Societal Complexity and Diminishing Returns in Security

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Discussions of security in recent years have frequently concerned the ways in which the complexity of technologically advanced societies can be an Achilles' heel. Various observers and real-life events have drawn attention to how relatively unsophisticated threats against air travel, power grids, computer networks, financial systems, lean manufacturing processes, and the like can have devastating effects. There has been little effort, however, to approach the problems that complexity poses for security in a comprehensive way, though this is not to say that work applicable to such a purpose has failed to appear.

In *The Collapse of Complex Societies,* Joseph Tainter argues that societies can reach and pass a point of diminishing marginal returns to investment in societal complexity.[1] Eventually, this eats away at their slack, which can be understood as that "human and material buffering capacity that allows organizations and social systems to absorb unpredicted, and often unpredictable, shocks." In other words, slack is the untapped human and material resources for pursuing new endeavors or meeting emergencies. This lack of slack leaves these organizations and systems increasingly vulnerable to collapse as a result of such a shock, for example, military invasion.[2] Although concern with diminishing returns in the areas of defense and economics has long been a part of discussions of international security, appearing in the theoretical summations of authors such as Robert Gilpin and John Mearsheimer, Tainter's work (and the field of complexity studies in general) have had little impact on security studies to date.[3]

This article argues that security is becoming an area of diminishing returns to complexity for today's advanced societies because of the diminishing returns from investments in complexity in general, the risks posed by the interconnections this growing complexity creates, and the rising cost of security forces. Before proceeding to the argument's details, however, some clarifica-

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1. Joseph Tainter, *The Collapse of Complex Societies* (New York: Cambridge University Press, 1988), pp. 91–126, 209–216.
2. Gene I. Rochlin, *Trapped in the Net: The Unanticipated Consequences of Computerization* (Princeton, N.J.: Princeton University Press, 1999), p. 213.
3. Robert Gilpin, *War and Change in World Politics* (New York: Cambridge University Press, 1981), pp. 80–81; and John J. Mearsheimer, *The Tragedy of Great Power Politics* (New York: W.W. Norton, 2001), pp. 76–79.

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tion of what "complexity" means, why it rises, and why it can lead to diminishing returns is in order. According to one definition, complexity refers to "asymmetric relationships that reflect organization and restraint" between the parts of a system.[4] As such, the characteristic features of complex systems are their composition from a large number of components with a dense web of connections between them; a high degree of interdependence within them; an openness to outside environments, rather than their being self-contained; "synergy," meaning that the whole is more than the sum of its parts; and nonlinear functioning, so that changes in these systems have effects disproportionate to their size, either larger or smaller.[5] Such nonlinearity and synergy come with an exponentially increased range of possible interactions, including unplanned interactions, making an incomplete understanding of at least some processes also an aspect of complex systems.[6]

A more complex human society therefore "has more institutions, more subgroups and other parts, more social roles, greater specialization, and more networks between its parts. It also has more vertical and horizontal controls and a greater interdependence of parts," which may interact in unexpected ways.[7] Also in keeping with the greater interdependence and interconnection between a larger number of components, more complex societies have a larger information load. This is the case for both communications and information processing.

As a larger information-processing burden indicates, complexity carries costs. Institutions, networks, and the like require energy for their sustenance; vertical and horizontal controls inhibit personal freedom; and so forth. Given that such costs make human beings generally "complexity averse," why does complexity tend to rise over time? W. Brian Arthur offers three explanations.[8] The first is that competition and interdependence among entities create niches that new entities can fill in a process of "coevolutionary development." "Diversity begets diversity"—that is, a multiplicity and variety of elements allowing

4. T.F.H. Allen, Joseph Tainter, and Thomas W. Hoekstra, *Supply-Side Sustainability* (New York: Columbia University Press, 2003), p. 346.
5. Thomas Homer-Dixon, *The Ingenuity Gap: Facing the Economic, Environmental, and Other Challenges of an Increasingly Complex and Unpredictable Future* (New York: Alfred A. Knopf, 2000), pp. 111–115.
6. Charles Perrow, *Normal Accidents: Living with High-Risk Technologies* (New York: Basic Books, 1984), p. 78.
7. Allen, Tainter, and Hoekstra, *Supply-Side Sustainability*, p. 64.
8. W. Brian Arthur, "On the Evolution of Complexity," in G. Cowan, D. Pines, and D. Meltzer, eds., *Complexity: Metaphors, Models, and Reality* (Cambridge, Mass.: Perseus, 1994), pp. 65–78.

a greater variety of possible connections, which translates into an ever-more elaborate web, in technology or economics as well as ecosystems.[9] The advent of the automobile, for instance, created niches for paved roads, motels, and traffic lights.[10] The second explanation Arthur offers is that competitive environments encourage individual entities to improve their performance by adding new subsystems in what is known as "structural deepening." In other words, a system becomes more complex so that it can operate in a wider range of environments, sense and react to exceptional circumstances, service other systems so they operate better, or enhance reliability.[11] Arthur offers the example of the jet engine, which in Frank Whittle's design in the 1930s contained only a single moving part. Today's jet engines, which can put out thirty to fifty times as much thrust, are much more complex with up to 22,000 parts. The third explanation Arthur offers is that large systems of entities can incorporate simpler systems to boost performance in what is known as "software capture."[12]

Nevertheless, even though complexity proves a successful strategy much or most of the time, this is not always the case. As Murray Gell-Mann has observed, a complex system "under the influence of selection pressures in the real world, [engages] in a search process . . . that is necessarily imperfect."[13] A system does not always adapt appropriately, and even adaptations adequate to a particular challenge have effects that are maladaptive.[14]

This article explores the three trends mentioned above. The first trend, analyzed in the section "Complexity and Slack," is one of diminishing returns from investments in complexity in general. This section establishes that advanced societies are becoming more complex. It then advances the economic evidence for diminishing returns to investments in complexity. Finally, it demonstrates that societal slack is shrinking as a result.

The second trend, analyzed in the section "Interconnection and Vulnerability," is the tendency in social and technological systems toward tighter coupling between their components, and more "scale-free" networks, with their attendant vulnerabilities, as societies grow more complex. The result is that

9. Stuart Kauffman, *At Home in the Universe: The Search for Laws of Self-Organization and Complexity* (New York: Oxford University Press, 1995), p. 297.
10. Ibid.
11. Arthur, "On the Evolution of Complexity," p. 69.
12. Ibid., p. 74.
13. Murray Gell-Mann, "Complex Adaptive Systems," in Cowan, Pines, and Meltzer, *Complexity*, p. 22.
14. Ibid.

more points exist to be attacked while the effect of any single attack is magnified, creating a need for stronger protection at more points.

The third trend, discussed in the section "Rising Security Costs," is the increasing cost of the means of security in the face of threats such as terrorism and weapons of mass destruction. In particular, this section examines security expenses rarely looked at in such studies, such as the cost of police and other emergency and law enforcement units, private security outlays, and "hidden" expenditures such as insurance rates, all of which are apparently headed upward.

In the conclusion this article brings the implications of all three trends together. The end result, it argues, is that as today's advanced societies grow more complex, they become less able to absorb shocks. At the same time they offer more points to attack, any one of which can have greater effects because of their heightened interconnectivity. The cost of defending against any of these shocks also rises. As a result, these societies are less and less secure. The conclusion also discusses some possible ways of coping with the problem, central to which is the judicious development and application of a range of new technologies.

Complexity and Slack

Tainter's focus is on a particular category of maladaptation, societal investment in complexity for diminishing returns, in which the returns to each unit of investment shrink (or even become negative). This shrinking in turn reduces societal slack over the long term, which is something that Tainter has argued is the case for today's advanced societies. There are three necessary prerequisites to substantiating this line of argument: (1) establishing that advanced societies are actually becoming more complex; (2) determining that such changes correspond to a pattern of diminishing returns; and (3) confirming that these diminishing returns are consuming slack.

COMPLEXITY AND ADVANCED SOCIETIES

The measurement of complexity is a highly controversial matter, with some experts questioning even the feasibility of trying to do so.[15] Nevertheless, a basis for measurement has been suggested by theorists, with some consensus ex-

15. Phillip W. Anderson, "The Eightfold Way to a Theory of Complexity," in Cowan, Pines, and Meltzer, *Complexity*, p. 11.

isting that the quantity of information required to operate or represent a given structure is a guide to a system's level of complexity.[16] Where social systems are concerned, a feudal, agrarian economy requires less information to operate than an advanced industrial economy, and is therefore less complex. The change in an entity's information load is one way of measuring whether that entity is becoming more complex, as would be the case with a shift from an agrarian economy to an industrial one.

The indicators report a dramatically rising information load as economies are "informatized."[17] One expression of this is that spending on information and communications technology as a share of nonresidential, fixed investment rose from 15.2 percent to 31.4 percent in the United States between 1980 and 2000, with comparable increases in the European Union and Japan.[18] There is also a rising volume of communication, travel, and trade—in short, interconnection and interactivity, which can be identified with increasing complexity. Virtually every indicator of the level of such traffic shows a long, upward trend, with per capita traffic volume doubling in North America between 1960 and 1990.[19] The daily volume of person-to-person email messages, virtually zero twenty years ago, stood at 21 billion in 2002, a figure that the International Data Corporation estimates will rise to 35 billion by 2006.

Between 1950 and 2000, world trade generally expanded faster than gross domestic product (GDP), and more than three times as fast during the 1990s.[20] Although it is often stated that international trade levels were higher in the pre-1914 period than they are currently, this observation tends to ignore the more complex character of the trade. One aspect of this greater complexity is increased "production sharing," that is, trade in components or parts rather

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16. This is consistent with the recommendations of complexity specialists in the past, who have proposed two methods, "algorithmic complexity"—namely the quantity of information needed to reproduce a system's behavior—and "self-dissimilarity," which refers to the difference in characteristics of a system at varying levels of analysis. For their treatments of these respective approaches, see George Chatin, *Algorithmic Information Theory* (Cambridge: Cambridge University Press, 1987), pp. 91–126; and David Wolpert and William Macready, "Self-Dissimilarity: An Empirical Measure of Complexity," Working Paper No. 97–12–087 (Santa Fe: Santa Fe Institute, 1997).
17. Rochlin, *Trapped in the Net*.
18. The change in Europe's case has been from 6.9 percent to 16.9 percent; in Japan's, it has been from 7 percent to 16 percent. Organization for Economic Cooperation and Development (OECD), "Data—ICT Investment in OECD Countries, 1980–2000," http://www.oecd.org/dataoecd/45/20/2766404.xls.
19. Andreas Schafer and David Victor, "The Past and Future of Global Mobility," *Scientific American*, Vol. 277, No. 4 (October 1997), pp. 58–61.
20. World Trade Organization, *International Trade Statistics, 2001* (Geneva: World Trade Organization, 2001), Table II.1. Table II.1 can be located at http://www.wto.org/english/res_e/statis_e/its2001_e/its01_longterm_e.htm.

than fully fabricated manufactures.[21] The growing trade in services, exemplified by the outsourcing of work from accounting to software writing internationally, and the sheer volume of international financial flows have no previous analog. Lowered trade barriers, moreover, have commonly brought more rather than less legal and administrative infrastructure, as with entities such as the World Trade Organization. At the same time, contrary to the claims of those who believe that globalization is bringing about the death of the state, governments—a major source of complexity—have grown larger rather than smaller in this period.[22]

In short, complexity, and in particular the complexity created by more technology and economic integration, is increasing rapidly—but to what end? The second issue, namely whether these investments are producing diminishing returns, remains unanswered.

COMPLEXITY AND DIMINISHING RETURNS

An obvious approach to determining the relationship between complexity and diminishing returns is to look at economic trends, given the overwhelmingly economic orientation of the increased complexity. There is widespread evidence that several economic sectors are showing diminishing returns to investment in complexity, including agriculture, energy production from fossil fuels, and heavy, bulk-processing manufacturing such as steelmaking.[23] The same is true for certain elements of the service sector, generally noted for lower productivity growth than fields such as education and health care.[24] The costs of these two services are increasing at a markedly more rapid rate than economic growth, and without showing commensurate improvements in either their contribution to economic productivity or health standards.[25]

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21. This comprises 30 percent of world trade in manufactures and is growing more rapidly than trade in finished products according to a recent study. Alexander J. Yeats, principal economist, Development Research Group, World Bank, "Just How Big Is Global Production Sharing?" January 1998, http://www.econ.worldbank.org/docs/347.pdf.
22. International Monetary Fund, *World Economic Outlook: A Survey by the Staff of the International Monetary Fund* (Washington, D.C.: International Monetary Fund, 2000), pp. 171–173.
23. Paul Kennedy, *Preparing for the Twenty-first Century* (New York: Random House, 1993), pp. 65–81; Allen, Tainter, and Hoekstra, *Supply-Side Sustainability*, pp. 351–369; and W. Brian Arthur, "Increasing Returns and the New World of Business," *Harvard Business Review*, Vol. 74, No. 4 (July–August 1996), pp. 100–109.
24. The lower productivity of the service economy is sometimes offered as an explanation for why mature economies grow more slowly. Gilpin, *War and Change in World Politics*, p. 165. Walt Whitman Rostow, *The World Economy: History and Prospect* (Austin: University of Texas Press, 1978), pp. 270–273.
25. Allen, Tainter, and Hoekstra, *Supply-Side Sustainability*, pp. 83–95. Health care costs increased 50 percent faster than the incomes of OECD states in the 1990s. "Health Spending Outpaces

Several areas of high technology, such as aerodynamics, are also producing diminishing returns, requiring much greater investment for much more modest results.[26] The most striking exception to this pattern, at least according to the conventional wisdom, is information technology, which is widely credited with driving the continuing increases reported in productivity.[27] It should be remembered, however, that the information society remains underpinned by the older technologies of moving parts and fossil-fuel energy sources.[28] It should also be remembered that the full costs of information technology are rarely taken into account, this being an area where capital (i.e., software and computers) depreciates very rapidly, eating more deeply into productivity increases than is generally noted by economists.[29]

Moving beyond single sectors of the economy, there is evidence that economies in the aggregate are also producing diminishing returns. The world economy grew by 5.3 percent a year in the 1960s, 3.9 percent in the 1970s, 3.2 percent in the 1980s, and only 2.3 percent in the 1990s.[30] Moreover, alternative indicators suggest that even the sagging figures for GDP growth offer a brighter picture than may actually be the case. GDP does not take into account the ecological, social, or long-term economic costs of such activities (i.e., the maladaptations accompanying rising complexity, as Gell-Mann may put it). For that reason, some economists have turned to other indicators that would take into account such costs and that, incidentally, make explicit a connection between certain kinds of complexification and diminishing returns.

Net domestic product (NDP), for instance, is broadly comparable to GDP but takes into account the depreciation of capital. Given the rapid depreciation of information technology relative to more traditional kinds of capital, the gap between rates of U.S. GDP and NDP growth has increased from 0.1 percent in the 1960s and 1970s to 2 percent from the late 1990s on.[31] Such a wide gap sug-

Economic Growth," *OECD in Washington*, No. 37 (September 2002), p. 2. OECD, "Education at a Glance—OECD Indicators, 1998," November 23, 1998, http://www1.oecd.org/media/publish/pb98-42a.htm. Between 1990 and 1995, the cost of education rose more quickly than GDP in fourteen of nineteen OECD countries.

26. Michael E. O'Hanlon, *Technological Change and the Future of Warfare* (Washington, D.C.: Brookings, 2000), p. 194.

27. Arthur, "Increasing Returns and the New World of Business," pp. 100–109.

28. Allen, Tainter, and Hoekstra, *Supply-Side Sustainability*, p. 368.

29. Indeed, it is possible that information technology has been an area of overinvestment. Rochlin, *Trapped in the Net;* and Roland Spint, "What Statistics Do and Do Not Tell Us About Economic Growth," OECD Forum 2003, http://www1.oecd.org/forum2003/speeches/spant.pdf.

30. This happened even as the level of world trade rose annually by 5.6 percent in the 1980s and 7 percent in the 1990s. World Trade Organization, *International Trade Statistics, 2001*.

31. Spint, "What Statistics Do and Do Not Tell Us About Economic Growth."

gests that "real" economic growth in the advanced economies is lower than reported, with equipment depreciation consuming a significant portion of their gains. A 4 percent growth rate would be effectively cut to a "real" rate of 2 percent.

Another alternative is the general progress indicator (GPI), which accounts for a still wider range of the side effects of economic activity that can undermine growth in the long run, including resource depletion, environmental damage, lopsided income distributions, unemployment, and debt.[32] While U.S. per capita GDP grew 55 percent between 1973 and 1993, GPI per capita declined some 45 percent.[33] Rather than a slowing increase in national wealth, the conclusion that can be drawn from the use of GPI is its gradual erosion through negative growth.

DIMINISHING RETURNS AND REDUCED SLACK

A long-term trend of diminishing returns to heightened complexity is strongly suggestive of shrinking slack but insufficient to prove it, the two trends being closely connected but not synonymous. Another approach is necessary to settle the third issue, whether societal slack is actually shrinking. The most obvious is an examination of the level of governmental activity relative to a state's income over an extended period, particularly taxation, spending, and debt. Government, after all, is uniquely positioned to command slack in the event of exogenous shocks, making its ability to do so a way of measuring how much slack exists in the system. A combination of increased taxation, spending, and debt indicates that governments are less and less able to live within their means, that public goods are becoming more expensive, and that a society is spending a higher share of its income on debt service rather than investment or consumption.[34] With taxes and debt levels high, governments also have less leeway to raise taxes further or undertake new types of activity. In other words, because more of their resources are already committed elsewhere, less slack is available to be mobilized when it is needed.

As already stated, government has grown in recent decades, with taxes and

32. Clifford Cobb, Ted Halstead, and Jonathan Rowe, "If the GDP Is Up, Why Is America Down?" *Atlantic Monthly*, Vol. 276, No. 4 (October 1995), pp. 59–78; and Jonathan Rowe and Judith Silverstein, "The GDP Myth: Why 'Growth' Isn't Always a Good Thing," *Washington Monthly*, Vol. 31, No. 3 (March 1999), pp. 17–21.

33. Cobb, Halstead, and Row, "If the GDP Is Up, Why Is America Down?"; and Row and Silverstein, "The GDP Myth."

34. The slowing of growth in the tax base supporting the government in question aside, such circumstances are also suggestive of the government's own investments in complexity being to diminishing returns, as with its ability to provide social services.

spending rising throughout the developed world—as have debt burdens. Tax revenue rose from 31.5 percent to 38.4 percent of GDP between 1970 and 2002 among the Group of Seven advanced industrial nations.[35] Spending rose at an even swifter rate, with the result that the proportion of gross debt to income almost doubled between 1977 and 2002 alone.[36] Notably this rise continued despite post–Cold War reductions in military spending; the scaling back of welfare states, as with lower public spending on education; major reductions in public spending on infrastructure and research and development; and the savings that privatizing and decentralizing government services were supposed to generate.[37]

There are also reasons to think that states will continue moving in this direction of greater spending and indebtedness.[38] The most widely discussed of these is that mandatory spending is increasing as a percentage of government expenditures, so that even with more money being levied, governments have less leeway in making spending decisions.[39] This is partly because of the pressure that aging populations put on social safety nets, which appear to be growing less effective as a way of achieving their goals, particularly pension plans and health care systems.[40] Also consistent with a trend toward older populations (but not solely due to it), savings rates have declined throughout the advanced world, and private debt has risen, meaning a shallower well from which governments can draw in times of need.[41]

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35. "International Fiscal Comparisons," in Department of Finance, Canada, *Fiscal Reference Tables*, October 2002, http://www.fin.gc.ca/frt/2003/frt03_9e.html.
36. Central government outlays in the Group of Seven countries rose from 32.1 percent to 40.3 percent of GDP during the 1970–2002 period. Gross debt rose from 41.8 percent to 78.1 percent between 1977 and 2002. Although budget deficits shrank during the boom of the late 1990s, they have since returned to their former levels, running at 3.7 percent in 2002. Ibid.
37. OECD, "Education at a Glance—OECD Indicators, 1998"; Barry Bosworth, *Prospects for Savings and Investment in Industrial Countries*, Brookings Discussion Papers No. 113 (Washington, D.C.: Brookings, 1995); and OECD, *Economic Outlook*, No. 69 (June 2001), p. 182.
38. Congressional Budget Office, "A 125-Year Picture of the Federal Government's Share of the Economy, 1950 to 2075," long-range policy brief, July 3, 2002, http://www.cbo.gov/showdoc.cfm?index?3521&sequence=0.
39. In the United States, mandatory spending rose from 32 percent to 59 percent of the federal budget between 1962 and 2002.
40. Congressional Budget Office, *The Budget and Economic Outlook: Fiscal Years 2004–2013*, http://www.cbo.gov/showdoc.cfm?index=4032&sequence=0. Old age spending alone is projected to rise by 3–4 percent of GDP by 2050 from the present level of 7.5 percent. OECD, *Economic Outlook*, pp. 145–167.
41. Lester Thurow, *The Future of Capitalism: How Today's Economic Forces Shape Tomorrow's World* (New York: Penguin, 1996). The U.S. savings rate—an extreme example, but with parallels elsewhere—dropped from 8 percent in 1980 to 1 percent by mid-2002. Milt Marquis, "What's Behind the Low U.S. Personal Savings Rate?" Federal Reserve Bank of San Francisco, *Economic Letter*,

Defense economics in recent years underscore this tightening of finances. Yet defenders of recent increases in U.S. defense spending have frequently argued that the United States managed to spend 37.5 percent of GDP on defense in 1945, and then 5 percent or more of its annual income in the Cold War.[42] Implicitly, the United States could do the same today. What those making this argument commonly miss is that the federal government was much smaller at the outset of World War II, and also less indebted.[43] Postwar economic growth was also sufficient to enable the United States to "grow out of" its debt, cutting it by three-quarters as a share of GDP.[44] By contrast, the spike in U.S. national debt in the 1980s suggests that the decade's defense expenditures, in the range of 5–6 percent of GDP, were less supportable than the much higher levels of the 1950s.[45] Current defense spending in the area of 4 percent of GDP in the early years of the twenty-first century produces budget deficits and increases in the debt burden comparable to those of the 1980s.

In short, the less-taxed, less indebted United States of the World War II era had considerable slack on which to draw, and a high growth rate enabled a rapid fiscal recovery. More recent trends, however, have been toward diminishing returns to investment in complexity, as evidenced by slowing growth. Moreover, these investments have consumed slack, as seen in rising debt levels and shrinking savings. Nor is this to be regarded as a temporary aberration,

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No. 2002-09, March 29, 2002. Payments on debt as a percentage of household income have risen gradually from 12.46 percent in 1981 to 14.02 percent in 2003, driven largely by a steady rise in mortgage payments. Federal Reserve Board, press release, "Household Debt Service and Financial Obligations Ratios," http://www.federalreserve.gov/releases/housedebt/default.htm. Debt as a proportion of income also rose from 56 percent to 81 percent of disposable income between 1983 and 1994—and 100 percent by the end of the decade. Glenn B. Canner, Arthur B. Kennickell, and Charles A. Luckett, "Household Sector Borrowing and the Burden of Debt," *Federal Reserve Bulletin*, April 1995, p. 323; and David Broder, "Our Crushing Personal Debt," *Washington Post*, September 1, 2002.

42. Office of Management and Budget, Executive Office of the President, *Historical Tables: Budget of the United States Government, Fiscal Year 2003* (Washington, D.C.: U.S. Government Printing Office, 2002), p. 116.

43. Federal revenue was 6.8 percent of GDP, compared with 18 percent in 2002. Debt relative to GDP was 52.4 percent in 1940, compared with 60 percent in 2002. Even in 1944, at the peak of spending during World War II, federal revenues were 20.9 percent of U.S. GDP, compared with 20.8 percent in 1999—tax levels being as high in peacetime during the 1990s as at the height of that conflict. Ibid.

44. Federal debt fell from 121.6 percent to 32.5 percent of GDP between 1946 and 1980. Office of Management and Budget, *Historical Tables.*

45. Between 1952 and 1960, defense spending ranged from 9.3 percent to 14.2 percent of GDP, but during those same years gross debt dropped from 74.3 percent of GDP to 55.9 percent. Between 1981 and 1988, defense spending ranged from 5.3 to 6.5 percent of GDP, but the debt rose from 32.5 percent to 51.9 percent, to eventually peak at 67.3 percent in 1996. Ibid., pp. 116–117.

as indicators suggest this pattern will continue well into the early decades of the twenty-first century.

Interconnection and Vulnerability

In addition to leaving advanced societies less slack, greater complexity may mean more vulnerability because of the higher level of interconnection it entails. Certainly, the opposite is typically considered true: that is, a high level of interconnection between components can often contain or ameliorate disruptions, a point well established in the ecological literature. Where societies are concerned, the existence of a large number of interconnections empowers a state to respond to security threats by enabling it to better monitor its domain and move military and police forces as needed.[46] A large number of interconnections also suggests that it is a fairly simple matter to "summon aid to the injured points, erect bypasses around them, and find substitutes for them" in the event of disruptions, as Martin Van Creveld put it in *Technology and War*.[47]

The reverse, however, can be true just as often. In practice, the same infrastructures that allow states to cope with threats also open avenues for those same threats they mean to guard against, be they an invading army or a terrorist cell. Consequently, the conduits must be guarded not only against exploitation by a hostile force but also against attacks on the conduits themselves—passenger aircraft, for instance, being favorite targets of terrorists. More important, the dense web of connections within a society can more widely propagate the effects of any attacks that do occur.

The question then becomes: what sort of interconnections give a society the ability to recover quickly and which do the opposite? Charles Perrow has made the case that it is a question of the tightness of coupling within a system. Tightly coupled systems, which are short on slack, are also intolerant of delay and contain invariant sequences not allowing for improvisation.[48] For that reason there is no room for failure, which means that buffers and redundancies have to be built in, rather than being "fortuitously available." Consequently, tightly coupled systems are highly susceptible to "idiosyncratic threats," meaning that "if one can find a weakness through which safety factors can be

46. Peter Lieberman, *Does Conquest Pay? The Exploitation of Occupied Industrial Societies* (Princeton, N.J.: Princeton University Press, 1996), pp. 25–28.
47. Martin Van Creveld, *Technology and War: From 2000 B.C. to the Present* (New York: Free Press, 1989), pp. 307–308.
48. Perrow, *Normal Accidents*, pp. 93–96.

overloaded or bypassed, he can cause imploding, catastrophic failure."[49] Power grids demonstrate how this can happen. In November 1965 the shutdown of one of six lines carrying power into Ontario's electric grid from the Beck plant outside Toronto disabled much of the Canadian system.[50] When the demand for electricity from Canada went off-line, Beck's output into New York doubled, surging through the U.S. grid, endangering plants all over the northeastern United States, and compelling utilities to take their systems off-line. The result was that in the space of four seconds, much of Canada and the northeastern United States were left in the dark. Although this blackout resulted from an accident rather than an attack, it does suggest possibilities for sabotage capable of producing similar effects.

Oil pipelines offer another example of a tightly coupled system, one entailing more localized but also longer-term disruption than is generally the case with power grid failures. The sabotage of the pipeline between Iraq and Turkey in August 2003 closed off the flow of oil from the fields in Kirkuk—40 percent of Iraq's total production.[51] No other way exists to move the oil, and the shutdown of the damaged section rendered the rest of the pipeline inoperative at a cost of an estimated $7 million a day in lost oil sales and a small but noticeable rise in world oil prices. Moreover, even after the repair of such a pipeline, it is a matter of days before the process can function normally again. Meanwhile the infrastructure remains vulnerable to further disruption, the Kirkuk pipeline proving no exception to the rule. Consequently, the time given by authorities for which the critical pipeline would be inoperable increased from three weeks to three months (early November). In the face of later attacks, the authorities suggested that the pipeline could be out of service indefinitely, though operations did finally resume in March 2004.[52]

Certainly, electric grids and oil pipelines may be dismissed as relatively old-fashioned technology. Nevertheless, they will remain critical parts of modern infrastructures for a long time to come. There is also good reason to believe that the connections most characteristic of advanced societies are creating tighter coupling, and the greater vulnerability that goes along with them. One

49. Montgomery C. Meigs, "Unorthodox Thoughts About Asymmetric Warfare," *Parameters*, Vol. 33, No. 2 (Summer 2003), p. 9.
50. Ibid.
51. "U.S. Battles Iraq Pipeline Blaze," *BBC News*, August 18, 2003, http://news.bbc.co.uk/2/hi/business/3159135.stm.
52. Even then the resumption was only at partial capacity. "Iraq's Kirkuk Pipeline Needs Millions of Dollars' Worth of Repairs," CNEWS, March 9, 2004, http://cnews.canoe.ca/CNEWS/World/Iraq/2004/03/09/375986-ap.html.

reason is that tight coupling is widely seen as the key to extracting greater efficiency and productivity from a system.

This pattern is reflected in many of the post-Fordist production approaches that rely on computers and other information technologies. The combination of accelerated production rates and smaller, more highly specialized workforces makes a given disruption (i.e., the loss of a man-hour of work) more costly. The number of man-hours required to produce a ton of steel, for instance, dropped from 10.5 in 1980 to 2.2 by 2000 largely because of automation and information technology.[53] Older, "less efficient" ways of going about an activity are eliminated, and user autonomy is restricted through standardization of process and procedure, making sequences more rigid and leaving even less room for improvisation.[54]

Just-in-time (JIT) manufacturing, in which components are delivered just as they are needed, is an example of such a slack-free, tightly coupled process—and can be quickly disrupted when these are interfered with, as demonstrated by the terrorist attacks of September 11, 2001. The tightening of security following the attacks produced major bottlenecks in supply-chain management systems, with trucking coming to a near halt along the borders the United States shares with Canada and Mexico.[55] According to a U.S. government report, "Transportation issues played havoc with order flows and drove up shipping costs"; the plants most dependent on JIT (such as those belonging to Ford, Honda, and Toyota) stopped working. At the macroeconomic level, the result was a 1 percent drop in U.S. industrial production in the month of September, largely resulting from the disruption of industry in the week before normality returned.[56]

Tighter coupling can also be regarded as a consequence of "coevolutionary development," in which niches create still other niches, as with the example of the automobile cited earlier. Without automobiles, there is little need for motels, traffic lights, and paved roads, so that economic sectors involved with these similarly suffer. Given the connection of such trends with rises in complexity, it stands to reason that more complex economies are more dependent

53. Industrial College of the U.S. Armed Forces, *Strategic Materials*, Industry Study 5240–18 (Washington, D.C.: National Defense University, Spring 2002), http://www.ndu.edu/icaf/IS2002/2002%20Strategic%20Materials.htm.
54. Rochlin, *Trapped in the Net*, pp. 35–50.
55. Brian S. Wesbury, "The Economic Cost of Terrorism," *September 11, One Year Later: A Special Electronic Journal of the U.S. Department of State*, September 2002, http://usinfo.state.gov/journals/itgic/0902/ijge/ijge0902.htm.
56. Ibid.

on niche activities tightly interconnected with one another. The effects of this in the face of disruption were also demonstrated by the September 11 attacks.

The terrorist attacks on one niche of the aviation industry (air travel, which suffered $15 billion in losses in 2001 and 2002 because of the September 11 attacks and subsequent disruption) translated into losses for other sectors.[57] Deliveries by Boeing, the world's largest supplier of commercial airliners, were down 28 percent in 2002 from the previous year, to 381 from 527.[58] In anticipation of the reduced demand for its aircraft after the attacks, Boeing alone announced 30,000 layoffs.[59] Along with the major airlines and Boeing, airports and other related concerns scaled back operations, eventually cutting about 400,000 jobs worldwide according to one estimate.[60] These job losses in turn had "multiplier" effects in the areas where they were located, while the falloff in air travel and international travel generally damaged other sectors such as tourism, which many estimates indicate lost millions of jobs as a result of the attacks.[61] Meanwhile insurance companies, faced with paying out indemnities in the tens of billions of dollars, increased premiums for some types of insurance more than 300 percent in a year's time, with a doubling across the board thought likely in a permanent and significant elevation of the cost of doing business.[62] In short, even excluding elevated spending on security and longer-term effects such as higher insurance rates, the September 2001 attacks did hundreds of billions of dollars in economic damage in the United States and abroad.[63]

Buffers and redundancies can be built into tightly coupled systems, such as a backup pipeline, larger inventories, or greater reserves of capital, to keep com-

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57. U.S. House Committee on Transportation and Infrastructure, press release, "Financial Condition of America's Aviation Industry in Aftermath of September 11th Attacks to Be Focus of Congressional Oversight Hearing," September 20, 2002, http://www.house.gov/transportation/press/press2002/release354.html.

58. "Boeing's Deliveries Off 28 Percent; Meets Lowered Goal," *Boston Globe*, January 6, 2003.

59. Paul Nyhan, "State Jobs: 9/11 Fallout Lingers," *Seattle Post-Intelligencer*, September 8, 2003, http://seattlepi.nwsource.com/business/138439_terroreconomy08.html.

60. Cardiff University Business School, press release, "Employment Turmoil in the Aviation Industry," January 18, 2002, http://www.cf.ac.uk/news/releases/0201/020118.html.

61. One high estimate is that the attacks produced a 7.4 percent drop in tourism for 2001 and 2002, with a loss of 10 million jobs. World Travel and Tourism Council, press release, "End of the Tunnel in Sight for Travel and Tourism—Recovery Forecast Mid 2002," March 17, 2002, http://www.wttc.org/mediaCentre/020317%20End%20of%20Tunnel%20TSA%202002.htm.

62. Office of Homeland Security, *The National Strategy for Homeland Security*, http://www.whitehouse.gov/homeland/book/, p. 65.

63. One commonly cited estimate is $120 billion in damage to the U.S. economy alone. Wesbury, "The Economic Cost of Terrorism."

panies going in lean times. These are deliberate investments rather than something fortuitously available, however, and the redundancies themselves, aside from being costly, can be a cause of additional breakdowns. This appears to have been the case with, for instance, nuclear reactors, where the addition of redundant components was "the main line of defense" against failure, but also "the main source of failures."[64]

Planners may also consciously choose not to invest in such buffers. Redundancy and slack are conventionally perceived as a drag on efficiency, and therefore a cost to be cut rather than as a good in social and technological systems.[65] At the same time, the tendency is toward leaner operations and ever-shorter time horizons in business, as well as rising competitive pressures.[66] The pressure is therefore significant to opt for efficiency over reserve capabilities that may be useful in the event of an emergency. One result is that a lack of unused capacity, or "headroom," in an electric grid's power lines frequently turns what might otherwise be an isolated system failure or local problem into a large-scale power failure.[67] Such attitudes also tend to persist even after such incidents, as has been the case with just-in-time manufacturing, calls to rethink such practices post-September 11 proving short lived.[68]

It also stands to reason that with some aspects of a complex system's functioning typically ill understood, decisionmaking in this area is likely to be of poorer quality than in other cases. In some instances, buffers are inherently difficult to build, as with certain kinds of interconnection. Scale-free networks, such as the internet, tend to have critical hubs or nodes that are connected to a far larger number of elements than average (as opposed to random nets such as the highway system, where each element connects with only a few others).[69]

The internet, for instance, is held together by a relative handful of web pages of disproportionate value. The same is also the case with the air travel system in the United States, which relies on hubs where passengers catch connecting

64. Perrow, *Normal Accidents*, p. 73.
65. Seth Scheisel, "In Frayed Networks, Common Threads," *New York Times*, August 18, 2003. This attitude is not only deeply ingrained in business practices from Henry Ford and Frederick Winslow Taylor on, but is also consistent with current thought on risk assessment and cost-benefit analysis. See Perrow, *Normal Accidents*, pp. 306–315; and Rochlin, *Trapped in the Net*, pp. 51–73.
66. Thurow, *The Future of Capitalism*, pp. 279–309.
67. Scheisel, "In Frayed Networks, Common Threads."
68. Barry Eichengreen, "The United States and the World Economy after September 11," in Craig Calhoun, Paul Price, and Ashley Timmer, eds., *Understanding September 11* (New York: New Press, 2002), p. 125.
69. Alberto-Laszlo Barabasi and Eric Bonabeau, "Scale-Free Networks," *Scientific American*, Vol. 288, No. 5 (May 2003), pp. 60–69.

flights. One consequence of the "hub-and-spokes" system is the ease with which disruptions can translate into major, widespread delays. Recent research has shown that networks such as these may be highly vulnerable to coordinated attacks, the critical threshold for the propagation of a "contagion" through them being virtually zero. Additionally, attacking as few as 5 percent to 15 percent of the elements in such a network can bring down the entire network.[70] A foretaste of such possibilities has been hinted at by the internet's susceptibility to spam email and viruses, single examples of which, such as the "Love Bug," inflicted billions of dollars in damages—and remained pervasive a year after its supposed eradication. Even though the key nodes in a system can be better protected, they are not always easy to identify; in any event, the connectivity of systems rules out a "silver-bullet solution."[71]

Tighter coupling between the components of today's complex societies, and in particular the vulnerability of scale-free networks to coordinated attack, mean that an attack on any one point can have wider effects, reducing the "tolerance for breakdowns and errors" anywhere along the line.[72] The tendency is also toward more components, as niches for new ones are created and new subsystems added, so that more points exist to be attacked. A larger effort is therefore required to protect a larger number of targets, a rough analog with defending a longer front, making for an abrupt increase in a society's security burden without a comparable expansion in its resources. This has already been the case, the relative rise in U.S. security expenditures since September 11 being far greater than economic growth for the period of that rise.

The same is suggested by the prospect of "terrorist-proofing" modern society, as by improving ventilation systems and providing better safeguards for energy distribution systems as called for in a June 2002 report of the National Research Council.[73] This was in line with a historical pattern: an attack on a single target leads to the fortification (terrorist-proofing) of entire classes of targets indefinitely, as with the heightened precautions surrounding the boarding of airliners following September 11. Indeed, in this event it also led to the

70. Ibid.
71. House Science Subcommittee on Technology, "The Love Bug Virus: Protecting Lovesick Computers from Malicious Attack," hearing report, May 10, 2000, http://www.nist.gov/hearings/2000/lovebug.htm.
72. Jean-Marie Guehenno, *The End of the Nation-State*, trans. Victoria Elliott (Minneapolis: University of Minnesota Press, 1995), pp. 19–34.
73. Committee on Science and Technology for Countering Terrorism, National Research Council, *Making the Nation Safer: The Role of Science and Technology in Countering Terrorism* (Washington, D.C.: National Academies Press, 2002).

fortification of facilities not targeted by the terrorists in the attacks, such as the broad effort to upgrade harbor security. The resulting effort to deploy U.S. law enforcement personnel in foreign ports to clear ships bound for the United States raises another key point: a characteristic of complex systems is an openness blurring the boundaries, the absence rather than presence of connection becoming what is difficult to establish. Where security is concerned, this fosters a propensity to "push[ing] the border outwards."[74] In the case of the war on terror, any state that is seen to harbor terrorists is regarded as a threat to be met with force as necessary, effectively placing the whole planet within that border and pushing the perimeter out to its theoretical limit.

Even so, the cost of even the most ambitious counterterror effort may seem paltry as compared with arms races between great powers. It is well worth remembering, however, that empires facing no great power threats have been overwhelmed by unconventional threats against which they attempted to fortify themselves. Following the barbarian attacks and the spike in banditry of the third century, the Roman Empire shifted from preclusively defending its borders to creating broad areas of military control, and ultimately civilians were safe only behind fortifications.[75] The attendant loss of key linkages, the sacrifice of economic productivity to security accompanying such circumstances, and the massive cost of fortifying the empire (and other, related controls) fed into a pattern that eventually drove the Roman Empire to collapse.

Rising Security Costs

Making matters worse is the rising cost of the forces required to provide a given level of security, let alone the higher one that a society with depleted slack and more sensitive and numerous vulnerabilities would appear to require. Security forces, after all, are no less prone than other societal institutions to becoming more complex or to showing diminishing returns to investment in complexity.

These trends are exemplified by the increasing concern with asymmetrical

74. "Statement by U.S. Customs Commissioner Robert C. Bonner: Hearing on Security at U.S. Seaports, U.S. Senate Committee on Commerce, Science, and Transportation," February 19, 2002, http://www.customs.ustreas.gov/xp/cgov/newsroom/commissioner/speeches_statements/archives/feb192002.xml.

75. Edward Luttwak, *The Grand Strategy of the Roman Empire: From the First Century A.D. to the Third* (Baltimore, Md.: Johns Hopkins University Press, 1979), pp. 159–170.

warfare. While the term has been badly abused in the past decade, the focus in such discussions is generally on how smaller powers can use low-technology weapons and commercially available resources to defeat more powerful militaries.[76] Put in the language of complexity theory, it can be described as a less complex force's strategy for exploiting the vulnerabilities of a more complex opponent. Not surprisingly, these scenarios typically assume that small powers are on the defensive against an enemy invested in "heavy metal" weapons, vulnerable to global public opinion, and with a low tolerance for casualties—in other words, an opponent operating with little slack.[77]

The entry of weapons of mass destruction into such scenarios only highlights the exorbitant cost of reliably defeating (rather than deterring the use of) those weapons, a mission likely to be one of the principal sources of new military investment in the years to come, as with U.S. investments in missile defense. The ability to reliably shoot down such missiles poses extremely difficult problems, sufficiently great that whether it can be done at all is highly controversial.[78] Even though missile defense certainly poses unique technical challenges, the larger problem is arguably its being a new kind of mission, namely planning for confrontations with the "strength in madness" of irrational actors.[79] Arguments for missile defense assume an opponent prepared to strike despite the certainty of its devastation in a counterattack, and so is looked to for a level of security far beyond the levels traditional realist calculations were meant to provide.[80]

Certainly, many states have responded to these various challenges simply by buying less in the way of defense, spending a smaller part of their incomes on their militaries. Such reductions, however, may be illusory, the character of security spending instead shifting, given that measurements of defense spending (for instance, as a percentage of GDP) tend to cover solely military expenditures. Law enforcement and emergency management units, let alone private

76. Martin Libicki, "Rethinking War: The Mouse's New Roar," *Foreign Policy*, No. 117 (Winter 1999–2000), pp. 30–43; and Michael T. Klare, "Waging Post-Industrial Warfare on the Global Battlefield," *Current History*, Vol. 100, No. 650 (December 2001), pp. 433–437.
77. Libicki, "Rethinking War."
78. Nader Elhefnawy, "Four Myths about Space Power," *Parameters*, Vol. 33, No. 1 (Spring 2003), pp. 131–132.
79. Zaki Laidi, *A World without Meaning: The Crisis of Meaning in International Politics*, trans. June Burnham and Jenny Coulon (London: Routledge, 1998), pp. 105–122.
80. Keith Payne, *Deterrence in the Second Nuclear Age* (Lexington: University Press of Kentucky, 1996).

security expenditures, are simply not represented, but these are significant and growing. Largely excluding military expenditures, the United States spends $100 billion a year on homeland defense, approximately 1 percent of its GDP.[81] Law enforcement cost the United States 1.57 percent of GDP in 1999.[82] According to a conservative estimate, private business spends $55 billion annually on private security in the United States (another 0.5 percent of GDP), a figure expected to rise by 50–100 percent as a consequence of the September 11 terrorist attacks.[83]

All of this suggests that the portion of modern economies devoted to defense spending may be significantly underestimated by the conventional measures by 3 percent or more. Added to the elevated level of defense spending following the September 11 attacks, far more than 4 percent when the costs of operations in Iraq and elsewhere are included, it appears that U.S. spending on security has returned to Cold War levels. Although the argument can be made that this is only because Cold War–era expenditures on criminal justice and private security are not included in such a comparison, this would require ignoring the presently elevated importance of such expenditures. The line between war and crime has become increasingly blurred as nonstate actors such as warlords and criminal syndicates become the principal participants in armed conflict, largely subsidized by illegal activities such as drug trafficking, and for that matter, the criminalization of states.[84] The same is true for the agencies combating such organizations, where the line between military and police forces in prosecuting the war on drugs or protecting states from terrorist threats to the homeland has become blurrier, a point raised by the room for argument over whether al-Qa'ida is a criminal rather than military threat.[85] In ei-

81. Office of Homeland Security, *The National Strategy for Homeland Security*, p. 65.
82. National Center for Policy Analysis, "Using the Private Sector to Deter Crime," *Study* No. 181, http://www.ncpa.org/studies/s181/s181b.html; U.S. Department of Justice, Bureau of Justice Statistics, "Expenditure and Employment Statistics," http://www.ojp.usdoj.gov/bjs/eande.htm; and Bureau of Justice Statistics, *Sourcebook of Criminal Justice Statistics, 2001*, http://www.albany.edu/sourcebook/.
83. Another cause of the airline industry's losses was the cost of elevated security measures required in the wake of the September 11 attacks, such as new baggage scanners that cost $4–$5 billion just to purchase. International Institute for Strategic Studies, *Strategic Survey, 2001/2002* (London: Oxford University Press, 2002), pp. 48–49.
84. Martin Van Creveld, *The Transformation of War* (New York: Free Press, 1991), p. 116. For a discussion of the phenomenon of "criminalized states," see Jean-François Bayart, Stephen Ellis, and Beatrice Hibou, *The Criminalization of the State in Africa* (Bloomington: Indiana University Press, 1999).
85. Michael Howard, "'9/11' and After: A British View," *Naval War College Review*, Vol. 55, No. 4 (Autumn 2002), pp. 11–22.

ther case, however, the cost of law enforcement rose 140 percent in relative terms in the United States from 0.65 percent of GDP in 1965 to 1.57 percent (as mentioned above), and private security spending is generally thought to have risen over the period as well. As observers sometimes put it, there were twice as many public police as private ones in 1970, but the reverse was the case by 1990, despite the large jump in public expenditure on law enforcement.

Consequently, a comparison between figures including these other categories of security spending in addition to defense still suggests a trend of diminishing returns to these investments. The movement in this direction is only continuing with the war on terror. This fact appears doubly problematic when the information burden is considered alongside the financial one. New technologies and a rising volume of communication and trade continually increase the amount of activity that must be watched, and it seems that the burden is already unsustainable. An examination of the events prior to September 11 suggests that the problem was less one of inadequate intelligence collection than inadequate processing and coordination.[86] The National Security Agency, for instance, was already collecting far more intelligence than it could analyze effectively or quickly. Congressional inquiries showed an enormous backlog of unexamined communication elsewhere, totaling "millions of hours of talk by suspected terrorists—including 35% of all Arabic-language national-security wiretaps by the FBI—had gone untranslated and untranscribed."[87] One notable example was a message since interpreted as warning of the attack, but not translated until the next day, despite the priority given to al-Qa'ida communications.

The problem has likely worsened as a result of the war on terror, given that the number of wiretaps tripled after the attack, and the difficulty government agencies have had acquiring additional personnel with the requisite linguistic skills.[88] Over the longer term, the rapid growth in the volume of communication will outstrip anything likely to be achieved by efforts to hire more analysts; simply keeping up with the rise in email flows would mean watching a volume of communication growing by about 16 percent a year. Reforms hing-

86. House Permanent Select Committee on Intelligence and the Senate Select Committee on Intelligence, *Report of the Joint Inquiry into Intelligence Community Activities before and after the Terrorist Attacks of September 11, 2001*, House Report No. 107–792, December 2002, http://a257.g.akamaitech.net/7/257/2422/24jul20031400/www.gpoaccess.gov/serialset/creports/pdf/fullreport_errata.pdf.

87. Daniel Klaidman and Michael Isikoff, "Lost in Translation," *Newsweek*, October 27, 2003, p. 28.

88. Ibid.

ing on stepped-up intelligence collection, epitomized by the proposed Total Information Awareness program, may only worsen the problem by gathering massive amounts of data acknowledged to be of minimal security value.[89] "More" is simply not synonymous with "better" in this case.

Conclusion

Investments in complexity seem to have passed a point of diminishing returns in the area of security by creating higher levels of vulnerability, which can only be borne by disproportionately rising security expenditures. Less slack exists to absorb shocks; more points of attack emerge, as do more connections for radiating the effects of the attack throughout the whole of a system; and the means for defending those points becomes more costly.

The result is a strained society under constant pressure to do more with less. In some cases, however, the reverse may be true: that is, accomplishing less when more needs to be done. A search for alternatives to the continued pursuit of diminishing returns is a logical response, to stop investing in areas that do not pay off and look to investing in those that do. One way may be to concentrate on ameliorating the maladaptive effects of adaptation, as by building more fuel-efficient automobiles to curb pollution and dependence on unreliable foreign energy supplies. Of course, the diminution of slack means fewer resources with which to pursue such approaches, and the tendency toward diminishing returns to complexity generally implies less promise, but certain policies could well pay off, as with the example given above.

Nonetheless, the long-term solution to such problems, as Tainter suggests, is likely to be a new technology or an "energy subsidy" (i.e., the acquisition of greater resources through expansion). Given that mere resource extraction has reached its limits as a solution to the problem of diminishing returns, a technological solution is more necessary than ever, suggesting another area for careful investment for producing increasing returns. The precise character of the technological solution, however, is far from obvious. Investment in informa-

89. The Total Information Awareness (TIA) program, which involved the use of a computer system to "mine data" from private databases in search of signs of terrorist activity is an example of a program likely to be beleaguered by the sheer expansion of the quantity of available data. Dr. John Poindexter, "Overview of the Information Awareness Office," http://www.fas.org/irp/agency/dod/poindexter.html. Although the TIA program was canceled, other data-mining programs remain. "Pentagon's Terror Research Shuffled to Other Agencies," *USA Today*, February 22, 2004, http://www.usatoday.com/news/washington/2004-02-22-terror-projects_x.htm.

tion technology, widely touted as the area of increasing returns, is insufficient by itself given its dependence on mechanical industries and a fossil-fuel energy base. Moreover, some of the ways in which it is presently exploited may even contribute to the problem.[90] Even if government and business have made unwise use of the available technologies, however, and more restrained policies are deemed to be well in order, more research and development may be called for. The same growth in computing power that has accelerated equipment depreciation may also enable advances in artificial intelligence and robotics, allowing them to bear much of the burden of complexity in the future.[91] Moreover, where information technology has been the object of overinvestment, areas such as renewable energy sources have arguably seen underinvestment.

At the same time, fortifying or monitoring everything must be explicitly recognized as impossible, and security as inherently imperfect. Certain improvements in infrastructure design or intelligence collection may prove rewarding, but these are likely to be comparatively modest in contrast with terrorist-proofing whole societies or "total information" efforts—such as, perhaps, concentrating improvements on key nodes in scale-free-type networks. From a societal-level perspective, the best course is likely to be decoupling key systems so that attacks on any one point do less damage, and certain technologies could facilitate this. The renewable energy sources most likely to supplant fossil fuels have the potential to underlie a highly decentralized system of energy production and distribution.[92] A move to more numerous, smaller airports and aircraft could do this for transportation.[93] "Desktop manufacturing" and variants on it, may offer a basis for manufacturing that is at once more efficient and less tightly coupled, potentially culminating in viable, nearly self-sufficient microfactories in the future.[94]

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90. Rochlin, *Trapped in the Net.*
91. Ray Kurzweil, *The Age of Spiritual Machines: When Computers Exceed Human Intelligence* (New York: Viking, 1999); and Hans Moravec, *Robot: Mere Machine to Transcendent Mind* (New York: Oxford University Press, 2000).
92. Lester R. Brown, *Eco-Economy: Building an Economy for the Earth* (New York: W.W. Norton, 2001), pp. 97–120; and Union of Concerned Scientists, "Lessons from the August 2003 Blackout," September 15, 2003, http://www.ucsusa.org/clean_energy/renewable_energy/page.cfm?pageID=1248.
93. James Fallows, *Free Flight: From Airline Hell to a New Age of Travel* (New York: PublicAffairs, 2001).
94. For some thoughts on this matter, see Thomas K. Adams, "Radical Destabilizing Effects of New Technologies," *Parameters*, Vol. 28, No. 3 (Autumn 1998), pp. 99–111. See also Douglass Mulhall, *Our Molecular Future: How Nanotechnology, Robotics, Genetics, and Artificial Intelligence Will*

Finally, assessments of security costs must count private security and law enforcement and emergency services expenditures as part of a state's spending on security: for example, baggage scanners should be recognized as just as much a defense buy as a fighter plane. Better accounting needs to be made of hidden costs such as higher insurance premiums resulting from terrorism. With or without such accounting, it is admittedly less clear whether investment in areas such as police and private security has yet reached a point of diminishing returns. What is clear, however, is that the relative and absolute cost of these activities has increased massively in a relatively short period of time, and with uncertain results.

Better accounting may contribute to better decisionmaking over the long term, but in the end the solution is likely to remain primarily technical. Of course, there is a danger in pinning the hopes for resolving such pressing problems on unproven technologies. History is replete with technological revolutions that naysayers said would never happen. There have also been disappointments, however—for example, the overoptimistic claims about space exploration and commercial fusion. It is also dangerous to ignore the significant downsides that exist to these technologies, or to disregard the fact that the "social ingenuity" (to borrow Thomas Homer-Dixon's phrase) for implementing them must go hand in hand with the technical ingenuity that created them.[95] Nevertheless, their playing a critical role in a solution to this problem is a possibility, and one that should be of concern not only to futurists but to students of security as well.

Transform Our World (Amherst, N.Y.: Prometheus, 2002); and Eric Drexler, *Engines of Creation: The Coming Era of Nanotechnology* (New York: Anchor, 1986).
95. Homer-Dixon, *The Ingenuity Gap.*