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The Damocles Zone

> "My other piece of advice, Copperfield," said Mr. Micawber, "You know. Annual income twenty pounds, annual expenditure nineteen (pounds), nineteen and six, result happiness. Annual income twenty pounds, annual expenditure twenty pounds ought and six, result misery".
>
> —Charles Dickens, *David Copperfield*, 1850

Charles Dickens had no training in the sciences, but that is hardly a prerequisite for an understanding of what seems to be a fact of life—that a *sustained* shortfall in one's circumstances—and not only the financial, of course—can eventually lead to catastrophic consequences. It would seem that after lengthy immersion in such dire straits, those affected enter a state of existence in which even trivial setbacks such as an unexpected bill, a minor fall, a modest bout of food poisoning, a common cold, or freezing weather that in normal circumstances would be taken in their stride, can lead to serious difficulties or even disaster simply because they have reached the end of their tether and can no longer cope. During that precarious phase it might seem to the disinterested observer that tiny causes can become amplified to produce disproportionately huge effects on its victims. Moreover, they seem to be powerless to do anything about it—that is, they will have entered the Damocles Zone (see Poster 5).

However, it is not only the poor unfortunates who might find themselves in such a predicament. It potentially awaits us all, not only as individuals, but as societies, nations, and civilizations, and perhaps extending to humanity itself. Passage into the Damocles Zone is not necessarily the result of transient

Scientific Freedom: The Elixir of Civilization, by Donald W. Braben

Poster 5: The Sword of Damocles and the Damocles Zone

The Roman politician and philosopher Marcus Tullius Cicero, writing in his *Tusculan Disputations*, Book 5, tells a story about King Dionysius II of Syracuse and the sword of Damocles. He says (translated by C. D. Yonge (1812–1891)):

> XXI. This tyrant, however, showed himself how happy he really was; for once, when Damocles, one of his flatterers, was dilating in conversation on his forces, his wealth, the greatness of his power, the plenty he enjoyed, the grandeur of his royal palaces, and maintaining that no one was ever happier, "Have you an inclination," said he, "Damocles, as this kind of life pleases you, to have a taste of it yourself, and to make a trial of the good fortune that attends me?" And when he said that he should like it extremely, Dionysius ordered him to be laid on a bed of gold with the most beautiful covering, embroidered and wrought with the most exquisite work, and he dressed out a great many sideboards with silver and embossed gold. He then ordered some youths, distinguished for their handsome persons, to wait at his table, and to observe his nod, in order to serve him with what he wanted. There were ointments and garlands; perfumes were burned; tables provided with the most exquisite meats. Damocles thought himself very happy. In the midst of this apparatus, Dionysius ordered a bright sword to be let down from the ceiling, suspended by a single horse-hair, so as to hang over the head of that happy man. After which he neither cast his eye on those handsome waiters, nor on the well-wrought plate; nor touched any of the provisions: presently the garlands fell to pieces. At last he entreated the tyrant to give him leave to go, for that now he had no desire to be happy. Does not Dionysius, then, seem to have declared there can be no happiness for one who is under constant apprehensions?

Following Cicero's thought-provoking story, I will use the term *Damocles Zone* to describe that state within which its occupants are suddenly exposed to grave and imminent danger. That might be the case even though the obvious signs have been benign until that moment. On moving into the Damocles Zone, not only does one's fate become precariously balanced but also survival is probably impossible without external intervention. Although a disastrous outcome is virtually certain, no estimate can be made as to when it might actually happen.

The existence of Damocles Zones of one kind or another is an intrinsic property of the universe we live in.

mishaps such as storms, tsunamis, earthquakes, or even being caught in someone else's war. A healthy society should indeed be able to take these things in its stride. Their impact on individual victims can be disastrous, of course, but experience shows that societies generally recover remarkably quickly. Such

disasters can arise out of the blue and may come about as accidentally as a car crash with few implications for humanity as a whole. The Damocles Zone has wider and deeper origins, however, and its effects would only rarely be reversible.

If the universe were dominated and controlled by linear processes we would always be safe from risk, accidental or otherwise. By *linear processes* I mean any process in which the consequences of an action are predictable and directly proportional to its causes. I might push you in a friendly way, say, with a force that might normally move you a few inches, and in a linear world you would indeed move only a few inches. On the other hand, if you were standing at the edge of a cliff, you might go over the edge and suffer consequences that would probably be nonlinear and unpleasant. But if linear processes ruled the world, there would be no cliffs. Cliffs are always the result of some discontinuous and perhaps tumultuous event. In a linear world, all surfaces would either be flat or very gently undulating. Skiing would be out because without tumultuous events there could be no mountains. But that would be the least of our worries for another important reason—in a linear world not only would we be safe from all risks but there would also be no people and probably no world, either.

Our understanding of the universe is rather limited, of course. However, one feature that seems well established is that the universe is shaped and determined entirely by *nonlinearities*; that is, the nonlinear relationships between every entity—space, time, energy, matter, and so on—of which the universe is composed. This prosaic and tongue-twisting word is therefore the source of everything that is interesting and exciting, that makes life worth living, and indeed that makes it possible to live. Eventually, nonlinearities always lead to instability. There seems little doubt that the universe's very creation, regardless of whether one accepts the Big Bang theory, comes from spontaneous instabilities from which matter emerges, and by which, on the scale of the universe, energy is conserved. Other types of instability seed the creation of individual stars, planets, and galaxies. The very chemical elements on which life on Earth is based (carbon, oxygen, nitrogen etc.) come from yet another—the spontaneous explosion of stars (supernovas) that flood the universe with them. We have yet to discover precisely how life on Earth emerged, but we do know that proteins play an essential role in the later stages of that process, and that proteins are essentially unstable.* If they were not, we could not exist as there could be no living cells, no renewal through birth and death, not only of cells but of whole organisms, and no mutations and no evolution. Even when life on Earth became established, its later extensive development into higher forms became possible and sustainable only because of physical

*Proteins are essential components of all living cells of all organisms. They may differ in sequence, shape, and function, but they must all be able to fold into specific three-dimensional structures. These structures are not rigid. They each have a restless and dynamic existence, which involves unfolding and refolding, complex association and dissociation.

instabilities in the core of the planet. They led to the steadily expanding crystallization of the solid-iron core at the heart of Earth's hot interior, and in turn to the subsequent turbulent flows in the conducting outer core of molten iron that generate the magnetic field needed to protect higher life-forms such as ourselves from much of the harsh and damaging radiation from the Sun and beyond. Thus, without nonlinearities we would not only all be dead—we would never have lived.

That brief tribute to instability, however, omits a very important caveat. Although nonlinear processes would seem eventually to dominate every system ever observed, the universe at any one time is nevertheless a curious mixture of the linear and the nonlinear. Instability must be followed by a period of stability otherwise nothing new would survive. Unfortunately, these considerations take us into one of the most profound of all the sciences that at least on the astronomical scale is poorly understood—thermodynamics. Thus, the universe also seems to be characterized by the property that an ordered system evolves in such ways that it always becomes less ordered—that is, entropy must always increase as the arrow of time goes only one way. (As far as we know, the direction of that arrow never reverses.) Eventually, therefore, the universe will become an amorphous soup in which no structures can exist* and nothing can ever happen—a bleak prospect, indeed. But returning to present reality, it goes without saying that we do exist. Our immediate astronomical neighborhood also seems generally stable, and most of us can enjoy mostly quiet lives. Entropy's eventual absolute hegemony, therefore, can be understood only if it applies to the universe as a whole.

On this viewpoint, therefore, some systems might behave linearly for long periods provided that a sufficient number of other systems behave nonlinearly (thereby becoming less ordered) over the same time so that the entropy of the universe indeed always increases. That anthropic thinking would seem to rationalize our existence nicely,† but while all this may be true, the mysterious forces harmonizing entropy's inexorable rise over astronomical timescales need not concern us here. On the everyday timescale, Nature *depends* on instability. Paradoxically, nothing could exist without it. In nucleic acids, the need for instability is well established—evolution depend*s* on mutation and rearrangement of DNA. Without the ability to break down or to promote

*The universe is expected to become more and more disordered until it finally ends up as a featureless goo, but according to present understanding, that depressing fate is scheduled after the passage of such a ridiculously long time—perhaps 10^{100} years—that it would seem only to indicate the extent of our ignorance.

†As Richard Feynman and colleagues put it: "For some reason, the universe at one time had very low entropy for its energy content, and since then the entropy has increased. So that is the way to the future. That is the origin of all irreversibility, that is what makes the processes of growth and decay, that makes us remember the past and not the future, remember the things which are closer to that moment in the history of the universe when the order was higher than now, and why we are not able to remember things where the disorder is higher than now, which we call the future" (Feynman et al. 1963).

changes in the constituent elements of living systems, there would be no development. However, the complex processes that make up living systems such as humans, say, are all subject to rigorous control, for which, of course, there must be appropriate feedback mechanisms. A human, for example, is made of some 10^{14} cells in some 200 different types of tissue, and their behavior is linear—that is, predictable—for most, if not all, of our lives.

The quest to understand the requisite control mechanisms in biology is now a major scientific discipline. As Mathew Freeman explains in a recent review (Freeman 2000):

> The intercellular communication that regulates cell fate during animal development must be precisely controlled to avoid dangerous errors. How is this achieved? Recent work has highlighted the importance of positive and negative feedback loops in the dynamic regulation of developmental signalling. These feedback interactions can impart precision, robustness and versatility to intercellular signals. Feedback failure can cause disease. . . . Negative feedback occurs when, for example, a signal induces the expression of its own inhibitor; it serves to dampen and/or limit signalling. Positive feedback occurs when a signal induces more of itself, or of another molecule that amplifies the initial signal, and this serves to stabilize, amplify or prolong signalling.

Researchers generally seem to regard instability as a nuisance that they must deal with. However, instability is essential to Nature's purposes, and so researchers should also be able to use it to their advantage. Indeed, Colin Self's Venture Research work (see Chapter 7, VR 23) was dedicated to understanding its role in biology and particularly in the immune system. Nonlinearity is at the heart of all biochemical processes, which Nature ensures are regulated by the appropriate feedback controls. The degree of instability can therefore be understood as being related to the need for feedback. If a process were to persist for too long (i.e., if its instability were too low), the process would go out of control unless the requisite negative feedback were applied at the right time. Alternatively, a weak and transient response to a stimulus (i.e. if its instability were too high) would need to be amplified by positive feedback if the response were to be effective. When we accidentally cut ourselves, for example, we need not normally fear for our lives. This is because antigens invading from the outside world almost instantaneously trigger the activation of a blood-clotting agent that seals the wound so that eventually it can heal. The next step is equally crucial. The agent must then be switched off! If the agent had too little instability (i.e., if it were too stable) it would exert its effect for too long, resulting in our entire blood supply rapidly coagulating into a solid mass following even a minor accident. Conversely, if the agent were too unstable, its effect would be transient and ineffective, and blood loss would continue unabated. Nature gets the balance just right, of course, or we would not be here.

Indeed, life would appear possible only because of a truly vast number of exquisitely balanced controls, not only at the molecular and cellular levels but

also at the macroscopic levels in all living organisms. Thus, for example, these controls maintain human body temperature at approximately 37 °C independently of whether we are resting, sitting in a steaming sauna, or engaged in vigorous exercise. At the cellular level, cells are constantly dividing and reproducing, of course, processes that even in healthy people may frequently and hopefully transiently go out of control. If uncontrolled growth persists, it would lead to tumors and cancers, but a fully functioning immune systems will quickly restore growth to its normal levels. At the molecular level, regulation is similarly complex. As John Maddox puts it: "A cell is a self-regulating biochemical democracy in which the several parts are continually casting votes in the form of the chemical signals they transmit. The genome is to the cell as the Supreme Court is to the national judiciary" (Maddox 1998).

Other types of feedback would seem to operate at much higher levels of organization such as communities, nations, or perhaps even civilization itself—their study generally going under the name of *cybernetics*.* Even though individual human behavior would seem almost infinitely variable, such skilled operators as advertisers and politicians seem able to identify traits to which a surprising number of us conform and on which they can focus their manipulative powers. Depressingly, therefore, many of us can be persuaded to eat when we are not hungry, and to believe half-truths as gospels. However, the control that most interests me in this context is not necessarily the result of any purposeful action, and was first described by the Scottish philosopher and political economist Adam Smith. In 1776, he published his *Inquiry into the Nature and Causes of the Wealth of Nations*, in which he argued passionately for free trade. This was a very heretical view at the time as the conventional wisdom strongly held that the total volume of trade was fixed by the supply of gold and silver. In what became one of the most quoted passages in economics, he wrote (in Book 4, Chapter 2) (the italics are mine)

> . . . every individual . . . neither intends to promote the public interest, nor knows how much he is promoting it. By preferring the support of domestic to that of foreign industry, he intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain, and he is in this, as in many other cases, led by *an invisible hand* to promote an end which was no part of his intention.

Diversity of opinion is endemic in economics, but Smith's opus has been celebrated at every major anniversary since its publication. In 1976, for example, hundreds of assessments† were published, leaving no doubt that even after 200

*Founded by the American mathematician Norbert Weiner in the 1940s to examine the role of various feedback mechanisms in such diverse areas as systems control, computer science, philosophy, the organization of society, and in biology itself.

†See, for example, Terence Hutchison's article on Adam Smith's *The Wealth of Nations*, published on the book's bicentennial, which gives references to many other reviews published at earlier anniversaries (Hutchison 1976).

years his work is still influential. There has also been a considerable debate on precisely what Smith meant by his invisible-hand (Grampp 2000) reference, his supposed reasoning including the forces arising from altruism, a joke, or merely luck. However, I would like to adapt Smith's term to give it a slightly different meaning. It may or may not be what he had in mind, but it seems consistent with his writings.

As I see it, Smith identified a powerful social feedback mechanism that promotes growth and prosperity. The operational details of Smith's invisible hand may not be understood, but by his reference to invisibility Smith implies that understanding is unnecessary; we should merely sit back and allow it to work. That begs the question, of course, but my interpretation of Smith's meaning is that individuals should be free to form their own judgments on what is important, and to do whatever they believe is necessary to bring their ideas to fruition. In another of his books, *The Theory of Model Sentiments*, he writes about altruism and a person's derivation of pleasure from another's happiness although, as he puts it, "he himself derives nothing from it"—which is perhaps an inverted schadenfreude. But that person may derive something from it. If one can see that happiness stems from one's actions, regardless of any personal benefit, that person would have had the pleasure of achievement. That in itself may be sufficient reward, especially if one could take personal pride in the social benefits flowing from what one had done.

Following Robert Solow's transformative discovery in economics (see Chapter 2), we now know that technical change is by far the dominant source of long-term economic growth, but such change can come in many forms. Its technological component is well understood, and global expenditure on the search for new and improved technologies is enormous. However, although the pursuit of efficiency has always been an institutional priority, it is only in the past few decades, following the revolutionary developments in computing and communications, that it has been possible rigorously to implement that pursuit. Consequently, institutions now revel in the powers of their new toys. We now live in an age in which efficiency—that is, *perceptions* of efficiency—is paramount, particularly in resource allocation and use. But the relationship between efficiency and creativity is not understood.

This serious situation should be of concern to everyone because as members of civilized society we are all stewards of creativity. Before the approximate watershed date of 1970—the "dawn of the age of efficiency"—we could safely assume that creativity, like the blooming of wildflowers, would take care of itself. Provided they were sufficiently determined, pioneers were generally free to tackle any problem that interested them. That assumption is now invalid. For technology, pioneers can usually get backing because they can point to tangible objectives whose potential benefits can be assessed. Unfortunately, science is dominated by philosophy. Peer endorsement for radical (but abstract) challenges is therefore seriously problematic simply because an advance statement of a justifying case cannot always be made.

It is likely, therefore, that a latter-day Adam Smith might have to deal with such criticism as: "Mr. Smith, you *claim* that although every individual intends only his own gain, he is led by an invisible hand to promote ends that were no part of his intention. *But where is the proof for your assertion?*" As the eighteenth-century Adam Smith had offered none, his radical views could have been safely dismissed as merely an expression of opinion. However, a sufficient number of influential people appreciated the value of his thinking, and so Smith's ideas took root. Rigorous proof might have been unnecessary because his assertion struck a chord with their experience and understanding of human behavior. That is, they were free to take it on faith without having to subject it to the interminable rounds of bureaucratic assessment our new Age routinely demands. Today's world is truly bizarre. The emperor's new clothes are constantly admired although many can see that he is stark naked. But Smith's invisible hand and other philosophies advocating freedom seem to be denied *because* it is impossible to see them. They cannot be rigorously assessed, therefore.

My assertion is that the guiding force behind Smith's invisible hand is *creativity.* When most, if not all, researchers were free to explore, Smith's invisible hand could work its magic. Growth was fostered, therefore, even though it was not part of scientists' original intentions. Indeed, as my philosophical wizard pointed out in Poster 3, that is precisely what happened up to the so-called Golden Age of economic growth that began to end around 1970. As civilizations develop, populations expand. Thanks to Mr. Solow, we know that economic growth is led by technology but diminishing returns will soon follow unless we find new technological veins, and nowadays their most reliable source is new science. As things stand today, however, the funding agencies will allocate freedom only when they agree that researchers' objectives are appropriate to today's circumstances. As a result, putative members of a twenty-first century Planck Club are highly likely to be frustrated. Thus, our proxies (politicians and other leaders, public and private research funding organizations, etc.) are seriously undermining a vital part of the feedback that prevents civilizations from becoming unstable and that keeps us away from the Damocles Zone.

Instabilities of one kind or another finally get us all eventually, of course, but experience shows that we do have some control over when it might happen. Life expectancy at birth in 2000, for example, was some 77 years in the United Kingdom and the United States, while it was some 37 years in Zambia.* In contrast, in 1842 in Manchester (UK), for example, a professional male had a life expectancy at birth of 38 years (Wood 1991), whereas that of a manual worker was only 17 years. These improvements might cavalierly be attributed to the fruits of a developing civilization, but they stem entirely from ingenuity, especially in science and technology. There seems to be no reason in principle why these favorable trends should not continue, albeit perhaps at

*US Census Bureau's International Database.

reduced rates, but institutions must understand that we can reap rich harvests only if scientists are free to cultivate their creativity.

The figures on life expectancy alone indicate that although there is no escape from the fact that complex systems on average always evolve toward instability, evolution rates of specific systems should be controllable if we apply the appropriate feedback. But first we must find them, of course. Initially they may be invisible, and so our proxies must maintain the environments in which creativity can flourish as they did until relatively recently. For any given system, therefore, progression toward the Damocles Zone is not necessarily inevitable. Indeed, it would seem that we might defer entry indefinitely on any human timescale provided that the warning signs are recognized and appropriate actions taken.

What might those signs be? Jared Diamond has described the events that supposedly led to the Easter Island collapse, but as I mentioned, those who criticized the crazy policy of building escalating numbers of stone statues would probably have had no forum. If they had, collapse might have been avoidable. The appropriate actions in that case would have been for the islanders, when they took up residence on the island, to invite a few of their number to advise on the implications of policy decisions—in today's language, they might represent, say, an Ecology Research Unit. Had they done so, it seems likely that this unit would have noticed the signs of deterioration as the island moved inexorably towards the Damocles Zone.

It might have worked something like this. As the island is normally swept by very strong winds, one might reasonably expect the Unit's scientists to monitor tree movement as a function of wind speed at treetop level, and to measure the corresponding wind speeds at ground level. As the islanders continued to cut down trees more rapidly than new ones could grow, the scientists would probably have noticed that as tree cover was reduced some tree movements sometimes approached their elastic limits even when winds were unexceptional, and that wind speeds at ground level were also increasing. Thus, it should have been obvious that the island's ecology was beginning to lose the flexibility to withstand elements it had successfully resisted for millennia. A reasonable reaction in those circumstances would have been for the Unit to seek, say, a moratorium on statue building for a few years. They could have told the authorities that if they continued to cut down trees, then one day, probably without warning, they would not only have to manage with fewer trees but with none at all, with all the grave consequences that would entail. Had the authorities heeded my imaginary Ecology Research Unit's warnings, they might then have agreed on a reasonable rate of stone-statue building, entry into the Damocles Zone might have been avoided, and Jared Diamond might have written about a sustainable success rather than a catastrophic collapse.

The world is vastly more complicated than tiny Easter Island, of course, but many great and extended civilizations have either collapsed or dwindled in the past. We may not fully understand the precise reasons for their passing,

but a few causes arising from various forms of mismanagement seem dominant. Thus, Mesopotamia's poor irrigation policies led to increasing soil contamination and starvation—ancient Rome's corrupt bureaucracy had ambitions outstripping the capacity of its stagnating economy. Today, it is not difficult to see increasing causes for concern. As a would-be member of a putative Global Prosperity Research Unit, a group that would assess and advise on *all factors* that might influence global prosperity—intellectual as well as material—it seems that per capita economic growth is an important indicator. Material prosperity is not everything, of course, but it does seem to be a necessary if not sufficient condition for global prosperity. The rates of growth in world gross domestic product (GDP) seem to be hovering around 1.5% per person per annum. If that figure is correct, would it be adequate? Would the scientists at my imagined Global Unit be happy that a 1.5% margin above stagnation will keep us clear of the Damocles Zone?

Another cause for concern is that the world's economic systems are becoming increasingly monolithic. This tendency might be stimulated by the emerging economies' wish to increase their share of global prosperity. *The Economist,* in a "Survey of the world economy" published on September 16, 2006, said:

> Last year the combined output of emerging economies reached an important milestone: it accounted for more than half of total world GDP (measured at purchasing-power parity). This means that the rich countries no longer dominate the global economy. The developing countries also have a far greater influence on the performance of the rich economies than is generally realized. Emerging economies are driving global growth and having a big impact on developed countries' inflation, interest rates, wages and profits.

Thus, for example, in 2006, China became the largest holder of foreign exchange reserves,* and the British steel industry was transferred to the ownership of Indian capitalists. The energy and vigor of the emerging economies should indeed increase global prosperity, but surely their effects will have a sustained impact on growth only if their contributions are new, and not merely based on producing existing ranges of goods and services more efficiently and cheaper than the advanced world can.

However, it should go without saying that monolithic systems lack diversity, that traditional font of ingenuity. By their very nature, such systems seek to impose uniform structures of customs and practices, and by promoting harmonization they discourage individuality. Thus, individuals or nations must either conform or be prepared to face the pressures arising from nonconformity. This trend does not seem consistent with the enhancement of global stability.

Economic growth may not be everything, but buoyant growth creates optimistic environments and the resources to deal with the trials and tribulations

*Holding $941 billion, China narrowly overtook Japan in 2006. Taiwan was the third largest holder, with Russia fourth. See *The Economist* p. 98 (Sept. 2, 2006).

that our proxies should expect to beset us from time to time. Today, it seems generally agreed that the most important problems facing humanity include terrorism, the rise in religious fundamentalism, pollution and global warming, poverty and disease, the security and availability of energy supplies, and the huge potential increase in the resource needs of the emerging economies. China and India together, for example, represent approximately 40% of the world population. It is an awesome list, especially as various pundits at various times have described *each one of these problems* as representing the gravest threat to global stability. Thus, humanity seems to be faced with a diversity of slippery slopes leading to Damocles Zones regardless of whether my own concerns are included.

The list of problems may be daunting, but they may not be the most important. In 1957, a group of senior California Institute of Technology (Caltech) scientists ambitiously published their forecasts for the next hundred years in a book (Brown et al. 1957)* based on deliberations at some 30 conferences involving senior industrialists and other leaders. Their estimate of the most important problems for the next hundred years might bring included the threat of nuclear war, population growth and food production, resource allocation, and the problems arising from the spread and intensification of the advanced world's (particularly the US) industrial culture.

The book contains fascinating discussions on humanity's prospects and problems from the perspectives of 1957. It was, of course, a nightmare time when miscalculation could with very little warning have plunged the world into a devastating nuclear war. That threat may now have subsided, but the authors very appropriately drew attention to the perils of forecasting, as they should. Even though the book was written by eminent scientists, it contains no inkling of the dramatic revolutions in electronics and communications that began to pervade the world only some 20 years later. On their fears for world food production, the authors would also no doubt have been astonished to learn about the Green Revolution that began to transform agriculture in the 1960s. Within a few decades of their forecasts, some parts of the world were plagued by so-called food mountains, and their governments paid farmers *not to produce food.* However, it would be most unwise to assume that such profligate policies will endure. In the light of the increasing demands from the developing countries, it would not be surprising to see food production once more on the growing agenda of critical problems facing humanity.

Although none of the problems that Brown et al. identified have entirely gone away, one can see the marked change in emphasis. Their book concludes: "The problems which we face in the years ahead are indeed both numerous

*This august publication includes a foreword and a postscript written by Sir Solly Zuckerman, who was later to be the UK's first Chief Scientific Adviser, and a preface from Lee A DuBridge, President of Caltech and a senior colleague of Vannevar Bush (see Chapter 3) during World War II with overall responsibility for the development of radar. I am grateful to Terry Clark for drawing this book to my attention.

and grave, but, theoretically at least, it seems likely that they can be solved by the proper application of our intelligence" (Brown et al. 1957, p. 152).

For the few decades following the book's publication, authorities did indeed ensure that intelligence was properly applied. Notwithstanding, therefore, that the authors assessed the problems as "numerous and grave," they did not, in sharp contrast with today's world, recommend that humanity's intellectual resources should be marshaled into deriving specific solutions to each problem. The academic authorities continued to allow intellectual endeavor full and free rein because that's what they had always done. Significant proportions of industry did much the same. It does not follow, of course, that we can automatically attribute the high and unprecedented rates of economic growth of the Golden Age to those simple policies. There may be other reasons. But, as a follower of Solow, my working hypothesis throughout this book has been that unconstrained creativity eventually leads to new opportunities and new growth. Conversely, although directed creativity may sometimes be advantageous in the short term, it eventually leads to diminishing returns and falling growth. As the authorities' actions over the last 25 years or so seem to have had precisely that effect, while it is not rigorous proof—always problematic in economics—the hypothesis would seem to merit serious attention.

Today's problems might not prove as transient as some of those foreseen in 1957. To make matters worse, the fact that the world is intrinsically nonlinear means that the spontaneous creation of new nonlinearities cannot be ruled out. Furthermore, each one will need to be controlled by its own feedback mechanism if stability is to be maintained. Thus do the events of history progress. Even the most carefully prepared predictions will probably be wrong, therefore, and our supposed list of current problems may still be far from complete. However, this is not a prescription for despair. Our best strategy in these circumstances should be the old one of striving to understand as much as possible about the present in the reasonable hope that it will be sufficient preparation for the future. We are not straws in the wind. Our very progression from the ranks of the primitive primates 5 million years ago seems entirely due to the random flowering of our innate intelligence. It has seen us through ice ages, plagues, wars, floods, droughts, and other environmental mayhem. There is every reason to expect that its "proper application" will continue to see us through indefinitely.

As things stand at present, that optimism hinges crucially on that simple word "proper." There is no doubt that the potential power of intellect is widely appreciated—the pen is mightier than the sword and so on—but the nature of its chief characteristics seem not be understood at all. History shows that the more powerless creative individuals become, the more they are immersed in environments that institutionalize dogmatism. Very few new ideas emerged from the suffocating environment imposed by religious dogma during the Dark Ages, for example. Creativity is a delicate plant. Everyone who has had an idea is usually plagued by doubt and uncertainty. Is it really original? Is it correct or valid? Does it matter? For creativity to flourish, it does not

necessarily need encouragement. Indeed, since its origins are not understood it may be impossible to encourage. But intellectual pioneers need environments that *accommodate* dissent, as I tried to explain in my *Pioneering Research*. Should it be surprising, therefore, that many seem to have lost their inspiration when they must struggle every day with the all-pervasive dogma on efficiency and accountability, however well intentioned its originators might be?

Pundits may presume the current threats the greatest ever, but the ill-considered actions of our proxies are making them much worse because they are undermining the creation of the very feedback mechanisms that have always kept us from the brink. Our universities have been reservoirs of creativity for the past 900 years. They have served us superbly well, as long as they have been free.

Industry, too, has a crucial role. Unfortunately, the great companies seem to have virtually ended their support for exploratory research. Today, it has been deemed that technology rules. Research is now the servant of technology, and apparently, each project must prove in advance that it can pay its way. In May 2004, the British Petrdeum (BP) Group's Vice-President of Technology said in a speech entitled "*Technology: Demonstrating value to the corporation*": "Nevertheless technology, like every aspect of what goes on in any well-run business, constantly has to justify itself—to demonstrate value to the corporation. It's not, and never can be, an end in itself."

How times change! In the 1960s, IBM's Chairman, Thomas Watson Sr., began the Fellows Program in which he appointed Fellows (he called them his "wild ducks") for 5 years to be "dreamers, heretics, mavericks, gadflies, and geniuses." Their remit was simply to "shake up the system." The Fellows Program has been supremely successful. Only some 165 scientists were appointed, but five of these won Nobel Prizes. General Electric and Bell Laboratories ran similarly distinguished programs. In 1980, as I have mentioned, BP launched Venture Research, arguably one of the most ambitious and imaginative exploratory research initiatives in industrial history, and supported it for 10 years. But then came a recession. In 1992, IBM suffered the biggest loss in US corporate history, and the company was "reborn" shortly afterward. But common sense prevailed, and the company still runs the Fellows Program, although its Fellows now seem to have somewhat less freedom than wild ducks typically enjoy—among other things, they are now *expected* to advance IBM's technological leadership.

Nevertheless, IBM today seems to be one of a very few major companies that appreciate the full value of unconstrained intellectual endeavor. Nicholas Donofrio, IBM's Senior Vice President, Technology and Manufacturing, said in his 2004 Hinton Lecture (Donofrio 2005):

> . . . about 25% of what we spend in research we spend on what we would call pure research. It may be maths—I am sure you remember Benoit Mandelbrot fractals. I am not sure that they sell computers, by the way. . . . We did all this work with the scanning tunneling microscope, not knowing what would come of

> it. We did the basic work on high-temperature superconducting materials that has at least prodded some other people to do even more seminal work in that area. We will never capitalize on that work to be candid with you, but that does not bother us because smart people like to be near smart people. We have a simple philosophy. If you have one or two Nobel Laureates, I do not care whether they are working in that area or not. If they go to the cafeteria and people say, "I saw her," or "I saw him." It is great. . . .

These prescient remarks are extraordinarily courageous for an industrial leader in today's climate, and reminiscent of past industrial visionaries. Even senior academics might think twice about advocating expenditure that might be perceived as leading to less-than-optimal returns on investments of "tax dollars" or other currencies for fear of being trumped in their bids for funds.

The pharmaceutical companies—known colloquially as *pharmas*—have traditionally made considerable investments in research. Their research budgets have increased some 50-fold since 1970, and nowadays big companies might devote more than $5 billion a year to R&D. Yet there is widespread concern about the decreasing output of new drugs. As ever, the discovery of new products depends on having research environments that encourage flair and creativity. Instead, as Pedro Cuatrecasas points out: "Scientists must contend with 'management by objectives,' hierarchical and autocratic organisations, mandates from strategic planning groups, detailed and rigid scheduling, constant reporting, and achievements driven by milestones and flowcharts" (Cuatrecasas 2006).*

The role of product champions, so essential in industry, has virtually disappeared as the consequences of being "wrong" in today's climate can be severe. In the sciences generally, as I have explained, twentieth-century Planck Club members would be unlikely to get funded today. Similarly, virtually every "blockbuster" drug ever marketed (AZT, acyclovir, cimetidine, fluoxetine, etc.) would be unlikely to survive what Cuatrecasas describes as the current well-managed and efficient go/no-go systems. Moreover, companies are increasingly reviewing their activities against what others are doing (benchmarking), rather than exploiting their own skills and experience.

Never before, therefore, have we been in greater need of people in any walk of life who will "shake up the system" and liberate it from second-guessing bureaucracy. With the possible exception of global warming (see Poster 4), most of our current problems stem from human actions or neglect, and in principle, therefore, there is no reason why we should not solve them. On the basis of past experience, directed solutions—for example, the development of radar during World War II—are possible only if the intellectual environment is sufficiently fertile to give the authorities these options. Otherwise, they will be little more than a waste of money. Finance is crucial, of course, but that should not be a problem if economies are buoyant, as they are likely to be if

*I am grateful to Desmond Fitzgerald for drawing Cuatrecasas' paper to my attention.

their scientists are free. Thus, creativity is at the heart of a powerful positive-feedback loop. The authorities seem unaware of that simple fact; indeed, they are acting to inhibit it.

In summary, therefore, essential steps for avoiding collapse would seem to include the following:

- The establishment of research initiatives aimed at creating a twenty-first century Planck Club. In time, we could have a global network of such initiatives that should eventually lead to increased economic growth and buoyant economies.
- The emergence of altruistic sponsors to help fund these initiatives.
- The creation (or perhaps the re-creation) of an extensive network of universities that will encourage and foster scientific freedom.
- The emergence of industrialists who will convince shareholders that a small proportion of industrial activities should be free of short-term assessment.

I will suggest how they might be taken in the following chapters.