edu/access-ifs*; Randers 2052 data from *http://www.2052.info/download/* accessed Jan. 11, 2018; OECD 2018 data extracted on September 3, 2018, 22:54 UTC (GMT) from *https://stats.oecd.org/*.

h. Summary of Scenarios Developed by Others

All told, we have reviewed the results of 30 different scenarios created by others: five SSP scenarios modeled by each of three different groups; five scenarios generated at the Pardee Center (a baseline scenario and four sensitivity runs); eight scenarios generated by Hillebrand and Closson representing various combinations of low/high economic growth, energy prices and global harmony; Randers' 2052 scenario; and an OECD 2018 long-term scenario. While other scenarios may project higher or lower growth rates, we believe these scenario sets reasonably capture the extent of long-range scenarios currently in use in the economic community. These scenarios capture various modeling approaches and projection horizons, but all of them can be considered long-term, projecting to at least 2050.

Tables 10 and 11 summarize these scenarios for the world, the U.S. and China and require a few introductory comments. For all of the scenario sets, the data sources provide results for other countries and/or regional groupings, with many of them providing results for virtually all the world's countries and for various country groups. The tables capture both aggregate and per capita GDP growth rates for the 50-year period 2010-2060, on both annualized and cumulative bases, with the historical 50-year period 1960-2010 provided for comparison. Many of the scenarios were projected to 2100, but the additional 40 years are not provided here, to allow for comparability with those scenarios with a shorter projection horizon. Growth rates were generally declining over time in these scenarios, such that growth rates for the period after 2060 were lower than those before. Of the three sets of SSP scenarios, we have included only the IIASA set in order to make the table more digestible (see the SSP discussion for additional detail on the other sets). The Randers scenario was projected only to 2050; we extrapolated to 2060 using the average of the 2010-2050 growth rates, which tends to overstate the growth results, because Randers projected declining growth rates by year. Finally, our projection of Hillebrand and Closson Scenario 8 errored out after 2045 for unknown reasons; we have extrapolated this scenario from 2045 to 2060 the same way we extrapolated the Randers scenario.

Some key comments on the results for the 20 scenarios shown in these tables are as follows:

- None of these scenarios generates 50-year growth rates in aggregate GDP as high as the historical 1960-2010 growth rates, either for the U.S., China or the world as a whole. On a per capita basis, growth rates do exceed historical growth rates in several

scenarios for the world as a whole, but not for the U.S. or China individually. The more favorable global growth in per capita GDP is partly attributable to developing economies other than China but also partly due to the fact that China, while projected to grow more slowly than in the past, is a larger portion of the global pie and is still projected to grow considerably faster than the world as a whole.

- The median scenario is generally equal to the IFs base scenario, which is consistent with the objective of that scenario. Under that scenario, global GDP would grow at 2.3 percent annually (these metrics are geometric means), roughly tripling over the period; U.S. GDP would grow at 1.5 percent annually, roughly doubling over the period; and Chinese GDP would grow at 4.1 percent annually, roughly quintupling over the period. Comparatively, over the historical period, global GDP grew at 3.8 percent per year, increasing more than sixfold, U.S. GDP grew at 3.2 percent per year, nearly quintupling, and China's GDP grew at 8.1 percent per year, increasing 48-fold over the period. GDP per capita, while not as striking because it does not reflect the impact of slowing population growth, shows a similar pattern for this scenario. Global GDP per capita is projected to double, while it tripled over the historical period; U.S. GDP per capita is projected to increase by less than 70 percent, after tripling over the historical period; and Chinese GDP per capita is projected to quintuple, after increasing 23-fold over the historical period. It is clear that by the standards of the period since 1960, lower growth is a mainstream expectation for long-term scenarios.
- So if all these scenarios exhibit low growth by historical standards, what constitutes low growth within this range of scenarios? The lowest growth among these scenarios is generated in the Hillebrand and Closson Scenario 2, Global Backtracking, which combines low economic growth with low energy prices and global disharmony, and which they assessed as having a medium probability. In this scenario, growth is negligible, with aggregate GDP growing a cumulative 64 percent globally and 36 percent in the U.S., and per capita GDP growing only 13 percent globally and 11 percent in the U.S. China only doubles its aggregate and per capita GDP in this scenario.
- More broadly, six of the 20 scenarios generate global GDP growth rates of 2 percent or less and per capita GDP growth rates (with one exception) of 0.9 percent or less, six scenarios generate U.S. GDP growth rates of 1.1 percent or less and per capita GDP growth rates of 0.7 percent or less, and seven scenarios generate Chinese GDP growth rates of 2.5 percent or less, with per capita growth rates slightly higher because population is projected to decline.

Table 10

COMPARISON OF ALL REVIEWED SCENARIOS, ANNUALIZED GDP AND PER CAPITA GDP GROWTH FOR THE WORLD AND SELECTED COUNTRIES, 1960-2010 VERSUS 2010-2060

	Annualized GDP Growth Rate			Annualized per capita GDP Growth Rate		
	US	China	World	US	China	World
Historical 1960-2010	3.2%	8.1%	3.8%	2.1%	6.5%	2.1%
Scenarios 2010-2060						
Mean	1.5%	2.9%	2.2%	1.1%	3.1%	1.6%
Median	1.6%	3.2%	2.2%	1.1%	3.4%	1.6%
Min	0.6%	1.4%	1.0%	0.2%	1.5%	0.3%
Max	2.6%	4.1%	3.5%	1.7%	4.5%	3.1%
IFs Base	1.5%	3.2%	2.3%	1.0%	3.4%	1.5%
SSP1 Sustainability - IIASA	1.9%	3.7%	3.0%	1.2%	4.0%	2.6%
SSP2 Middle of the Road - IIASA	1.8%	3.6%	2.8%	1.2%	3.8%	2.2%
SSP3 Regional Rivalry - IIASA	1.1%	3.3%	2.2%	1.0%	3.5%	1.3%
SSP4 Inequality - IIASA	1.7%	2.8%	2.2%	1.2%	3.3%	1.6%
SSP5 Conventional Development - IIASA	2.6%	4.1%	3.5%	1.6%	4.5%	3.1%
GEO-4, Markets first	1.7%	3.4%	2.4%	1.2%	3.5%	1.7%
GEO-4, Policy first	1.5%	3.3%	2.3%	1.0%	3.4%	1.7%
GEO-4 Security first	1.3%	2.0%	1.8%	0.9%	2.1%	0.8%
GEO-4, Sustainability first	0.7%	3.2%	2.1%	0.5%	3.4%	1.6%
HC1 - Catching America	2.1%	3.9%	2.9%	1.7%	4.1%	2.2%
HC2 - Global backtracking	0.6%	1.5%	1.0%	0.2%	1.7%	0.3%
HC3 - Peaceful transition	2.0%	2.5%	2.5%	1.5%	2.7%	1.8%
HC4 - Regional mercantilism	1.1%	1.4%	1.3%	0.7%	1.6%	0.6%
HC5 - New bipolarity	2.2%	2.3%	2.3%	1.7%	2.5%	1.5%
HC6 - Ecoworld	1.0%	1.4%	1.4%	0.5%	1.5%	0.9%
HC7 - Ambition fuels rivalry	2.1%	2.1%	2.2%	1.6%	2.3%	1.4%
HC8 - Disasters promote unity	1.1%	2.9%	1.7%	0.6%	2.8%	0.7%
Randers 2052	0.6%	3.6%	2.0%	0.4%	4.0%	1.6%
OECD 2018 baseline	1.9%	3.3%	2.6%	1.4%	3.4%	2.3%

Table 11

COMPARISON OF ALL REVIEWED SCENARIOS, CUMULATIVE GDP AND PER CAPITA GDP GROWTH FOR THE WORLD AND SELECTED COUNTRIES, 1960-2010 VS 2010-2060

	Cumulative 50-year GDP Growth			Cumulative 50-year GDP per capita Growth		
	US	China	World	US	China	World
Historical 1960-2010	374%	4713%	543%	187%	2229%	180%
Scenarios 2010-2060						
Mean	120%	345%	214%	73%	393%	130%
Median	118%	391%	204%	73%	427%	118%
Min	34%	97%	64%	11%	115%	13%
Max	267%	662%	462%	133%	814%	351%
IFs Base	108%	391%	210%	67%	423%	115%
SSP1 Sustainability - IIASA	157%	504%	332%	85%	625%	254%
SSP2 Middle of the Road - IIASA	142%	472%	301%	78%	560%	196%
SSP3 Regional Rivalry - IIASA	74%	416%	198%	65%	462%	95%
SSP4 Inequality - IIASA	127%	299%	196%	83%	407%	119%
SSP5 Conventional Development - IIASA	267%	662%	462%	116%	814%	351%
GEO-4, Markets first	129%	430%	233%	78%	464%	130%
GEO-4, Policy first	109%	407%	217%	68%	438%	129%
GEO-4 Security first	90%	173%	138%	57%	176%	53%
GEO-4, Sustainability first	42%	390%	181%	26%	432%	116%
HC1 - Catching America	189%	591%	328%	131%	628%	196%
HC2 - Global backtracking	36%	109%	64%	11%	128%	13%
HC3 - Peaceful transition	166%	247%	248%	113%	273%	141%
HC4 - Regional mercantilism	75%	105%	92%	41%	123%	33%
HC5 - New bipolarity	191%	219%	209%	133%	244%	113%
HC6 - Ecoworld	61%	97%	104%	31%	115%	53%
HC7 - Ambition fuels rivalry	178%	186%	197%	123%	209%	104%
HC8 - Disasters promote unity	73%	315%	133%	33%	294%	43%
Randers 2052	34%	490%	164%	21%	609%	121%
OECD 2018 baseline	160%	402%	270%	99%	430%	216%

Taken together, these scenarios suggest ranges of expectation for low, medium and high growth rates over the next 50 years for the world, U.S. and China, as shown in Table 12.

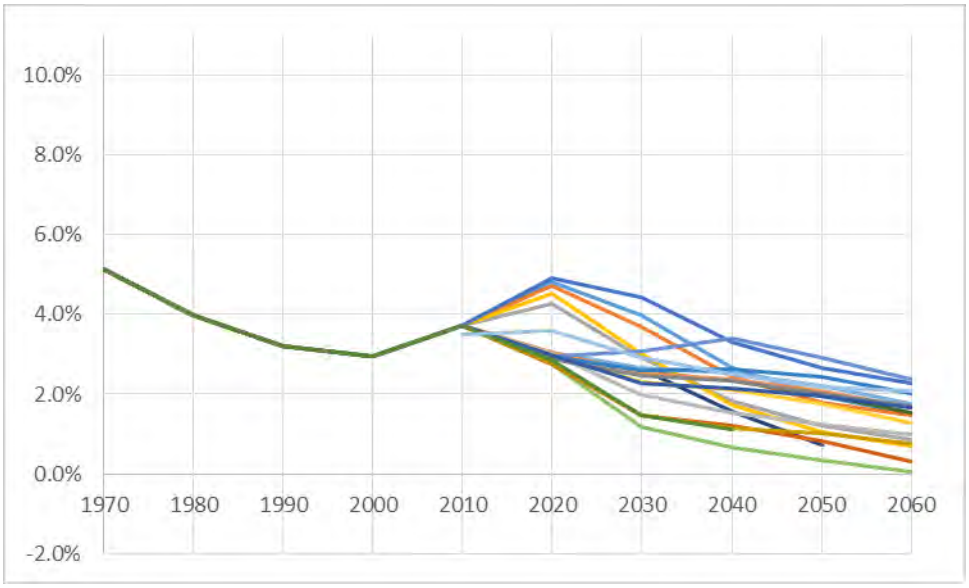
Table 12
GROWTH RANGES IN SECTION IV SCENARIOS COMPARED WITH 1960-2010

	Historical 1960-2010	Low	Medium	High
World aggregate	3.8%	1-2%	2-2.5%	2.5-3.5%
World per capita	2.1%	0-1%	1-2%	2-3%
U.S. aggregate	3.2%	0-1%	1-2%	2-3%
U.S. per capita	2.1%	1-2.5%	1-1.5%	1.5-2%
China aggregate	8.1%	1-2.5%	2.5-3.5%	3.5-4.5%
China per capita	6.5%	1-2.5%	2.5-3.5%	3.5-4.5%

One interesting comparison in Table 12 is the similarity between the U.S. growth over the past 50 years and China's expectations over the next 50 years.

The 50-year average growth rates, of course, do not tell the whole story of these scenarios. Generally, growth rates are projected higher in the early years and decline over time, as illustrated in Figure 11 for global aggregate GDP. See Appendix A for similar graphs for the U.S., China, the rest of the world and per capita GDP. From these scenarios, we have selected the Hillebrand and Closson Scenario 4, Regional Mercantilism, as the basis of our Section V analysis, as further discussed below.

Figure 11
SUMMARY OF SECTION IV GROWTH SCENARIOS, 2010-2060; GLOBAL ANNUALIZED GROWTH RATES BY DECADE VERSUS ACTUAL, 1960-2010[12]



[12] Figure 11 shows pattern and dispersion of the scenarios summarized in Tables 11 and 12, so the series have not been labeled.

i. Low-Growth Scenario Baseline: Hillebrand and Closson Scenario 4, Regional Mercantilism

This discussion is based on Chapter 5 of Hillebrand and Closson (2015), with additional thoughts from the researchers.

Upon review of all of the scenario sets discussed above, we selected Hillebrand and Closson Scenario 4, Regional Mercantilism ("HC4"), to use as the basis of our insurance/pension system analysis in Section V. Below, we describe further this scenario and the reasons for selecting it for further analysis.

Scenarios from the Hillebrand and Closson set were appealing for further analysis due to the robust scenario construction framework used by the authors and because the scenarios were modeled quantitatively in IFs. The Hillebrand and Closson scenarios, like other scenarios modeled in IFs, are extremely useful to someone trying to understand model flows since so many variables are available for study. While other scenario sets include population and GDP, with little else, these eight scenarios provide a large variety of variables for the user to choose from. Starting with a workshop to develop ideas, and the IFs base scenario to maintain consistency, three variables were combined with binary results. Energy prices, economic growth and geopolitics are split into good and bad outcomes, and eight scenarios have been built using each of the combinations. Each of the eight has been qualitatively thought through to maintain internal consistency, a challenging achievement, given the complexity involved.

Among the Hillebrand and Closson scenario set, Scenarios 2, 4, 6 and 8 were appealing for further analysis because they were consistent with the low-growth focus of this paper. HC4, treating each of the three key variables as negative, was chosen as a suitable scenario for further analysis because of this combination. This scenario was also selected because several elements of the scenario are consistent with recent international developments. In particular, this scenario is characterized by increasing protectionism, with barriers to trade and immigration increasing as nations become more insular. It includes volatile energy prices through the 2010s but envisions higher oil prices than current levels.

Results of the scenario show the interaction of high energy prices, weak economic growth and global disharmony in an environment called regional mercantilism. In this scenario, the United States loses its role as economic growth leader and reserve currency, resulting in a lost respect for democratic capitalism. Gaining in influence are China, state capitalism and populism generally, resulting in a rollback of trade and economic freedoms gained since the latter half of the 20th century.

Trade becomes more regional (moving away from the World Trade Organization) in this multipolar scenario. Protectionism leads to trade wars even as energy prices rise, with supply shortfalls and expensive renewables. Fears of domestic conflict rise due to limited economic opportunities and rising income inequality, and foreign policy by all parties becomes increasingly insular. Western democracies suffer from unfunded entitlement promises to the elderly and other safety nets. This reduces foreign direct investment and increases domestic political strife as international tensions rise, including conflicts due to resources. Not surprisingly, this scenario predicts the overthrow of weak democratic regimes in developing countries, with increases in drug wars, terrorism and piracy.

The scenario forecasts results to 2100, with the world's combined GDP growing at lower rates each decade and the non-OECD countries, especially China, catching the United States. Using

real GDP per capita and 2005 purchasing power parity, the United States grows from $42,100 in 2010 to $48,700 in 2050, while China increases from $6,800 to $17,500.

Protectionism brings back the era of The Gilded Age, where those who are connected to power do best while overall growth and employment are not shared with the masses. Aging populations and high payments to seniors through government-sponsored retirement and health programs become unsustainable as populations begin to shrink. Power in government leads to abuses that incapacitate leadership. Prices increase as foreign competition falls, but wages do not keep pace and taxes increase.

As the United States looks inward, countries like Iran are released to accept foreign investment and rejoin international markets. Following failed carbon emission agreements, China and India import coal from the United States as oil becomes less plentiful and coal becomes a cleaner option than today. Insurgencies increase, based on ideological, ethnic and profit-inspired groups and networks. Regional trading blocs of 15 or more countries include (names are representative) the Asian League (dominated by China), Trans-Pacific Partnership (assumed to be led by the U.S., as was the case at the time these scenarios were developed, and including Australia, Canada and Mexico), EU2050 (including Turkey, Israel and the Balkans), the African Union and the Islamic Brotherhood (a moniker used by the authors for an Islamic trading block dominated by Iran).

By 2050, growth rates have slowed to numbers anticipated by Robert Gordon at 0.5 percent or less. Income transfers from young to old dominate the latter part of the forecast period, but migration policies continue to discourage movement, even within regional trade blocs like the European Union. Countries like Russia that did not use money collected from resources to build up other industries lose in stature. The Russians take advantage of a fractured diplomatic environment by staking claims to newly accessible fossil fuels in the warming Arctic. India is a big loser, as it has poor relations with potential regional trading partners. The African Union has a large population but is impeded by poor governance and weak economic growth.

j. Section Conclusion

There is quite a bit of literature developing long-term growth forecasts and scenarios. Many tie together qualitative and quantitative assessments in ways allowing the reader to anticipate if the scenario will be relatively high or low growth. We have reviewed a significant number of these scenarios, including several multiple-scenario sets. All the scenarios we reviewed could be considered low-growth, in the sense that they all exhibit declining growth rates and 50-year average growth lower than the last 50 years.

Rather than consider several similar and overlapping low-growth scenarios, we opted to consider one scenario for further analysis. After reviewing the scenario sets we selected Scenario 4 of the Hillebrand and Closson project, nicknamed Regional Mercantilism by them and referred to here as HC4, for analysis in the following section as we discuss the implications of a low-growth environment on insurance and pension practices. This scenario falls in the lower third of the scenarios we reviewed and generally projects average annualized GDP growth rates less than 2 percent globally and less than 1 percent in the U.S. over the period 2010-2060.

V. Impact of Low Growth on Insurance/Pension Sectors

a. Introduction

In Section IV, we explored a range of long-term economic scenarios and projections created by a number of different authors. The most useful and robust scenarios begin qualitatively, with a narrative or story. Likely relationships are explored through the narrative, and quantitative scenarios are constructed with these relationships in mind. Several of the scenarios reviewed in Section IV were developed in this way. In Section V, we extend this concept to study how the insurance and pension sectors might be affected by, and might respond to, such a scenario. In the process, we will explore the difficulty of constructing a robust and internally consistent scenario, the inherent uncertainty in the key relationships assumed in any scenario and the need for a healthy skepticism in evaluating any quantitative scenario.

The scenario serving as the basis for our Section V analysis is HC4, as discussed in Section IV. Our analysis will make use of quantitative models of this scenario developed in IFs by Hillebrand and Closson, whose output we have downloaded, and we discuss a number of different variables from this model output.

In Section IV, we discussed model risk and the importance of model validation and careful analysis of model results. In some cases as we reviewed the IFs model output for HC4, we questioned an element of the model output or projected relationships among variables and include discussion of these instances as examples of the model review process, without necessarily reaching a definitive conclusion. In addition, there are other cases where we might expect a different result in a different low-growth scenario with different drivers, and we make note of some of these cases during the discussion. Finally, as discussed in Section IV.c, in the course of our review, we discovered an error in the IFs treatment of interest on government debt, which the Pardee Center was not able to correct prior to publication. We concluded that this error would invalidate our quantitative analysis of asset-related effects and that demonstration of a qualitative review would be valuable, so we have not utilized the IFs results. This experience highlights the importance of validating and analyzing your model results carefully.

In a typical risk management taxonomy, risks and opportunities are classified as asset-related, liability-related, operational and strategic. We follow this classification in discussing the impact of the HC4 scenario on the insurance and pension sectors and the potential industry responses. To illustrate both qualitative and quantitative scenario analysis processes, we use contrasting approaches for liability and asset risks. For liability risks, we begin with quantitative projections of HC4 from the IFs model, critiquing those results and discussing how alternate scenarios might differ. For asset risks, our analysis is primarily qualitative, partly because of the IFs model error noted above, but also to illustrate and emphasize the importance of such qualitative analyses. We begin with the liability risk discussion, followed by the asset risk discussion, and the operational and strategic risk discussion, wrapping up with a discussion of potential industry responses.

b. Implications for Liability Risks and Assumptions

Mortality and Morbidity

Mortality and Morbidity in IFs

The IFs model projects country-specific mortality by age, gender and 15 cause-of-death groupings, based on the Global Burden of Disease models developed by Mathers and Loncar (Mathers and Loncar, 2006). Mortality rates are projected primarily as a function of several distal (distant, or indirect) drivers—per capita GDP, education, smoking impact and time—with time factors based on regression models of historical mortality improvement. In addition to the distal drivers, the model also overlays the impact of several proximate (direct) drivers—childhood undernutrition, adult body mass index and obesity, water and sanitation, indoor and outdoor air pollution—with the proximate drivers themselves impacted by some of the same distal drivers. IFs incorporates feedback loops, such that changes in mortality (and morbidity), in turn, affect per capita GDP and related variables through their impact on such factors as the productivity of labor and capital and the size of the workforce.

IFs measures morbidity primarily in terms of disability rates, with the modeling of morbidity based directly on the modeling of mortality.

Health care spending—both public and private—is modeled in IFs but is largely independent of mortality and morbidity, except at very young ages. This is based on research by Nixon and Ulmann, which found that "increases in health care expenditure are significantly associated with large improvements in infant mortality but only marginally in relation to life expectancy" (Nixon and Ulmann, 2006). See additional discussion below.

Mortality and Morbidity: HC4 Versus IFs Base Scenario

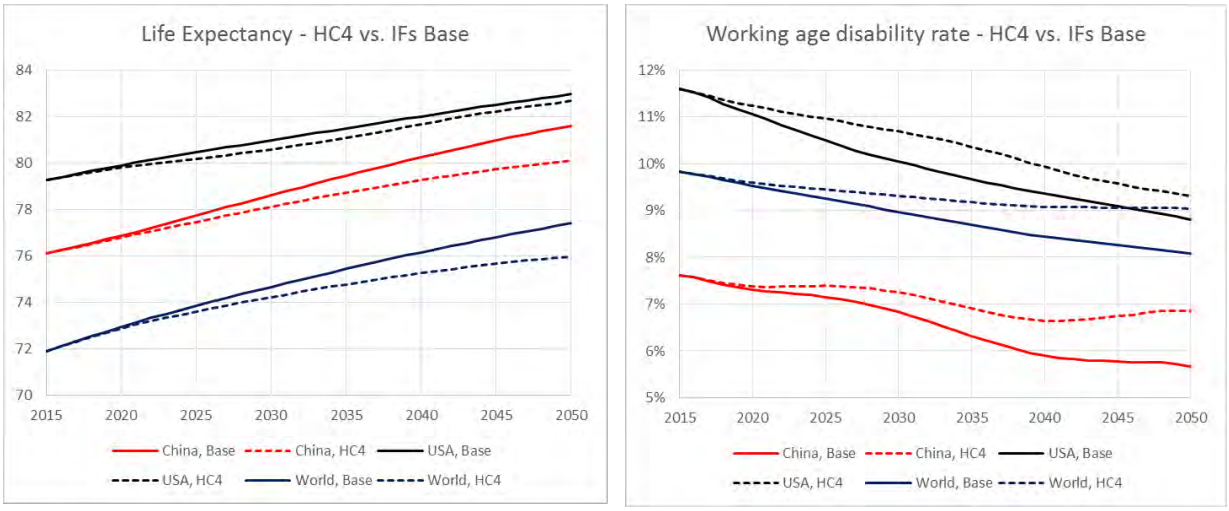
Mortality and morbidity outcomes in scenarios projected in IFs can be affected indirectly by changes in such factors as GDP growth and education or directly through changes in the mortality modeling parameters. In the HC4 scenario, none of the health or mortality-specific variables was modified from the IFs base scenario, so all changes in mortality and life expectancy are driven indirectly by changes in other parameters that contributed to limited GDP growth, higher energy costs and geopolitics.

Figures 12 and 13 demonstrate the difference in mortality and morbidity outcomes for China, the U.S. and the world in the HC4 scenario compared with the IFs base scenario. Figure 12 graphs projected life expectancies, showing moderately lower life expectancies for China and the world in the HC4 scenario, with the base scenario showing five to six years of improvement from 2015 to 2050 and HC4 showing approximately four years of improvement. The U.S., which has much smaller differences in GDP growth in the two scenarios, shows a negligible difference in life expectancy, with three to four years of improvement in both scenarios. To help translate these results into measures more meaningful for actuaries, we have calculated that four years of life expectancy improvement is roughly equivalent to accumulating 35 years of mortality improvement at a 1 percent rate for all ages, so the base scenario change in life expectancy equates to about 1.4 percent annual improvement for China and for the world and 0.9 percent improvement for the U.S., with China's and the world's annual improvement rates reduced by about 0.4 percent in HC4.

The measures of morbidity available in IFs model output are less useful for an actuarial audience and are more difficult to compare across scenarios. For Figure 13, we have used a "years living with disability at working age" variable divided by the working age population to estimate the working age disability rate. The initial U.S. disability rate measured in this way is about 1 percent higher than that reported in the *2017 Disability Statistics Annual Report* prepared for the Rehabilitation Research and Training Center on Disability Statistics and Demographics (Kraus et al., 2018), and the relationship among the rates computed for China, the U.S. and the world are counterintuitive and may suggest some measurement inconsistencies. Nevertheless, the relationship among the two scenarios is useful, with the IFs base scenario showing significantly greater reduction in disability rates than the HC4 scenario.

Figures 12 and 13

PROJECTED LIFE EXPECTANCY AND WORKING AGE DISABILITY RATES, U.S., CHINA AND THE WORLD, HILLEBRAND AND CLOSSON SCENARIO 4 VERSUS IFS BASE SCENARIO



Source: Data generated from International Futures model, version 7.31. Downloaded from *http://pardee.du.edu/access-ifs*.

While these relationships are directionally reasonable, it is important to validate the results against other causal and correlated variables as well as the reasonableness of those other variables. This is a particularly important exercise with a complex model. As part of our evaluation of mortality and morbidity outcomes in HC4, we wanted to understand how these impacts related to changes in key drivers and variables that we would expect to positively correlate with these outcomes. In particular, we looked further at education, which is a key distal driver of mortality and morbidity in the IFs model, and health care spending, which we would expect to correlate with mortality and morbidity outcomes over the long term.

Table 13 shows growth in health care spending relative to both the growth in overall GDP and the increase in life expectancy in the IFs base scenario and the HC4 scenario. We related growth in health care spending to overall GDP through both growth rates and share of GDP measures, which indicate that while health care spending grows more slowly in HC4 than in the base scenario, it outstrips overall GDP growth in both scenarios. Each region's 2050 health care share of GDP is nearly the same in HC4 as in the IFs base scenario. We related the increase in life expectancy to growth in health care spending by computing the increase in life expectancy per $1,000 of increase in health care spending, with HC4 showing greater life expectancy gains per unit of health care spending than the base scenario. Both of these results should give pause

to the risk manager. First, it may not be reasonable to expect health care to crowd out other spending to the same degree when long-term growth is constrained. Second, it may not be reasonable for HC4's relatively low growth in health care spending to have such high impacts on life expectancy. Both of these points might support a view that one might reasonably expect HC4 mortality rates higher than those projected in IFs.

Table 13

COMPARISON OF HEALTH EXPENDITURES AND LIFE EXPECTANCY, U.S., CHINA AND THE WORLD, HILLEBRAND AND CLOSSON SCENARIO 4 VERSUS IFS BASE SCENARIO

	China		U.S.		World	
	Base	HC4	Base	HC4	Base	HC4
Health Expenditures per capita						
2015 - $000s	$ 0.4	$ 0.4	$ 9.1	$ 9.1	$ 1.1	$ 1.1
2050 - $000s	$ 4.4	$ 1.9	$ 18.4	$ 16.4	$ 2.7	$ 1.8
2015 to 2050 Change - $000s	$ 4.0	$ 1.5	$ 9.3	$ 7.3	$ 1.6	$ 0.8
% of GDP 2015	5.5%	5.5%	17.1%	17.1%	9.8%	9.8%
% of GDP 2050	12.1%	11.7%	24.5%	24.1%	12.9%	13.3%
Cum Growth 2015-2050	996%	386%	102%	81%	150%	72%
Ann Growth 2015-2050	7.1%	4.6%	2.0%	1.7%	2.7%	1.6%
Life Expectancy						
Life Expectancy 2015	76.1	76.1	79.3	79.3	71.9	71.9
Life Expectancy 2050	81.6	80.1	83.0	82.7	77.4	76.0
Life Expectancy Change 2015-2050	5.5	4.0	3.7	3.4	5.5	4.1
LE chg / $1000 chg in per capita spending	1.4	2.6	0.4	0.5	3.4	5.3
Per Capita GDP Growth 2015-2050						
Total GDP - Cumulative	403%	130%	41%	29%	91%	27%
Total GDP - Annual	4.7%	2.4%	1.0%	0.7%	1.9%	0.7%
Non-health GDP - Cumulative	368%	115%	29%	18%	84%	22%
Non-health GDP - Annual	4.5%	2.2%	0.7%	0.5%	1.8%	0.6%

Source: Data generated from International Futures model, version 7.31. Downloaded from *http://pardee.du.edu/access-ifs*.

Table 14 relates educational attainment to changes in education spending (using constant real dollars). Unlike health care spending, education spending growth does not outstrip GDP growth in either scenario. However, HC4 shows markedly greater educational attainment per unit of spending. For instance, in China the base scenario projects a per capita increase of $1,600 in education spending leading to a 2.7 year increase in average educational attainment, while HC4 achieves a 2.1 year increase in average educational attainment with a spending increase of only $400. Similar relationships hold for the U.S. and the world as a whole. The risk manager should ask whether such significant increases in educational attainment are aggressive given the limited education spending in HC4, and whether mortality is understated as a result.

Table 14

COMPARISON OF EDUCATIONAL ATTAINMENT AND EDUCATION EXPENDITURES, U.S., CHINA AND THE WORLD, HILLEBRAND AND CLOSSON SCENARIO 4 VERSUS IFS BASE SCENARIO

	China		U.S.		World	
	Base	HC4	Base	HC4	Base	HC4
Education Expenditures per capita						
2015 - $000s	$ 0.3	$ 0.3	$ 2.4	$ 2.4	$ 0.5	$ 0.5
2050 - $000s	$ 1.9	$ 0.7	$ 3.3	$ 2.8	$ 1.0	$ 0.6
2015 to 2050 Change - $000s	$ 1.6	$ 0.4	$ 0.9	$ 0.4	$ 0.5	$ 0.1
% of GDP 2015	3.8%	3.8%	4.5%	4.5%	4.3%	4.3%
% of GDP 2050	5.2%	4.4%	4.4%	4.1%	4.6%	4.1%
Cum Growth 2015-2050	587%	163%	36%	16%	106%	20%
Ann Growth 2015-2050	5.7%	2.8%	0.9%	0.4%	2.1%	0.5%
Educational Attainment						
Years of education Ages 20-29 - 2015	8.9	8.9	14.0	14.0	9.6	9.6
Years of education Ages 20-29 - 2050	11.6	11.0	14.8	14.6	11.8	11.2
Years of Education Change 2015-2050	2.7	2.1	0.8	0.7	2.2	1.5
YE chg / $1000 chg in per capita spending	1.7	4.7	1.0	1.8	4.4	16.4

Source: Data generated from International Futures model, version 7.31. Downloaded from *http://pardee.du.edu/access-ifs*.

Other Mortality Risks and Drivers

We have already discussed several long-term risk management questions with respect to mortality within the context of the modeling approach: Might one expect the HC4 slowdown in the growth of health care spending to have an even greater impact on life expectancy? Might one expect the growth in health care spending to be even slower than projected in HC4 given the low level of GDP growth? Might one expect educational attainment to grow more slowly given the slow growth in education spending, with resultant slowdown in mortality improvement? Now we discuss some additional factors not considered in the HC4 projections that could further limit mortality improvement or even contribute to increasing mortality.

As noted above, direct impacts to mortality assumptions have not been included in the HC4 scenario. What additional direct impact might this or other low-growth scenarios have on the drivers of health and mortality, either because of low growth itself or because of the drivers of low growth? According to a 2018 Society of Actuaries report, for the period 2009-2016, the U.S. population experienced average annual mortality improvement of 0.4 percent, compared with 1.5 percent for the period 1999-2009. This includes mortality increases over that seven-year period for ages 15-44 and 55-64. Compared with the 1999-2009 period, 2009-2016 mortality improvement had slowed or reversed for all major causes of death except cancer and pulmonary disease. Mortality from opioid overdoses more than doubled from 2009 to 2016 and nearly quadrupled from 1999 to 2016 (Holman et al., 2018, Appendices A and B). Suicides have also been on the rise, albeit more modestly than opioid deaths, increasing 15 percent from 2009 to 2016 and 30 percent from 1999 to 2016. On a combined basis, U.S. suicide and opioid mortality rates were nearly 0.27/1,000 in 2016, up from 0.13/1,000 in 1999, and exceeded 0.40/1,000 in the 25-54 age group, comprising as much as 18 to 33 percent of total 2016 deaths for these age groups.

Suicides and opioid deaths have been characterized as “deaths of despair,” a term used by Princeton’s Case and Deaton in their studies into the causes of increasing midlife mortality since

the year 2000 among white, non-Hispanic Americans (Case and Deaton, 2015, 2017). Muennig et al. have argued that these effects can be linked to indicators of increased despair going back to the 1980s and are not exclusive to the white population but that their effects in minority populations have been masked by the disproportionate impact of the crack and AIDS epidemics on those populations beginning in the 1980s (Muennig et al., 2018). Case and Deaton posit as a causative factor a "cumulative disadvantage from one birth cohort to the next … triggered by progressively worsening labor market opportunities at the time of entry for whites with low levels of education" (Case and Deaton, 2017). Muennig et al. measure the increase in despair through surveys of self-reported happiness and trust in others and posit causes including "economic stagnation since the 1980s for moderate-income households" and "failure of democratic institutions and regulations" (Muennig, 2018).

Other recent research into suicide rates finds the U.S. to be an outlier internationally, with suicide rates decreasing in most parts of the world. Possible reasons are varied and include increases in freedom for women in China and India; gradual recovery from the collapse of the Soviet Union, which sent suicide rates skyrocketing among Russian men in the 1990s; urbanization, which tends to limit the means for committing suicide; and government policies that have variously improved health care, retrained and placed the unemployed, and limited access to common means of suicide ("Suicide – Defeating Despair", 2018).

While many factors may contribute to these so-called "deaths of despair", some of the underlying drivers of such deaths might be considered characteristic of low-growth scenarios in general and the HC4 scenario in particular. Lack of economic opportunity is a common theme in the research into these deaths, and persistent lack of economic opportunity would be expected among many segments of the population in a long-term low-growth scenario. While existing research has often focused on segments of the population with lower income or lower education levels, those effects would likely spread to other population segments in the event of long-term growth stagnation. These effects might be exacerbated in the HC4 scenario, a scenario driven by nationalistic tendencies, by declines in trust and increases in conflict among segments of the population.

In addition to the factors mentioned above for the HC4 scenario, many low-growth scenarios, particularly those driven by climate change or other environmental factors, would impact human health and mortality in other ways. The International Actuarial Association (Gutterman et al., 2017) has reviewed and summarized research into the effects of climate change and mortality, concluding that climate change will have wide-ranging effects on mortality around the world, with most effects being adverse but some being favorable, and with certain vulnerable populations most exposed to adverse effects. Adverse effects are likely to include increases in certain infectious diseases, respiratory diseases and conditions, cancers, and heat-related conditions; increased incidence of drought and famine; weather events and natural disasters, including heat events, hurricanes and other flood events; and the impact of increased poverty. The recent increases in wildfire activity in the western U.S. have significantly affected air quality and may provide a case study for the impact of pollution on chronic disease mortality, even among populations not generally considered vulnerable. Favorable effects are likely to include the impact of warmer winter temperatures, improved crop yields in some regions due to warmer temperatures and a potential CO_2 fertilization effect, and the indirect benefits from mitigation and adaptation measures. On balance, these impacts are expected to be adverse but with widely varying and uncertain effects.

Pandemic risk presents a frightening chicken-and-egg question with respect to low growth and particularly with respect to a climate-driven scenario. A major pandemic, the scale of which has not been seen since 1918, due to plague or influenza or some new virus, might be a driver of a low-growth scenario. It would undoubtedly generate a major shock to the world economy, which could well persist for an extended period. At the same time climate change could impact pandemic risk in both predictable and unforeseeable ways. Historically, warmer and wetter cycles led to fewer rodents, so fleas carrying bubonic plague sought out alternate hosts, like humans (Zielinski, 2015). Increasing temperatures have already led to increases in the range of insect-borne diseases, and natural disasters are often followed by infectious disease outbreaks, such as cholera. In addition, epidemiologists are concerned with the unpredictable ways that "increased variation in weather patterns can result in changes in human and animal interactions," increasing the risk of diseases crossing over between animal and human populations (Ayscue, 2017). Perhaps even more frightening, scientists have discovered traces of previously eradicated diseases, such as smallpox and the Spanish flu, that could be exposed by thawing permafrost. Studies have found that certain viruses and bacteria are very hardy when frozen in permafrost, with some having been revived after being frozen for thousands or even millions of years (Fox-Skelly, 2017). While not captured in standard models of the effects of climate change or low growth, these risks cannot be discounted.

Mortality and Morbidity Consequences for the Life Insurance and Pension Sectors

It is a truism to say higher mortality rates increase life insurance costs and decrease pension costs. However, the discussion above relates to the broader population, and the impact on the life insurance and pension sectors will depend on how the covered populations are affected and how the industry is able to respond.

In many ways, the life insurance industry has been insulated from many of the adverse mortality effects described above because its target market (predominantly affluent) has also been insulated; because its underwriting practices and contractual exclusions have effectively screened out the higher-risk populations; and because its annuity contracts provide a natural, albeit imperfect, hedge. Pandemics impact most the groups that cannot reduce contact rates, so socioeconomic status is a key driver of both morbidity and mortality effects. Generally, one would expect the industry to continue to benefit from these protective barriers. The deaths of despair will continue to disproportionately affect those with lower incomes. The mortality burden of climate change is expected to disproportionately affect vulnerable populations who are generally uninsured. However, a low-growth scenario could affect insured mortality in significant ways. To the extent that a slowdown in mortality improvement is driven by a slowdown in health care spending or research and development, the insured population would feel that impact. In a period of long-term stagnation, an ever-increasing portion of the population might be subject to diseases of despair. Some effects of climate change—increased vulnerability of coastal populations to extreme events, increased vulnerability to infectious disease due to mutation and expansion of the habitat range of carriers—will no doubt affect affluent and insured populations. With respect to the annuity product hedge, if sales of such investment-based products suffer in a low-growth environment, the industry could lose the benefit of that hedge. All told, an industry that has made its bets on future improvements in mortality could find itself losing those bets. And it could find that its ability to cover its losing bets with ever-increasing amounts of new business would be constrained in a low-growth environment.

For the medical and accident & health insurance sectors, morbidity effects would largely track with mortality results, but cost of care considerations would be different. Expenditures in IFs use real prices, so the expenditure analyses discussed above do not reflect inflation. To the extent that benefits adjust with inflation, benefit costs would be subject to the same inflation considerations discussed above. Slower growth would also likely reduce investment in research and other forms of medical technology, slowing growth in the cost of care. IFs does model these dynamics, so this effect should be captured in the IFs output, but it is a result we were not able to analyze robustly and represents a potentially favorable effect for health insurers (if not for policyholders).

For the pension system, the mortality effects of a low-growth scenario would be expected to partially mitigate the effect on asset returns. Because the portion of the population covered by the pension system—including the defined benefit pension system, the defined contribution system and the Social Security system—is much broader than the portion covered by the life insurance system, pension mortality would be expected to more fully reflect the effects discussed above for population mortality. Two significant questions for the pension system are the effect by age and the effect by income level. To date, reversal of mortality improvement has predominantly affected younger ages and lower incomes, both of which limit its effect on pension liabilities. Case and Deaton have posited a cohort effect in which the cohorts with higher mortality rates at younger and middle ages will continue to experience higher mortality as they age, which would be more favorable to pension liabilities than if the effect is limited to lower ages. In addition, while the pension population is not dominated by the affluent to the extent the life insurance industry is, the affluent have higher benefits and account for greater liabilities, which limits the effect of mortality changes for lower-income participants. Ultimately, higher mortality in a low-growth scenario is bound to reduce pension liabilities, providing a partial offset to adverse investment effects, but the extent of that offset will depend on the breadth of the effects. The larger economic impact of higher mortality at older ages would be a reduction in public pension plan and nursing home liabilities.

Life, health and payout annuity products offered by insurers typically pay claims as nominal cash amounts, although a few policies include cost-of-living allowances that increase with inflation. Some casualty products include replacement features that restore the structure rather than a fixed cash amount. Those nominal benefits lose ground to inflation each year. For example, a family might take out a $100,000 face amount policy on each parent based on current needs, but after five years of inflation the coverage is inadequate. This may impact insurance risk, because with high rates of inflation, older policies (whose prices may not correspond to current conditions) quickly become immaterial, which may not be the case in a low-growth/low-inflation scenario.

Property and Casualty Risks

The short-term nature of property and casualty liabilities allows for frequent repricing, mitigating much of the liability risk that might arise from a low-growth scenario. These risks would be most impacted by a scenario with tipping points that drive rapid changes in experience over a short time or a scenario in which volatility increases dramatically—in short, a scenario that introduces “unknown knowns,” where past experience is not predictive of future experience over a short time horizon. The HC4 scenario does not carry any apparent unique or significant risks for these coverages, and we have not identified IFs output variables that are of significant use in evaluating these risks.

A factor that might be common across many low-growth scenarios is the impact of aging and deteriorating infrastructure. In any low-growth scenario, reduced investment would lead to aging roads, buildings, equipment and other infrastructure, both public and private, as a direct result of reduced investment. In addition, budgets to maintain existing structures could suffer, leading to more rapid deterioration. These dynamics could lead to an increase in property and liability insurance claims, although this effect would be expected to occur gradually over time.

A low-growth scenario related to climate change or other environmental factors would pose additional liability risks for property coverages. Indeed, the impact of climate change could lead to the ultimate "unknown known" scenario, where neither the expected value nor the variance can be expected to reproduce past experience, fundamentally undermining the actuary's ability to price many property and catastrophe risks using traditional methods. Even the methods described as "predictive" are based on statistical analysis of past data and may not be predictive in a changed climate. Reliable forward-looking pricing techniques are necessary to address climate risks.

c. Implications for Insurance and Pension Asset Risks and Returns

Interest Rates

Absent an event that triggers stagflation, we would expect interest rates in a low-growth scenario to be low. Imposing the business cycle on a low-growth scenario, the yield curve might invert more frequently, with short-term Treasury rates higher than the 10-year rate, but both long-term and short-term rates could stay low for a long period of time. Credit risk may rise to levels that make it hard to grow a business profitably, reflected in high credit spreads. The amount of leverage a business can support is dependent on the level of growth it achieves. If high-yield bonds tend to default, they will not be a good investment despite their high yields. This will drive bond yields even higher.

The most recent example of stagflation in the United States was driven by an oil shock in the 1970s, and a similar result could again be driven by oil. Since oil producers are few, they form a monopsony that can set oil prices outside normal forces of supply and demand. It is hard to come up with many other products where the same producer dynamics are likely to drive stagflation. Technology is one place there might be similar concentration. It's possible that a group of technology providers could form a cartel that controls access to some markets, with Amazon and Alibaba possible candidates shared here to better demonstrate the concept.

This does not mean that there are not other possible sources of high inflation and interest rates combined with low growth. As discussed in Sections III.e, III.f and III.g, unsustainable debt levels or cost-push inflation dynamics could drive inflationary pressure in some low-growth scenarios. However, whether driven by debt or commodity prices, we would expect periods of inflation to be corrective and short term in nature rather than a persistent effect of low growth.

In an environmentally driven low-growth scenario, supply shocks might be caused by such factors as resource depletion, impact of environmental degradation or natural disasters on productive capacity, or investment diverted to climate mitigation. Fresh water supply could become a primary driver of regional stress. These supply shocks would result in inflationary pressure.

In any low-growth scenario, deflationary pressures could result from higher unemployment rates and stagnant personal incomes, leading to reduced demand. Perhaps a scenario with a supply-shock trigger event leads initially to inflation, partially subsidized by government actions (tax reductions, Federal Reserve Bank actions), while longer-term demand pressures lead to lower prices in the long run. In potentially a worst-case scenario, barter systems return—and borrowing, and thus the need for a yield curve, would dry up, as no one was comfortable extending loans to any business.

Asset Returns

The value of an asset will eventually reflect a combination of the profits of the underlying company and the discount rate. As Benjamin Graham noted, while investors might treat price as a voting machine in the short run, eventually a weighing-machine analogy will align price and value (Graham, 1949). When the discount rate falls, as is the norm in a low-growth scenario, the inverse relationship with price leads to capital gains. Once expectations and reality both reflect a low level, that process stops. Then profitability drives the results. Some companies can do well by taking market share from their competitors, but it becomes hard for an entire industry or the market as a whole to do well. When rates rise, the opposite occurs—initially losses due to a higher discount rate and then reduced profitability due to the high cost of borrowing and higher expenses. In either case, uncertainty is high and expectations of asset returns are low or at best moderate.

If the low-growth scenario is due to an environmental event, returns will be low for the overall market, although certain industries may do well, depending on technology and regulations.

Available Asset Classes

In a low-growth scenario with low interest rates, investors will stretch asset classes to try to earn extra yield. Hedge funds will take on debt to leverage their returns, which may work in the short term. Long Term Capital Management (LTCM), a hedge fund run in part by Nobel Prize winners, was the poster child for picking up “nickels in front of a steamroller,” earning strong returns until rates rose and arbitrage opportunities became tougher to find. When some trades moved against the models, the ratios of debt to invested assets rose quickly and forced sales at reduced prices. Eventually, the Federal Reserve was forced to intervene, as they worried about systemic risk to the entire financial system due to potential contagion among lenders.

As discussed in Section III.f, some authors believe that persistent low growth could threaten the viability of the debt-based financial system. According to the National Association of Insurance Commissioners, bonds and mortgage loans made up 70 percent of the U.S. insurance industry’s cash and invested assets in 2017 (Wong, 2018). According to a 2018 Willis Towers Watson report, bonds comprised 27 percent of global pension assets (Urwin et al., 2018). A significant shift away from debt financing would fundamentally change the makeup of the industries’ invested assets. Such a shift might include widespread default that could threaten their solvency.

Asset/Liability Management

Asset/liability management (ALM), sometimes referred to as asset/liability matching, is a technique used to show the interactions between assets and liabilities across a set of economic

scenarios and investment strategies. The scenarios focus on interest rates over time. ALM metrics focus on duration and convexity, while the matching process often looks specifically at minimizing differences between cash flows at various times. ALM is used across the financial services industry. Liability-driven investing (LDI) is a subset of ALM used to reduce volatility of pension plans with respect to funding status and contribution requirements similar to matching techniques. Liability durations are often matched using investment-grade bonds, resulting in minimal impact on the funding ratio of a pension plan from future interest rate changes.

A challenge of ALM/LDI is that some asset classes don't work well with tools used to manage interest-rate risk. For example, equities have no maturity payment so duration means little. Proxies or simulations must suffice.

If economic growth and interest rates are both low but credited rates are above guarantees, ALM strategies designed to reduce risk for insurers and pension plans should work. If rates are negative, it will be difficult to manage the risk without large redundancies. Insurance products utilize nominal rates, as do pension requirements—so when earned rates are below that level, it creates problems. If growth is low and rates are high, uncertainty is high and worries increase about assets surviving in the amount expected to the date they are needed, but there is less of a need to accept credit risk, since nominal rates are above guarantees.

For longer-duration liabilities, there may not be comparable assets available, and this becomes especially problematic when there are long-term guarantees. Assets backing pension plans and products like long-term care insurance may not be able to invest long enough to match assets and liabilities, increasing the risk if interest rates move.

Of course, a variety of asset classes are used with insurance and pension liabilities. Going beyond interest-rate risk is best accomplished through economic scenarios that include credit and equity risk parameters. This analysis rarely leads to a single solution, and simulations and optimization shortcuts are often used along with experience to make the best decisions.

Investment Consequences

Institutional investors buy assets they expect to earn enough to pay off all claims and expenses, balancing risk and return. Their objectives, developed by selecting a level of risk (risk appetite) and determining a consistent level of return, are modified by constraints such as liquidity needs, time horizon, taxes and regulations. Insurers focus on bonds and similar asset classes, hoping to lock in earned income greater than is needed to support the liabilities (Maginn et al., 2007).

When earned rates are low, especially when lower than guaranteed rates, insurers are tempted to add non-interest-rate risk to make up the shortfall. These are risks the insurer typically does not have the expertise to manage well, and surprises often occur. Negative outcomes are reported as surprises, but for the industry, this is not an unexpected consequence.

Pension plans expect that their long liabilities will extend their planning time horizon, allowing them to accept equity-type risks. While expected returns increase, volatility of results is also higher. In addition, if low growth ultimately impacts expected returns on all asset classes, the impact on pension asset returns may be greater than on insurance company returns, due to a reduction in the equity risk premium. Some plans will adjust the amount of bonds relative to equities based on their funding ratio (market value of assets to value of liabilities), taking risk off the table when the funding ratio is high using LDI techniques or purchasing annuities for

recipients. When the funding ratio is low, the plan will try to stabilize itself using smoothing techniques that account for market cycles. Contribution rates may also need to increase in that scenario.

Reaching for Yield

Alternative Asset Classes

The economic world is split between borrowers and the savers who loan to them. The savers can be individuals or institutions, like insurers and pension funds. When guarantees are higher than can be typically earned on investment-grade bonds, and when earned rates are close to zero, the expectations of results cause savers to reach for higher returns with little concern for the additional risk added to the portfolio. A board-approved investment policy statement (IPS) can help manage this situation, forcing the investment team to defend the choices. These types of actions by investors can lead to bubbles forming and sometimes lead to financial crises. Financial fraud is also more common in these environments.

A new type of asset that amplifies results is inverse Chicago Board Options Exchange Volatility Index (VIX) funds. In February 2018, several were halted from trading after volatility of U.S. stocks spiked and traders betting on low volatility had to quickly unwind their trades (" Inverse VIX ETFs halted from trading", 2018). Had the investors stress tested this type of (commonly occurring) scenario, they would have been made aware of the risk. Mom and pop investors should not invest in these types of products. Others should not either, unless they fully understand the downside scenarios.

In another recent example, in November 2018, natural gas volatility caused accounts managed by optionsellers.com to be liquidated, often with net negative value, since some of the accounts did not have enough value to close out the positions (Meyer, 2018).

Higher Risk

Seeking greater returns, higher risks are deemed acceptable. Insurers will amend their IPS to allow a more risky portfolio. Higher risks are accomplished by taking more credit risk (junk bonds), collateralized loans (opaque, aggregation assumes diversification benefits that may never materialize), accepting illiquid cash flows for minimal additional return, and equities. Concentration risk is also something to be aware of—where a company has a good idea but ignores the benefits of diversification. This works great until the tides turn and the strategy ceases to operate correctly.

Some asset classes being used by insurers are Baa-rated bonds, barely investment grade and weighted toward sectors like oil and gas development, and securitized asset classes, like collateralized loan obligations. Investors should closely review any complex investments to make sure they understand how various interest rate scenarios (and other risks, in combination) will play out, including the impact of a rating downgrade.

During periods of stability, lenders seem to forget that borrowers can, and do, default. Low credit spreads, reduced covenants and leveraged deals are all signs that the market may be hot and due for a reset. Historically, credit events tend to act as a system reset, followed by high growth.

Reliance on rating agencies to vet investments was a major issue during the global financial crisis, and ignorance will not receive a pass in the future. Financial analysts should study this period in our recent history to learn about the practices that led to problems and why they should be avoided. Don't forget that history rhymes, so define these practices broadly.

Leverage

When rates are low, borrowing to gear up results becomes common and competitive pressures make it the norm. This is dangerous and can create a systemic risk for the financial services industry. Leverage can take many forms, and regulators have trouble keeping up with developments. Leverage can be placed inside assets, making the balance sheet look like there is no debt. Insurance is a form of leverage, with the float being the amount "borrowed" from policyholders and paid back when there is a claim. Risk metrics are able to understand the risks of leverage through stress testing. What ends up being a high-risk strategy can perform well for many years before the surprise event occurs, but results from a deterministic stress test help the risk manager support efforts to build resiliency through mitigation techniques.

Minsky Moment

High returns rarely come without high risk, and low reported risk coupled with high expected returns should make you especially nervous (e.g., Bernie Madoff). Investors, especially those who claim to be experts, who fall for a Ponzi scheme rarely get a sympathetic response from others when the scam is discovered. Dr. Hyman Minsky talked about how stability breeds instability (Minsky, 1992), where times of calm lead to less effort searching for risk until the bubble bursts. David Ingram shared a similar comment that risk grows in the dark (Ingram, 2010), when no one is looking. When times are good, we become complacent, and the risk team is considered a cost that can be reduced. This is exactly the time that risk analysis should be expanded. It's easy to find problems after interest rates spike to 20 percent. The financials give them away. It's during times of plenty that finding fraud and other hidden risks that have been accepted is hard and should be a point of focus. A risk owner wants to learn from the mistakes of others, not their own.

Many of these risks lead to liquidity crises, so it is especially important to identify sources of liquidity during these times of plenty when they really aren't needed. These can be letters of credit, excess cash or alternative sources. Many insurers use membership in the Federal Home Loan Bank System (FHLB) to provide this liquidity, but it remains to be seen if the government will simultaneously support a large number of insurers in the event of a liquidity crisis. It may be that FHLB could support initial liquidity requests but eventually run out of what is an unknown level of capacity. An analogy would be a lifeboat with a limited number of seats, with that number unknown to all prior to leaving port. Redundant sources of liquidity could provide resiliency during times of duress.

Impact of Structural Low Rates

Low growth, as described in the HC4 scenario, would lead insurers, pension fund managers and savers in general to reach for yield. This would provide additional sources of funding for higher-risk opportunities, leading to higher defaults. This isn't driven by the low rates but by an increased supply of funding for risky projects that reflects the needs of lenders for higher returns. Illiquid opportunities and high-yield bonds would be examples of assets that would be sought out.

On the other side of the ledger, leverage (borrowing) is intended to produce growth, but it multiplies results, good and bad. If increasing debt doesn't drive growth up, low growth must ultimately lead to deleveraging for government, business and individuals. Involuntary deleveraging is a crisis that could result in either default or inflation. Voluntary deleveraging would mean borrowers pay their debts and reduce their new borrowing, creating a lack of supply for savers to invest.

As we speculated in Section III.f, could this result in transition from a debt economy to a lease economy? Savers would own productive assets (e.g., real estate, business equipment) rather than lend to others to buy them and would be paid in rents rather than interest.

d. Operational and Strategic Risk

Operational risk may be broken down into several elements, most of which are not captured explicitly in a quantitative modeling system like IFs. Inflation has been discussed previously and would be a significant driver of operational costs. Insurance operations benefit from technological innovation, as do other industries, and technological innovation would be expected to slow in most low-GDP-growth scenarios as both a cause and an effect. Information security is critical to insurance operations, and the impact of low growth on cybersecurity risk is uncertain. Technological development enables both the perpetrators of cybercrime and the detection and prevention of those crimes. If that development slows, it is unclear whether this risk would increase or decrease, but the prudent risk manager should assume an increase in risk. Insurance companies have made use of outsourcing to reduce operating costs, and the impact on such efforts depends on the specific low-growth scenario. In the HC4 scenario, one would expect a near-term reduction in outsourcing and an increase in expenses as a result of trade barriers. Over the longer term, outsourcing could resume within regional trading blocs, but with smaller benefits than a global open market provides.

Normally reinsurance would play a big part in risk mitigation for insurers, but in a scenario like HC4 that discourages cross-border transactions, the diversification benefits of a multinational insurer may not be as broadly available.

Many insurance products pay a fixed amount when a claim occurs. This nominal benefit is common for life, payout annuity and supplemental health products. A low-growth economy tied to low inflation would mean these products do not need to be revisited as often, limiting the possibilities from cross-selling. If inflation is high, generally this is a favorable financial result for the insurer and encourages interaction with the policyholder that could lead to additional sales, as the customer's ratio of death benefit to income is rebalanced.

Strategic risks are also difficult to evaluate quantitatively from the results of a modeling system like IFs. Such risks must be considered qualitatively and must incorporate likely responses from the government and other sectors. Specific and unpredictable elements of a scenario may have a significant impact on a firm's strategic risk. In the HC4 scenario, international business strategies may be at risk as nations erect barriers. The life insurance industry has long followed an investment product strategy, selling many products as investment vehicles more than protection products. Such product strategies may be increasingly risky in a low-growth world, particularly one subject to significant inflationary risk. A low-growth scenario provides many potential considerations with respect to consumer needs and buying behavior. Lower GDP growth would likely result in smaller insurance coverage amounts. Lower growth might increase

the need for coverage among many consumers but also increase the tendency to go without coverage.

Some government responses, such as a universal basic income, could eliminate the need for some insurance coverage, while others, such as reductions in Social Security benefits, could increase the need for private-sector protection. This also reflects the shift from defined benefit employer-based plans to 401(k) defined contribution plans where the individual is responsible for the de-accumulation phase.

Need for such solutions may lead to the development of alternative pension schemes. An additional strategic risk for the pension sector is that the life cycle of a defined benefit pension plan for a specific company is not aligned with the life cycle of the company itself. The pension life cycle is always longer, so ERM tools are needed to ensure plan benefits will be paid. Regulatory valuation methods are back-ended, so it is especially important for internal risk tools to consider this potential mismatch, using realistic return assumptions and current funding ratios. Incentives may need to be developed to change current strategies, perhaps aligning incentives by reducing senior leadership bonuses when funding ratio shortfalls are large or do not shrink. The current valuation methods, during a long bull market, have left many private and public pension plans underfunded.

Strategic risks and opportunities for the property and casualty industry will depend on the nature of a low-growth scenario. Any low-growth scenario would likely see reduced investment and deteriorating infrastructure, which could impact the nature and terms of property coverage. Environmental risks could lead to a redefinition of what constitutes an insurable property risk. Low growth might also impact the terms and availability of liability insurance coverages, as those harmed by low growth increasingly seek someone to blame.

It is often said that an enterprise's most significant risks are strategic and operational risks, partly because they are so difficult to visualize and quantify. The discussion above only scratches the surface with respect to the impact of a low-growth scenario on these risks. The risk manager should consider these risks carefully in the scenario-development process.

e. Insurance and Pension Industry Responses

The following discussion covers ways that the industry might respond to the risks introduced by HC4 or other low-growth scenarios. Like strategic risks, the likelihood of these or other responses is dependent on factors that may be too uncertain to reflect in a quantitative model. This underscores the importance of scenario development as a qualitative process, first and foremost. How might governments react in a low-growth scenario? How do those responses affect the investment environment? How is the need for insurance and pension products affected? These and similar questions are matters of speculation—unknowable, but with tremendous consequences. Only a thoughtful scenario-development process can hope to capture the likely range of responses. With this introduction, following are some potential industry responses.

Metrics typically used by insurers and pension plans to reflect cost of funds could be at risk in a low-growth environment, especially if interest rates are low or negative. Cost of funds generally builds from the risk-free rate, adding a risk premium to develop a hurdle rate. This is then used as a discount rate to price insurance products and determine funding ratios for pension plans.

Other metrics typical in the finance industry—such as return on investment, return on equity and internal rate of return—would also need to be reinterpreted.

On the investment front, the industries have so far largely weathered the period of low interest rates since 2009, partly through product changes, partly by adding investment yield and risk through alternative investments, partly by assuming that interest rates will revert to higher levels and, not least, by the higher yield on previously purchased long-term assets that were invested to match the needs of the liabilities. The pension sector, with a significant allocation to equity and real assets, has also benefited from the equity bull market since 2009, although underfunding remains an issue due to high return expectations and low liability discount rates. We expect that in a prolonged low-growth environment, those responses would not be adequate, which begs the question, “what would suffice?” Many firms would likely reach for yield by taking on additional performance risk, which we believe would have predictably poor results, albeit with unpredictable timing. More prudent would be the recognition of a reduced yield expectation and adding protection against asset risks. Foremost among these might be inflation and the corresponding risk to nominal interest rates and credit spreads. While low interest rates continue to be considered a significant risk, the risk of low real interest rates combined with high inflation is perhaps underappreciated. While attempting to profit from additional asset risk in a low-growth scenario may not be prudent, limited availability of assets in traditional asset classes may necessitate a significant shift in investment mix. The industry should proactively review capital charges of all asset classes to look for those that are mispriced or provide arbitrage opportunities. The single capital charge across all equity investments may be a place to look to see if a stock of a company with a Aa rating is truly as risky as one whose credit risk is rated junk.

From a product standpoint, we would expect a de-emphasis on investment risk as a profit source, particularly in the life insurance industry. This de-emphasis could include a number of developments—a continuing shift from guaranteed products to variable or unit-linked products where the policyholder bears the investment risk; for fixed or nonlinked products, a shift toward the use of real interest rates rather than nominal interest rates to establish crediting guarantees and reserves, a shift toward shorter-term coverages with shorter duration liabilities and less inherent investment risk, a shift back toward more protection-focused products. In short, a shift back to products that follow the law of large numbers and pass along the benefits of risk pooling and away from systemic risks that endure feedback loops. Some of these changes could be considered a continuation of the developments of universal life, deferred annuity and variable products that began in the mid-1980s, ostensibly as a means of greater risk sharing with policyholders. Each step in that development has seen the adverse impact of risks—universal life guarantees, variable annuity guarantees—that were unappreciated or misunderstood by the industry. In a low-growth environment, the ability to recover from such risk management failures is compromised, making the prospective risk management all the more critical.

From the standpoint of mortality risks, life insurance companies and pension plans have known only steady, continual mortality improvement and increasing longevity for essentially their entire histories. The prospect of a long-term low-growth scenario introduces the possibility of a slowdown in, or even a reversal of, historical mortality improvement trends. Some low-growth scenarios may also increase the frequency and severity of mortality shocks due to events such as pandemics or war. For the life insurance industry, the most obvious responses to such developments would be to increase life insurance prices and underwriting standards, to

increase the use of reinsurance and other mortality risk management tools (e.g., war and suicide exclusions, underwriting for opioid use), and to increase marketing focus on annuities and other products offering the insurer longevity offsets (e.g., supplemental health, long-term care). In many low-growth scenarios, these responses might be sufficient. In other scenarios, such as the more extreme climate change scenarios, these measures may not adequately compensate for, or protect against, the increased mortality risk. In such scenarios, changes in the long-term nature of life insurance guarantees might be needed to guarantee the viability of the industry. This could mean a decline in the availability of permanent coverages or a return to participating insurance as the dominant means of providing life insurance coverage.

For the pension system, these mortality impacts could help mitigate the effect of low growth on asset returns. Inflation risk might also prove favorable for pension funding in some low-growth scenarios, with high nominal interest rates improving asset returns relative to retirement benefit streams that are not indexed to inflation. This inflation benefit would be applicable only to the liability for retired lives, as salary inflation implicitly inflates benefits for active lives. This combination of factors might provide a means to introduce new, more sustainable, models of defined benefit or hybrid pension plans. Contribution rates will need to increase, and added transparency could lead to a portable product that accumulates benefits for a payout annuity during the working years.

For the property and casualty industry, liability-side responses could vary significantly by the nature of the low-growth scenario. One liability-side response might be actuarial in nature—advancing actuarial pricing and reserving methodologies to rely less on historical but nonpredictive experience and more on prospective risk models. Other responses to increasing uncertainty would include reducing coverage limits, increasing reinsurance protection and abandoning geographic areas where risks are determined to be too high or unquantifiable. The property and casualty industry might also respond by increasing the use of industrywide experience studies for assumption development on certain types of coverage, making use of greater credibility to better identify experience trends and increase the granularity of the assumptions. Professional actuarial organizations could create recurring experience studies that are available to all in a transparent and standard form.

Of course for all these segments, industry responses would be driven by customer behavior and needs. Market opportunities in a low-growth scenario are uncertain and vary by scenario. A logical response to local low growth might be international expansion, as seen in Japan in recent decades. Some low-growth scenarios may provide significant international opportunities (e.g., as developing economies catch up to the developed world). However, in the HC4 scenario, opportunities for international growth are likely reduced due to international trade barriers. Within domestic markets, low growth might simultaneously increase the need for coverage and decrease the propensity to purchase for cash-strapped potential buyers. Appealing to those potential buyers and converting them into actual buyers at an acceptable price would be a key strategic conundrum. The equality or inequality of growth across socioeconomic strata would also provide various strategic opportunities. As inequality has increased in the last 30-40 years, there has been a fracturing of the affluent and middle markets in insurance. Absent government intervention, continued increases in inequality are likely and would probably lead to further fracturing of the insurance markets, potentially resulting in a dearth of coverage options for the lower and middle markets. Government policies to reduce

inequality would likely help maintain the middle market, unless they also reduce or eliminate the need for protection by increasing the safety net.

It is said that life is about the journey, not the destination. So it is with the exercise of considering responses to a low-growth scenario or any other scenario. The actual future is certain not to match the scenario, and real-world responses are certain not to be those contemplated in the planning exercise. But by engaging in the exercise regularly and robustly, one is better prepared to respond appropriately to whatever scenario arises. This will increase resiliency and allow those who practice it to better survive the long run.

Product Design

A low-growth scenario, accompanied by low interest rates, could lead to a new product cycle of insurance products. Those that reprice each year would not see a major change in direction, as they can adjust readily to any changes over the short term. Longer-duration products could unwind some of the product features that were developed following the rise in rates of the late 1970s and early 1980s. This includes general account-driven products that pass through investment returns, like universal life and fixed deferred annuities. Once expectations have changed and higher nominal rates are not considered likely, interest in these products would decline. Participating products would be sufficient for those interested in assumption upside.

A scenario where interest rates are at or below zero causes the greatest shakeup in insurance products. Many guarantee a nominal rate, including life, annuity (deferred and payout), disability and long-term care. The National Association of Insurance Commissioners (NAIC) could consider allowing companies to offer guarantees based on real interest rates. There are also grandfathered policies still accepting premiums that do not have any type of guarantee. These should be avoided by consumers and become at best a closed block for an insurer.

A low-growth scenario that incorporates high interest rates, or stagflation, is more difficult to predict the outcome for the insurance industry. One could hypothesize a move toward separate account products due to the uncertainty in the economy, with perhaps an investment component being added to some products and tying them to mortgages. Payout annuities that buy benefits with each premium received could also become popular in a high-interest-rate environment.

The Last Product Cycle

The portfolio method for investment income allocation spreads the income across all product lines, often using the average net reserve during the period. The investment year method moves beyond this to allocate investment earnings and interest credited, mapping the earnings more closely to the product lines and policyholders that provided the cash flow for the original investment. The investment year method was used earlier by pension plans but became common for crediting interest on retail insurance products only in the 1980s. Previously, whole life policies allowed policyholders to own mortality protection over their lifetime. Now options have expanded to include universal life insurance, as individuals were offered an alternative to products that bought term and invested the difference. As the equity markets rebounded in the 1980s, variable products put an insurance wrapper around separate account products and were sold as annuities and life insurance. The variable market has since expanded to include guarantees on investment returns and the timing of those returns, with some locking in the highest point of an index. These products are complex, and costs can be high. These risks are

systematic in nature, rather than the "law of large numbers" risks that insurers have traditionally accepted. Results have been inconsistent, with insolvency so far limited to a few companies with concentrated risks and not expanding to an industrywide issue that was systemic in nature.

Risks Without Returns

Expectations theory becomes very important if interest rates stay low for a long period, as would be expected during a low-growth economic environment. If rates are not expected to rise, so little upside potential is provided to the policyholder, sales could fall for universal life products. Risks that include many individual claims that smooth out on average using risk pooling would once again become the forte of insurers.

"Trust Me" Products

Insurance products can be thought of as "trust me" products for two reasons, and this is especially true for life insurance. One is the long-term nature of insurance. The company must be solvent when the claim is paid. This requires enterprise risk management and asset-liability management by the insurer. Both methodologies strike a balance between risk and return, seeking to provide good returns to the insurer providing capital while keeping risk low enough to ensure a margin of safety so the claim is paid when needed.

The other feature of "trust me" relates to products with nonguaranteed elements: account value and participating products. The insurer sets interest-credited rates and mortality charges, promising to pass on to the policyholder a share of actual results if more favorable than the guarantee. The company generally files its pricing opinion with its regulator but is not required to follow a specific formula in resetting these elements after inception. In some cases, companies have increased mortality charges to cover investment shortfalls. In other cases, credited rates have been reduced below the level required to maintain investment spread targets. Product managers are incented to err on the side of the company.

Going forward, will individuals believe that an insurer has treated—or will treat—them fairly? If not, these products will struggle for success, with insurers migrating to term policies or account-value products with separate accounts. A sign that trust has eroded would be a need for an insurance product backed by a separate account holding fixed income assets to guarantee the pass-through reflects actual results.

Non-Life Products

In a low-growth, low-interest-rate environment, as described by HC4, the reaction of insurers in Japan may provide some guidance. Avoiding products driven by account values, health policies may become an innovation hotbed due to the lack of investment return requirements. Some hurdles will need to be overcome, as the value of these products—and what they do not cover—has not always been transparent in the past. As a result, some regulators do not favor health products that are not all-inclusive, calling them junk insurance. A combination of education and marketing constraints may overcome this type of issue.

Other products, like long-term care (LTC), have nonguaranteed premiums. Historically, lower than expected investment returns and higher than expected claims have caused premiums to be reset higher. But in a low-growth environment, where claim levels have stabilized, LTC may

experience a comeback. This would be especially likely if government funding is no longer available for nursing home care under Medicaid.

If the low-growth environment is driven by environmental change, there will be new risks that were not considered previously. This will provide opportunities for some insurers, but in a challenging economic environment, some will not be able to afford coverage. Some of these products may be driven by an index rather than actual damage suffered. Examples would include average temperature for a geographic region, rainfall amount or the Keeling factor (measures carbon dioxide in the atmosphere). Agricultural insurance uses these types of factors today, which may be a leading indicator for future products for individuals and a source for ideas.

Investment Strategy and Management of Investment Risk

While many investors will be reaching for yield in a low-interest-rate environment typical of an HC4 scenario, a more material change will be driven by time horizon. Some bonds have been issued with maturities of 100 years, but the vast majority of assets with maturity dates go out no further than 30 years. Historically there has been enough data to justify determining a price or valuation, but if growth rates revert to levels not seen in 300 years, there is no reliable data to use that would be predictive. If the low growth is due to environmental changes, this situation becomes even worse. Historical data collected over recent periods would no longer be predictive. What investor would be willing to invest in Miami real estate for 30 years if sea levels were expected to rise by 10 inches over that period? These types of changes will revamp the investing landscape—in most places reducing prices, but in some lucky locations increasing the value of real estate.

Managing investment risk in such a scenario should already be contemplated today. Stress tests should include at least one that shows the expected changes in a scenario where temperature increases by one to two degrees. Prices will go lower as the situation gets worse, so moving principal repayments earlier in the schedule would be expected, and perhaps a varying rate schedule that increases over time would be appropriate. Even if these changes make sense, it takes only one competitor to ignore these changes before it becomes impossible for anyone to pursue that as a pricing strategy. Benchmarks and rules of thumb will need to change, and this is hard to accomplish in a competitive environment.

f. Section Conclusions

An extended period of low growth would be felt by the insurance and pension sectors in many ways. Some effects might be common across scenarios. Others would vary depending on how low growth is—in a negative or zero growth environment versus a low single-digit growth environment—and depending on the drivers of low growth. Certainly, the industry would be affected by how governments and society respond to the low growth.

In Section V, we have analyzed the potential impacts of various low-growth scenarios from a number of different perspectives. In doing so, we have shown the importance of developing a story, or qualitative basis, to help ensure internal consistency within a scenario. We have also demonstrated the use of a detailed quantitative model for projecting and evaluating a scenario, along with the risks, uncertainties and need to validate and challenge the internal consistency of such a model.

In Section VI, we will continue with a discussion of incorporating such scenarios into one's enterprise risk management framework.

VI. Enterprise Risk Management Implications

In Sections III-V, we have modeled a process for evaluating the risk of low growth, which can be stated thus:

- Understand the conventional wisdom. In Section III, we studied the economic models of growth, the drivers of growth and the history of growth.
- Evaluate the gaps in the conventional wisdom. In Section III, we also studied some headwinds to growth, potential drivers of a low-growth future.
- Seek the wisdom and knowledge of others. In Section IV, we studied a range of future scenarios created by a number of authors.
- Critically assess that knowledge. In Section V, we critically evaluated one scenario of low growth, both qualitatively and quantitatively.
- Apply learnings to your business. In Section V, we performed an analysis of how a low-growth scenario might specifically affect the risks of the insurance and pension industries, focusing on one specific scenario.

In most cases, our conclusions are qualitative and judgmental. A reasonable person could reach very different conclusions. In this way, the analytic process we have illustrated is more important than our results or conclusions. This is a process that can and should be followed by the practitioner in evaluating the risk of low growth. This process can also be applied to other macro-level risks.

This process, however, is just the starting point for taking low growth into account in one's risk management programs. Section VI discusses additional considerations for incorporating low-growth scenarios into one's risk management program.

a. Evaluating the Likelihood of Low-Future-Growth Scenarios

In the Hillebrand and Closson scenario set, four of the eight scenarios show weak economic growth. Those including global disharmony, with low or high energy prices, are considered of medium probability, while global harmony leads to two scenarios with low probability. The developers consider strong economic growth much more likely than weak. Scenario 2, global backtracking—combining low energy prices, weak economic growth and multipolarity—leads to 0.3 percent growth over the period covering 2010-2050. This result, the lowest of the scenario sets we have presented, is similar to GDP growth rates expected by Robert Gordon, as discussed in Section III.

Other scenario sets considered in Section IV generated GDP growth rates generally in the 1-2 percent geometric mean range over periods lasting to 2060. When climate change was considered, the growth rates were in the lower end of this range. This is materially lower than the 3.8 percent geometric mean recorded over the 1960-2010 period. Absent innovations that spark productivity, steady and reducing population levels will make it almost impossible to meet historical levels of growth in developed countries. Mitigation could occur in some countries if

immigration is encouraged—and also if a group such as those near retirement age were to stay in the workforce longer than the previous generation.

b. Risk Mitigation

Risk management means risk mitigation, not just risk identification. When talking about risk mitigation in a low-growth environment, there are several directions the discussion could go. In this section of the paper, we will avoid mitigation that focuses on altering exogenous factors—like climate change, population growth, technological innovation in the broader economy or colonizing the moon—and look at how insurers and defined benefit pension plans can address the risks they face due to economic factors.

Insurers writing products that are frequently repriced and have no interest-rate guarantees should be able to adjust premiums as needed, if regulators agree to justified increases when interest rates are low. The regulatory incentives are built around avoiding insolvencies, so these discussions will be difficult but necessary. Without investments providing income, the combined ratios for these products will need to be higher to generate expected returns. Hurdle rates will be lower, as they are built from returns on bonds with similar risks, so if the risk is comparable to a Aa bond, then the return would incorporate the risk-free rate and the additional return required to accept credit risk, among others.

Mitigation practices can be applied to the entire industry. Historically, when influenza became recognized as a threat following the 2002 SARS outbreak, the capital requirement was adjusted so all life insurers had to account for the additional, although infrequent, risk. This allowed companies that recognized the risk in the market by forcing all companies to price for the risk. This was accomplished by lobbying the NAIC for additional regulation, and a low-growth environment may be another instance where the industry will seek to proactively nudge regulation to evolve prior to any insolvencies due to the issue.

Products with guaranteed interest rates built in—both directly, as in products with an account value, and indirectly, where discount rates are embedded in the pricing algorithm—are in greatest need of regulatory relief if low growth rates lead to low interest rates. Statutory interest rate requirements currently can be relaxed only after an insolvency occurs. Proactive legislation that uses real rates rather than nominal rates, along with constraints requiring assets to be tied to liability duration targets, would align the insurer with the policyholder's best interests. Inaccessible nominal rate requirements lead to insurers reaching for yield by taking credit, liquidity and concentration risks, leading to accepting investment risks that are not fully understood and increasing the risk of insolvency.

Some risks can't be mitigated or hedged. Financial products extending longer than five years may find it a challenge to hedge those risks with derivatives. This is true for many separate account insurance products, such as guarantees around variable annuities. Another risk that is tough to mitigate is changing expectations. A structured settlement payout annuity written on a child could have payments lasting more than 100 years. If expectations are unknown for the future, this product can't be sold without accepting incredible risk. Historically, the defined benefit pension market has written a similar product for employers, averaging the returns needed over time by adding small, incremental liabilities each year. This product would be beneficial for individuals in today's market, where careers are not spent with a single employer. This product may not be possible over long periods when expectations are volatile. An individual

wants inflation protection, but only a government with the capability of printing money is able to offer that. This would be especially true in a low-interest-rate environment where profit margins are low. This product could be offered by employers by buying a competitively bid product from an insurer each year to move the liability off the sponsor's balance sheet.

Asset-liability management is a key to managing the risk when interest rates are low. Looking at various metrics to optimize results may include Macaulay, modified and effective duration, breakeven analysis and scenario planning.

c. Implementing Low-Growth Scenarios

The sorts of scenarios discussed throughout this paper differ from the economic scenarios typically used in actuarial projection models. Actuarial modeling scenarios project a path of economic variables—usually interest rates but frequently equity returns, inflation and other variables as well. These scenarios are intended to capture rapid-onset risks as well as long-term risks. They can be either deterministic, one at a time, or a stochastic set, where a group of scenarios are derived from a consistent set of assumptions. Deterministic scenarios can be individually developed or generated as a package. A package may have symmetry, with one good and one bad scenario or one up and one down scenario. It may be a regulatory requirement or something created internally. An individual deterministic scenario is often designed around specific exposures and tells a risk story to management and the board.

Many risks can be managed if they are regularly spaced out to meet expectations, such as a 4 percent probability of a certain earthquake occurring about every 25 years. Truly random events don't work this way, and some risks covered by insurance aren't random. Clustering, where risk events "bunch up" while maintaining overall expectations, is a material solvency risk. Modelers should know how many risk events their firm can endure over a short time period and consider risk-mitigation tools that align with the formalized risk appetite.

There are many drivers making the world change at a much faster pace than in the past, including technology and climate change. These have led to challenges due to unknown knowns, where historical data is not credible in the future. These time horizon issues should be considered, with assumption variances considered and product design changes considered that shorten the length of guarantees.

As discussed above, the scenarios described in Section IV are generally smooth; growth rates typically change gradually over the life of the scenario. But reality has stops and starts, with countries becoming more or less democratic in often cyclical ways. As an example, scenarios for a defined benefit pension plan should consider alternatives where asset classes do poorly in the early years of a simulation. As unexpected results and unintended consequences often result from risk interactions, a wide variety of risk occurrences should be tested. The modeler can then choose the ones that are most interesting for the specific block being tested.

Some specific scenarios to consider include:

- How low should growth be in a low-growth scenario (e.g., -5 percent, 0 percent, 1.5 percent), and how does this impact other variables, like interest rates, inflation and credit spreads?
- Inflation: low or high (stagflation).

- Combination scenarios that capture asset, liability, operational and strategic risks. These should be specific to an entity and potentially rotated to include additional possibilities.
- Other types of scenarios that might be considered for insurers in a low economic growth environment would include lower sales, higher/lower mortality, higher/lower morbidity and lower credit spreads to reflect the lower risk-free rates.

Early warning signals, leading indicators, should be developed concurrently with scenarios to address prioritization of emerging and evolving risks. These can include such obvious practices as monitoring the growth in GDP and the velocity of money, trending them graphically over long periods and comparing current rates with five- and 10-year rolling averages.

Identifying low-growth scenario-leading indicators will allow an entity to react quickly to a changing environment. For example, a pension plan that recognizes that growth has slowed relative to recent trends might automatically change required funding ratios to a higher level and shorten the period allowed to reduce the shortfall.

Qualitative

A deterministic scenario may start out using qualitative analysis, common-sense thinking about what a given scenario would mean for a specific block of business. This could be a subset of a product, perhaps issued in a period that forms a cohort, or a subsidiary or full product line. For example, if interest rates spike, what would be the risks to a deferred annuity block? If mortality falls, how is a block that combines individual life and payout annuity business impacted? How does an influenza pandemic impact a major medical health insurance or payout annuity line? How does a low-growth environment impact the homeowner or auto market? Thinking qualitatively through a scenario should always be done prior to quantitatively assessing it so result expectations can be set. This is where experience comes in, and incorporating ideas from outside the modeling and risk teams can be very helpful.

Quantitative

A quantitative model can be simplistic or complex. Modelers frequently go directly to complicated models, but often rules of thumb or an Excel spreadsheet can provide an answer that meets the needs of the person asking. This offsets the run time trade-off of a more complex model that takes much longer to create and report back. False precision can result from models that convert highly complex interactions into a single number (for example, economic capital) that is reported and becomes hard to update due to model improvements. Deterministic interest rate stress tests can graphically create a similar shape that a stochastic simulation would build, with much shorter run time. This can be a useful ERM exercise, especially when resources are limited. Modelers should look for shortcuts, or rules of thumb, that can use linear trends to estimate the impact of small changes in a variable. This should be relied on only for short periods of time—and the underlying models updated frequently. An example is replicating portfolios that estimate complex products and investment strategies with something much simpler and quicker to turn around. These estimates should incorporate higher-order interactions as well, looking at risk combinations.

Sometimes only a highly complex quantitative analysis will allow risk management to succeed. Interactions between risks, lots of optionality within a product and multiple investment choices can make it useful to build a big model. This should not be the default position.

Low-growth scenarios generally will require the analyst to build a quantitative model. Products are often complex or interact with assets in unexpected ways. Steps should be taken to automate as much of the setup work as possible; building in-force assets and liabilities requires the same extracts to be built each time. Making the process efficient allows more time to be spent performing analysis.

Some deterministic scenarios need to be run each year, either because the environment changes or because it is a regulatory requirement. Other scenarios can rotate, with some long-term assumptions run every five years or so to stay up to date with evolving risks within a block of business. An example would be a long-term care product line, now closed to new business, as it ages. Periodically, investment strategies should be tested, but it does not need to be done every year. Always ask yourself, what would I learn from recreating a previous stress test?

d. Contrarian View

Part of a good ERM process is thinking about what could happen differently. What has been missed? A strong scenario set will provide a first step, and common-sense analysis helps.

For many risks, including those associated with low growth, a risk manager constantly must think about where the conventional wisdom may be faulty, what rule of thumb may not be correct. An obvious example is the assumption that interest rates will be low because GDP growth is low. Stagflation has happened before and could happen again. Or what if innovation leads to a new era of high productivity and high growth rates? Product design changes are hard to anticipate. They should be re-evaluated constantly, with thought provided to how interactions with other risks might change the diversification benefits.

The effect of interest rates on account-value-driven products, including policyholder behavior and investment strategies, could differ from assumptions built into the models. As computer processing speed improves, adding model complexity becomes an option. Perhaps a universal life block could be segmented by how close it is to being fully funded, or an investment strategy could vary between segments of the block.

e. Game-Over Scenarios

Certain scenarios may be not worth considering in one's ERM program, not because they are implausible, but because they are game-over scenarios—scenarios in which the industry as we know it would not survive. Nuclear Armageddon or a massive asteroid strike is such a scenario, but other, less extreme, scenarios could potentially spell game over as well. While it is not fruitful to expend time and effort analyzing game-over scenarios, it is useful to be explicit about what scenarios are not worth considering. It is also useful to consider whether the industry might take action to alter the trajectory of a scenario that would otherwise signal systemic change to the industry.

In Section III.f, we discussed some potential unanticipated consequences of low growth for our socioeconomic systems. Some of these may be considered game-over scenarios for the insurance and pension industries.

f. Section Conclusions

Enterprise risk management is a way to balance risk and return. The tools available—through scenario planning, contrarian thought and common sense—help the analyst better understand the nuances of the block of business and where the shortfalls may lie. For low economic growth, it would be important to look at the risks as components in the analysis. What is causing growth to be low? Is it fertility, or are pandemics becoming more common? How is climate change impacting growth, and how might it change in the future? Which of the many evolving assumptions is likely to hit a tipping point and accelerate or change direction? This type of thinking will help when setting reserves for a life insurer or annuity writer but will become a competitive advantage when thought of as a capital, or insolvency, buffer. Thinking builds resiliency, and good ERM requires lots of it.

VII. Summary and Conclusions

We summarize our primary conclusions by section, followed by our overall conclusion.

Summary of Section III: Survey of Existing Literature

The era of economic growth began with the advent of the industrial revolution in the 1700s. While growth rates have varied over time and by country, compound growth has been the norm and the expectation over this period. The first 70 years of the 20th century, and 1940-1970 in particular, were an era of strong growth, reflecting the full integration of transformative inventions such as the lightbulb, the telephone, the automobile and the refrigerator; development of modern manufacturing methodology; and the unique set of conditions following the Great Depression and World War II that favored rapid growth in investment and productivity. Since approximately 1970, economic growth rates have fallen significantly in the developed world, with growth in aggregate GDP falling from more than 4 percent in the decade ending 1970 to approximately 2 percent since 2000. Rapid growth in the developing economies, led by China and India, has resulted in more modest declines in global GDP growth rates—from 5 percent to 4 percent for the same periods.

There is a rich and growing literature into the past and future impact of the factors contributing to the decline in growth—headwinds to growth, as described by Robert Gordon. These headwinds could be: demographic, with slowing fertility rates and aging populations, a limited ability to bring new segments of the population into the workforce and a leveling out of educational attainment; technological, with the breakthroughs of tomorrow proving less consequential than the breakthroughs of yesterday; environmental, with climate change leading to loss of productivity and diversion of investment, and resource constraints leading to increased production costs; sociopolitical, with increasing inequality and increasing class conflict; and geopolitical, with decreased global cooperation and increased conflict.

By and large, the economists' models are not adequate to evaluate the impact of these headwinds. The standard economic growth models do not capture such drivers. They are simple models employing just a few factors, with productivity growth through technological development being the one factor that can generate ongoing growth. These models rely either on an exogenous productivity growth factor taken as a matter of faith (neoclassical models) or

on virtuous cycles leading to self-sustaining productivity improvement (endogenous models). They do not explicitly capture any of the potential headwinds to growth and generally assume a high elasticity of substitution, meaning that they do not consider any impact of physical limits. Economic growth models are also production-side only, assuming that demand ultimately expands to meet production.

In short, the economists' models have been developed and calibrated to fit historical data and are not robust across nonlinear changes in conditions. Two hundred years ago, classical economic models were based on Malthus' theories of population dynamics, which accurately represented history but did not anticipate how the industrial revolution and pivots to food production could change those dynamics. Today's economic models are subject to the same sorts of errors. Economists, often working with those in other disciplines, have recently begun to develop growth models with more complete representations of various kinds of limits and more robust feedback loops, but results of these models are highly subject to uncertain assumptions.

The risks posed to growth by various headwinds are real but uncertain. The economists' tools are developing but are limited in their usefulness for predicting the impact of these headwinds. What opportunities, and risks, that are emerging today will be the drivers, and the limiting factors, of tomorrow's growth?

Summary of Section IV: Review of Scenarios

Whatever their limitations, economic growth models form the basis of most available long-term growth projections. While not voluminous, there are a number of sources of long-term growth scenarios or forecasts. Some of these may be considered forecasts (i.e., predictions). Others may be considered scenario analyses—projections intended to be consistent with stated conditions, intended to illustrate the consequences of those conditions but without ascribing probabilities to the outcomes. Some of these scenario analyses include multiple scenarios to capture alternate potential futures.

The most useful and robust scenarios start qualitatively as a narrative or story. The story captures likely consequences, feedback loops and responses to a set of conditions. Quantitative modeling of a scenario can be very useful not only for quantitative testing of consequences but also to test the limits of intuition, explore feedback loops and interactions among variables. Quantitative models can be simple or complex. Complex models may capture interactions more robustly but at the risk of overreliance on black-box calculations/assumptions and a false sense of precision. The IFs model is such a representation—modeling the physical, human and economic worlds in highly complex and interrelated ways. Such a model may be of considerable use in scenario building and scenario testing but must be used with understanding and great care.

We surveyed the results of 20 global long-term economic growth projections, generated by five authors, comparing projected growth rates for the United States, China and the world for the period 2010-2060 against historical growth rates for the period 1960-2010. These 20 scenarios include a full range of expectations—high growth, low growth and midrange growth. Even the high-growth scenarios exhibit growth rates generally lower than those of the historical period. The middle range results show both aggregate and per capita growth rates for the U.S. and China roughly half historical rates; the middle range is modestly more favorable for the world as a whole, as developing economies continue to catch up. The lowest of these scenarios shows

global growth rates of 1 percent on an aggregate basis and 0.3 percent on a per capita basis—effectively a return to preindustrial-era growth levels.

These projections are all based on long-term equilibrium models and, therefore, do not project shocks. However, shocks are to be expected, and the impact of both positive and negative shocks would likely be exacerbated in the absence of growth. These would include economic shocks (economic cycles, debt crises), geopolitical shocks (military and economic conflict), sociopolitical shocks (political revolutions, class conflict) and environmental shocks (natural disasters, climate dislocation).

Summary of Section V: Impact of Low Growth on Insurance/Pension Sectors

With respect to effects, both per capita growth and aggregate growth matter but in different ways. Growth in per capita GDP may better represent changes in the standard of living at the individual level. However, aggregate growth determines financial sustainability (i.e., whether future on- and off-balance sheet promises can be kept). Historically, population growth has been steady around the world, resulting in higher growth rates for aggregate GDP than for per capita GDP. As populations age and population growth begins to slow and even decline, this relationship will shift. Japan has shown that in at least some circumstances, gains in standard of living can be maintained (at least temporarily) in the face of low aggregate growth, though not without significant increases in debt.

One of the major uncertainties in forecasting the effect of low growth is to predict policy responses. The standard fiscal and monetary responses to low growth rates assume that growth is cyclical. Policies to stimulate growth involve accumulating government debt and stimulating borrowing by businesses and households. Systemic low-growth drivers would likely not respond to these stimuli so that they could stimulate debt crises rather than increased growth. If long-term growth capacity were truly reduced to near or below zero, a soft landing would require great foresight on the part of policymakers. The likelihood of either deflationary spirals or debt crises would be greatly increased.

Low growth would be likely to drive low real interest rates, except for a stagflation scenario. As a result, asset-side impacts are the most obvious consequences for the insurance and pension industries. Low growth would lead to lower real returns on fixed income assets and, ultimately, equity and alternative asset classes. Default and inflation risks would be exacerbated in some low-growth scenarios, leading to higher—possibly very high—nominal interest rates and higher nonperformance risk. Reaching for yield would lead to taking on uncompensated risk. The universe of available assets could change substantially. In the extreme case, debt markets could collapse permanently, leading to development of a new financial system that could be far simpler than the one it replaces.

Reduced growth would likely have mortality and health impacts. Adverse health effects would likely lead to additional deaths in any low-growth scenario due to slower improvement in living standards. The drivers of some low-growth scenarios, especially those due to climate or other environmental effects, would also have direct impact on human health, resulting in adverse health and mortality impacts. Psychological factors might further exacerbate mortality and health impacts. For those forecasts that include mortality impacts, most low-growth scenarios project that mortality improvement will continue. This is not a certain result, and mortality deterioration

could occur in some scenarios. This is especially likely in the U.S., where suicides and opioid use disorder have recently been trending up against lower rates elsewhere in the world.

Environmental factors contributing to low growth would likely lead to higher property damage and increased uncertainty in modeling and pricing property risks. These factors might also lead to increasing portions of GDP committed to remediation of property damage or mitigation of property risks, leaving a smaller share for productive investment and individual consumption.

Unanticipated consequences of low growth are likely. Systemic low growth is outside our range of experience, and extrapolation and intuition may not apply. These unanticipated consequences may include shocks as well as long-term trends that vary from expectations. Some low-growth drivers might lead to more significant unanticipated consequences than others. In particular, if low growth is driven by environmental factors, the results may be nonlinear as tipping points are reached.

In the life insurance industry, one might expect a shift from investment-focused products to protection-focused products, but likely with higher prices and potentially shorter-term guarantees. Risk sharing might increase further, with a shift to more separate account products and a resurgence of participating insurance. Efforts would be made to underwrite against the effects of low growth, with uncertain effectiveness. The market for life insurance protection would likely shrink and further fracture, with lower-income market segments facing an affordability crisis.

The pension sector would see offsetting effects from higher mortality and investment returns, with the net effect being uncertain. A stable environment would allow profitable pricing, so uncertainty is itself a risk. Low growth might cause firms to fail more frequently, exacerbating the disconnect between the firm life cycle and the life cycle of its pension benefits, intensifying funding crises and hastening the demise of the defined benefit system unless valuation methods are modernized. Alternatively, it seems possible that slowdown in mortality improvement could favor the trade-off in pension benefits for wages, increasing the interest in defined benefit plans, including portable DB plans.

The property and casualty and health insurance industry might experience increased pricing pressure due to asset changes, but these pressures would be mild compared with life insurance and pensions. The industry would be well served by its short-term policies and ability to reprice frequently. In an environmentally driven scenario, this may not be sufficient to compensate for the increased cost of property coverages and the increased uncertainty in those costs.

Overall, for industries where actuaries are typically employed, the goal in a low-growth scenario will be to move away from products with systemic risk and toward those that use risk pooling.

Summary of Section VI: Enterprise Risk Management Implications

Should risk managers consider low-growth scenarios in their ERM work? We think so. The likelihood of occurrence is not remote, it's plausible, and the magnitude of impact could be significant. Low-growth scenarios should be constructively qualitative and should consider combined impacts of multiple drivers. One should analyze likely consequences, including feedback loops and interaction of different variables, using both internal and external expertise.

Quantitative scenario modeling tools may be useful but should be used with care. It is important to understand the model dynamics, review the results carefully and interpret results with skepticism. Simple interest rate scenarios without also considering the concomitant economic effects may be of limited use. Quantitative results may be most useful to evaluate relative effects, not to set absolute expectations.

Ultimately, the likelihood and consequences of a low-growth future are highly uncertain, so near-term risk mitigation opportunities may be limited except for divesting the block of business. The result of one's ERM efforts may be risk-monitoring processes and contingency plans rather than trades or hedging programs. And these efforts may be just enough to build resiliency into products that last into the 22nd century.

Conclusion

There is an old joke based on an analogy between insurance company management and driving a car. The chief marketing officer has a foot on the accelerator, the chief financial officer has a foot on the brake, and the chief actuary looks out the rear window and steers. Our final conclusion with respect to economic growth is that it is time to stop looking out the rear window. While not necessarily part of the traditional actuarial toolbox, tools and methods are available for us to objectively evaluate the effect of economic growth and other macro-level assumptions on our industries as well as the risks of significant changes in those assumptions. As actuaries and risk managers, we must use such tools in a forward-looking way in order to effectively perform the risk management on which our stakeholders depend.

In this paper, we have presented some of these tools and modeled an approach for using them. We have presented the case for why risk managers should be concerned about low growth. We have presented and demonstrated an analytic framework for incorporating risks associated with low growth into one's ERM program. We hope that these prove to be useful tools as the insurance and pension industries navigate whatever future arises.

VIII. Ideas for Future Research

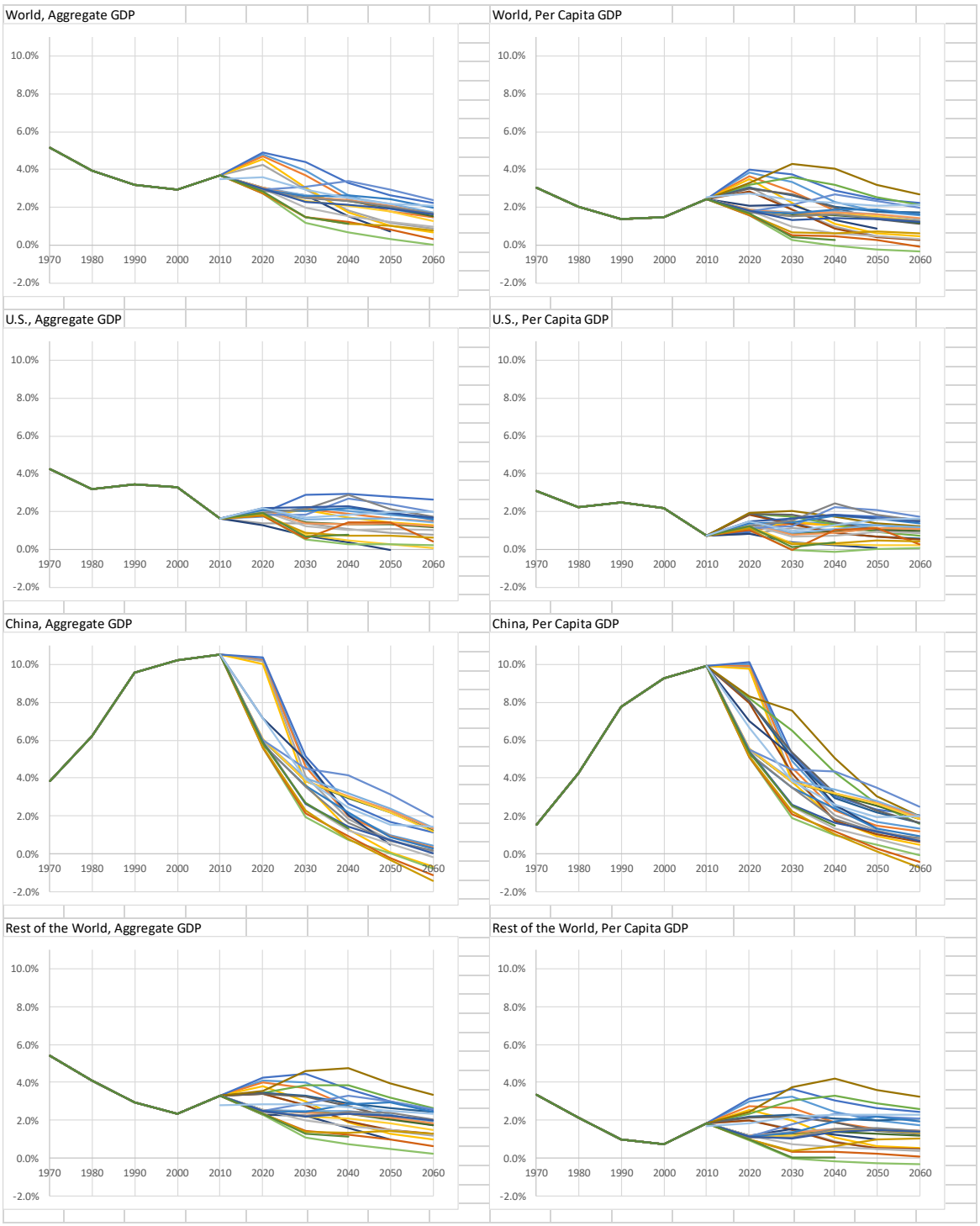
While a project of this scope can lead to almost unlimited ideas for future research, here are some ideas we consider particularly interesting or potentially fruitful:

- Alternatives to current GDP measures: Increasingly, the validity of GDP as currently measured has been questioned. Considerations for alternative measures are a potential area of future research, including:
  - Treating unharvested natural resources as capital and their depletion as a cost.
  - Explicitly capturing externalities in accounting measures—i.e., costs and benefits of business activities accruing to others, such as the effect of pollution (one method that accomplishes this would be a carbon tax).
  - Another way to think of interpreting the current accounting system is that we are borrowing at zero cost to dig up fossil fuels that will eventually have a cost that will have to be repaid.
  - Refining depreciation measures (e.g., explicitly capturing destruction by extreme events and increasing focus on NDP as opposed to GDP).

    - Alternate measures of happiness or well-being that are not based exclusively on economic output.
- Steady-state economy: Section III introduced the ideas of proponents of a steady-state economy—the idea that economic policies are set to maximize well-being at a sustainable level of production rather than to maximize growth in production. Analysis of low-growth scenarios in subsequent sections did not further explore the ramifications if such policies were to be adopted.
- Alternatives to debt-based financial system: Section III introduced research suggesting that there may be a growth imperative in the debt-based financial system, which could cause the system to collapse in the absence of growth. We refer to this concept in Sections IV and V, speculating that this could lead to a new and different financial system with a new universe of investments. The sharing economy could provide a path to future asset classes. Additional research could further develop these ideas.
- Complex adaptive systems can be extremely complicated, but increased processing speed of computers allows more detailed models and additional simulations to determine if the model simplifications introduced in neoclassical economics have achieved an appropriate balance between simplicity and accuracy. Insurance and pension models should be tested to learn more about the risk/return balance of products and what the key drivers are through an analysis of the distribution of results.
- Immigration is a two-edged sword, with one country accepting immigrants and one allowing them to leave. Managing these transitions driven by demography, economics and refugee status could be developed further through additional research.
- A modeling platform such as IFs is a potentially very powerful tool for actuarial scenario analysis, albeit one that should be used with caution. Follow-up research related to IFs could include the development of quantitative scenarios for actuarial use on the IFs platform, development of methods to overlay IFs scenarios with business cycles, nominal prices, nominal interest rates and other items not covered in the model, and research designed to inform actuaries regarding the use of the platform.

Appendix A: Summary of GDP Growth for Section IV Scenario Sets; Decadal Aggregate and Per Capita GDP Growth Shown by End Year of Decade—World, U.S., China and Rest of the World[13]

[13] These figures show patterns and dispersion of the scenarios summarized in Tables 11 and 12, so the series have not been labeled.



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About The Society of Actuaries

The Society of Actuaries (SOA), formed in 1949, is one of the largest actuarial professional organizations in the world dedicated to serving 32,000 actuarial members and the public in the United States, Canada and worldwide. In line with the SOA Vision Statement, actuaries act as business leaders who develop and use mathematical models to measure and manage risk in support of financial security for individuals, organizations and the public.

The SOA supports actuaries and advances knowledge through research and education. As part of its work, the SOA seeks to inform public policy development and public understanding through research. The SOA aspires to be a trusted source of objective, data-driven research and analysis with an actuarial perspective for its members, industry, policymakers and the public. This distinct perspective comes from the SOA as an association of actuaries, who have a rigorous formal education and direct experience as practitioners as they perform applied research. The SOA also welcomes the opportunity to partner with other organizations in our work where appropriate.

The SOA has a history of working with public policymakers and regulators in developing historical experience studies and projection techniques as well as individual reports on health care, retirement and other topics. The SOA's research is intended to aid the work of policymakers and regulators and follow certain core principles:

Objectivity: The SOA's research informs and provides analysis that can be relied upon by other individuals or organizations involved in public policy discussions. The SOA does not take advocacy positions or lobby specific policy proposals.

Quality: The SOA aspires to the highest ethical and quality standards in all of its research and analysis. Our research process is overseen by experienced actuaries and nonactuaries from a range of industry sectors and organizations. A rigorous peer-review process ensures the quality and integrity of our work.

Relevance: The SOA provides timely research on public policy issues. Our research advances actuarial knowledge while providing critical insights on key policy issues, and thereby provides value to stakeholders and decision makers.

Quantification: The SOA leverages the diverse skill sets of actuaries to provide research and findings that are driven by the best available data and methods. Actuaries use detailed modeling to analyze financial risk and provide distinct insight and quantification. Further, actuarial standards require transparency and the disclosure of the assumptions and analytic approach underlying the work.

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