TECHNOLOGY

If the most defining characteristic of the postindustrial age is the emergence of societies “organized around knowledge for the purpose of social control and the directing of innovation and change,”¹ it should not be surprising to find technology—understood as the material instantiation of knowledge, methods, resources, and innovation—identified as the first and most important building block for the production of national power. The number of technologies possessed by a country at any given point in time are not only vast and beyond enumeration, they also span the spectrum of sophistication, ranging from primitive implements all the way to the most cutting-edge products, which can be generated only as a result of attaining mastery over advanced scientific concepts and having both the resources and the ability to translate these concepts, first, into new components and, thereafter, into a larger socio-technical system built around the introduction of these new components. The focus on technology here, as a building block of national power, is centered exclusively on understanding a country’s ability to produce the most sophisticated “critical technologies” identified today. The issue of “what is a critical technology” is itself a complex and much debated question, and it cannot be either addressed or resolved in this monograph.² There is, however, a loose consensus in govern-

¹Bell, op. cit., p. 20.
²An excellent discussion of this question may be found in Bruce A. Bimber and Steven W. Popper, What Is a Critical Technology? (Santa Monica, CA: RAND, DRU-605-CTI, 1994). See also Popper et al., op. cit. (1998), pp. 125–133.
ment, industry, and among technologists on which technologies today are deemed to be critical; the National Critical Technologies Panel, for example, has identified 22 separate critical technologies that will be vital to both economic competitiveness and defense in the future. Any evidence of mastery (or of growing capability) in these areas would not only suggest that the target country is likely to be (if it is not already) a contender of significance in the struggles to dominate the cycles of innovation in the international economy but also that it has (or is attempting to create) the technological capabilities to produce instruments of coercion that could proffer an edge in the jostling common to international politics.

Analyzing the Technological Capabilities of a Target Country

Since this remains the analytical focus of the framework suggested in this report, the technological capabilities of any target country ought to be scrutinized at three levels:

The first level is the country’s capacity to produce the most important critical technology today. Since by common consensus the most important technology today appears to be information and communication technology in all its manifold guises, and since it is also acknowledged that the United States today has the lead in this area, scrutinizing the capacity of key target countries here is intended to disclose whether they are enhancing their capabilities as a result of diffusion, imitation, or innovations of their own. This evidence speaks primarily to whether potential competitors may be catching up with the United States in an arena where it already dominates.

The second level is the country’s capacity to produce the most important critical technologies of tomorrow. Even as the analysis continues of how competitors may be catching up with the United States in the critical technologies of today, it is important to examine whether competitors are making breakthroughs in other technology-areas that are currently assessed as harboring the potential to transform into the “leading sectors” of tomorrow: materials, manufacturing, biotechnology, aeronautics, and surface transportation, and

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energy and environment. Scrutinizing the capacity of key target countries here is intended to disclose whether they are enhancing their capabilities to challenge the economic primacy of the United States as a result of independent, pathbreaking innovations of their own in new technology-areas that could become the nucleus of new leading sectors tomorrow. Since it is never possible to determine conclusively in advance which technology-areas will remain critical for the production of future national power, observers ought to recognize that the candidate critical technologies of tomorrow may change if “new feats . . . [which] . . . initiate an uprush in another industry”\(^4\) ever occur in the United States or abroad. If such “feats” occur, the analytical focus ought to change accordingly. Since the current consensus appears to be that innovations in materials, manufacturing, biotechnology, aeronautics and surface transportation, and energy and environment hold the promise of producing the new leading sectors of tomorrow, the analysis here will focus primarily on these technology-areas even as it reiterates the argument that these currently salient areas could well be replaced by others over time.

The third level is the country’s capacity to produce the most important militarily-critical technologies of today. Since technological innovations are usually translated into militarily-relevant instruments by all candidate great powers, the analysis of technology as a building block of national power must include, finally, the scrutiny of a country’s ability to produce all the militarily critical technologies deemed to be vital today. These technologies will not be listed in this section, since they are large in number but, more importantly, are described elsewhere in some detail.\(^5\) The authoritative U.S. study of militarily critical technologies has identified about 2,060 militarily significant technologies, of which fully 656 were deemed to be critical for the purposes of developing advanced weaponry, all of which fell within eighteen broad technology areas which, in turn, are further divided into eighty-four subsections.\(^6\) Two considerations are relevant in this regard: First, the militarily-critical technologies


\(^6\)Ibid.
identified here span the technologies relevant for the production of leading-edge military instruments both today and, to some degree, tomorrow. Second, this list cannot be considered as cast in stone: the relevant militarily critical technologies will change over time depending on the innovations that occur in the overall national economic base. Consequently, observers must recognize that these technologies are identified on the basis of present estimations of what is possible, and as new technological breakthroughs occur in the wider economy, the range of technologies that lend themselves to critical military applications will also change pari passu.

Indicators of Critical Technologies

Information and communications. In an age defined by dramatic advances in information processing, it should not be surprising to find that information and communications have become the new leading sector of the global economy and, by implication, a good metric for judging national power. The number and kinds of technologies encompassed by the notion of an information technology network are vast and diverse, but the most important are those which refer to the critical computing and connectivity technologies that not only “transform . . . economic and social life in ways that hardly need elaboration” but can also be “used to create still better technology.” The 1991 Report of the Critical Technologies Panel lists seven separate areas of knowledge necessary to achieve technological excellence in this regard: high-performance computing and networking, software, data storage and peripherals, computer simulation and modeling, microelectronics and optoelectronics, sensors and signal processing, and high-definition imaging and displays.

High-performance computing and networking technologies are essential to the capability to process, store, and transmit information. These technologies provide the ability to manipulate, analyze, compute, and otherwise use information more accurately and quickly than the unaided human brain can. Computing technologies also

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7 Cohen, op. cit., pp. 42–43.
8 Goure, op. cit., p. 177.
9 U.S. Department of Commerce, op. cit.
Information and communications

Materials

Manufacturing

Biotechnology and life sciences

Aeronautics and surface transportation

Energy and environment

Militarily critical technologies

Indigenous production capability
Transplanted production capability
Trade access to technology
Basic-applied experimental research
Theoretical research

Figure 4—Critical Technologies and Illustrative Indicators

permit the storage of information in accessible forms. High computing performance is indicated by a large magnitude of computational power (the number of calculations in a given unit of time), a large input/output bandwidth (the number of information bits a computer can take in or produce in a unit of time), a high capacity to accommodate different kinds of software, and large storage capacity. Networking technology represents the complement to high-speed computing. It provides the capability to link computers as well as data, image, and voice communications by converting streams of binary data into acoustic, electronic, or photonic signals and vice versa. High-quality networking technology is indicated by the extent of bandwidth (higher bandwidths carry larger numbers of signals per unit time), the quality of transmission, the speed at which signals are processed and transmitted, and the security of the transmissions. Networking also contributes to speedier computing insofar as parallel processing by multiple linked computers results in faster problem solving, which may also obviate the need for gigantic single processors.
Computing capabilities are supported by software and data storage and peripherals technologies. Software provides the basis for applications that allow individuals to direct the physical hardware represented by the computer. Without software programs, computers would be unable to function and users could not interact with them. The quality of software can be judged by its level of sophistication (the complexity, or number of tasks it can accommodate smoothly), its diversity (the range of tasks), and by the flexibility of its program design (the ability of the program to accommodate unanticipated tasks). Software quality can also be assessed negatively, according to the presence of flaws in programming which might cause it to function deviantly. Data storage and peripherals provide the ability to interface physically with computers. Peripherals allow the entering, viewing, manipulation, and storage of data; they include such devices as CD-ROMs (compact disk, read-only memory), floppy disks, keyboards, mice, printers, and scanners. Their quality is best judged by their reliability.

The varied technologies of advanced computing provide the base for simulation and modeling technologies that construct artificial models of processes, actions, interactions, plans, or objects by utilizing high-level computer software and high-speed processors and enormous data storage, access, and retrieval capabilities at the hardware level. By allowing sophisticated, varied-condition testing of anything from completed systems to design prototypes to command methodologies, simulation and modeling technologies facilitate optimal planning and production, which contribute significantly to increasing innovation and efficiency while reducing risks. The adaptability, accuracy, and realism of simulations and models represent their measure of quality.

While the computational technologies identified above certainly represent critical components, the real distinctiveness of the postindustrial age derives from the connectivity of these components, which has enabled the creation of vast integrated systems than can control everything from banking to transportation. Computing technologies thus represent the muscle for manipulating, generating, and storing information, while communications technologies represent the nervous system that supports information and allows it to move from place to place. The most important communications technologies are those of microelectronics and optoelectronics. These technolo-
gies provide an ever-increasing capacity to process, disperse, and transmit information. Microelectronics employ microscopic electronic elements—semiconductors—which allow increasing miniaturization and integration of computing power at low cost. Optoelectronics emit, modify, utilize, and/or respond to optical radiation to augment conventional microelectronics. The most prominent development here is laser technology, which can be used as a highly precise cutting tool as well as an instrument for sensing and transmitting information and for guidance. Laser and other optoelectronic technologies have significant applications for industrial processing, telecommunications, computing, surveillance, guided weaponry, medicine, signal processing, and imaging. The best indicators identifying the quality of a country’s microelectronics and optoelectronic systems include their operating speeds, reliability, power, efficiency, longevity, and cost.

Two specific applications of microelectronic and optoelectronic technologies merit consideration as critical technologies in their own right: sensor and signal processing technology and high-definition imaging and display technology. Sensor technologies employ microelectronic devices to monitor and/or observe changes in their environment, while signal processing technologies transform the sensors’ electrical signals into usable information and transmit it to users. Together these two technologies enable automated systems to interact with the external world. The quality of sensor capabilities can be measured by the accuracy, reliability, and responsiveness of the sensors. Redundancy is also a key quality in a sensor array, since it may correct for localized flaws in the first three areas. The quality of signal processing is indicated by the system’s ability to discern between false and true signals, eliminate irrelevant noise, and produce accurate readings.

High-definition imaging and display technology provides the capacity to record and display images with high accuracy, clarity, and speed. This technology relies on capacity for real-time signal processing, high-rate data transmission, and data storage to enable a new level of sophistication in communicating information. Its best-known application is in high-definition television (HDTV), which can be used beyond entertainment for electronic imaging and document storage, digital photocopying, desktop publishing, industrial inspection and monitoring, and battlefield command and control. The
quality of high-definition imaging and displays can be determined from the resolution of the image, the quality of the picture, and the speed and efficiency of imaging transmission.

Although attention is properly focused on the criticality of information technology as the key to national, and military, power today, other technological inputs already play a crucial role and may well play an even more important role in the 21st century for the production of material power. They are described below.

**Materials.** Critical technologies in this category are those pertaining to materials synthesis/processing, electronic and photonic materials, ceramics, composites, and high-performance metals and alloys.

Advances in materials synthesis and processing make it increasingly possible to fashion new materials—atom by atom—to achieve a desired set of properties. The ability to synthesize new materials is central to technological progress in such vital industrial areas as microelectronics, aerospace, transportation, and energy.

The development of electronic and photonic materials is crucial for communications, image processing, and information processing. The key electronic material today is semiconductors. Silicon has, to date, been the dominant material in the manufacture of semiconductors. But future semiconductors made from the GaAs (gallium arsenide) compound offer the prospect of enhanced performance (leading to a new generation of supercomputers), and resistance to nuclear radiation (crucial for both military and space applications). Photonic materials are those that generate, detect, or transmit coherent light, including technologies such as lasers and fiber optic communications.

Advanced, high-performance ceramics have important high-temperature applications, and they also are used in applications that require the capacity to withstand extreme wear or corrosion. In aerospace, the heat-resisting properties of lighter-weight ceramics will be incorporated into the turbines of the next generation of jet engines, thereby increasing performance over the current generation of propulsion systems using heavier superalloys. Ceramics also are important for space vehicles, and they are used in the armor of AFVs. Ceramic components are also increasingly used in advanced automobile engines, semiconductors, and advanced cutting tools.
Ceramics also have potential as wear parts (high-performance aerospace bearings, seals, valves, nozzles, etc.).

Composites are materials hybrids comprised of reinforcing fibers or particles embedded in a matrix. The matrix and reinforcements combine to create a material with properties that are more useful collectively than those of the individual elements. Composites include polymer matrix composites, ceramic matrix composites, metal matrix composites, and carbon-carbon composites. Composites are integral to the manufacture of high-performance military aircraft, other defense systems (helicopters, missiles, AFVs), and space vehicles. Composites are becoming increasingly important in both civilian aircraft manufacturing and automobile manufacturing.

High-performance metals (including alloys) are stronger, stiffer, and more heat resistant than traditional structural metals (such as steel). High-performance metals and alloys are crucially important in the advanced aerospace sector.

**Manufacturing.** Critical technologies in this category are flexible computer integrated manufacturing, intelligent processing equipment, micro- and nanofabrication, and systems management technologies.

Flexible computer integrated manufacturing integrates product, process, and manufacturing into a single interactive network. It encompasses all aspects of manufacturing, including product engineering and design, production scheduling, part production, product assembly, subcontractor and vendor activities, inspection, and customer service. Flexible computer integrated manufacturing is important not because of its impact on any one product, but because it enhances the efficiency of a nation’s overall manufacturing industry across sectors. It is vital to economic growth and competitiveness in today’s globalized economy.

Intelligent processing equipment is the foundation on the factory floor upon which advanced manufacturing capabilities are based. Intelligent processing equipment includes robotics, sensors, and controls. Intelligent processing equipment is used across a wide spectrum of manufacturing activities, including machining, forming, welding, heat treating, composite fabricating, painting, testing, inspecting, and material handling. State-of-the-art intelligent process-
ing equipment is especially critical to maintaining competitive manufacturing capabilities, especially in high-technology sectors.

Micro- and nanofabrication involve the manipulation of materials at the microscopic, and atomic, levels respectively. Micro- and nanofabrication processes are essential in producing semiconductors. Microfabrication processes include lithography, etching, disposition, diffusion, implantation, and packaging. Other expected applications involve high-density integrated circuits, optoelectronic devices, quantum devices, and textured surfaces for biotechnology. Semiconductors and integrated circuits are, of course, at the core of the information and communications technologies. As such, they have important "downstream" effects on a state’s economy and on its military capabilities. Micro- and nanofabrication are crucial to attaining leading-edge capabilities in semiconductors and integrated circuits.

Systems management technologies are information technologies that allow implementation of advanced systems management concepts. They include product exchange tools, databases, data-driven management information systems, and interoperable information systems. Application of systems management technologies is crucial to attainment of leading-edge capabilities in manufacturing.

**Biotechnology and life sciences.** This category includes applied molecular biology, which is based on recombinant DNA technology, protein engineering, monoclonal antibody production, and bioprocessing. Recombinant DNA has fueled the creation of important therapeutic and preventive proteins, including vaccines, human insulin, human growth hormone, cancer-fighting agents, and drugs for blood disorders. Recombinant DNA technology also promises to lead to the development of gene therapy that will be able to prevent, or treat, inherited diseases. Recombinant DNA technology also has applications in areas such as agriculture and food processing. Protein engineering has important industrial applications, and it also has implications for the development of new therapeutic drugs. Monoclonal antibody production allows the development of specialized antibodies able to attack only a specific disease-causing agent or cell type. Monoclonal antibodies are used to treat cancer, HIV, and cystic fibrosis. They may also lead to the development of highly sensitive detection systems for plant and animal diseases, as well as
food-borne pathogens. Bioprocessing is the link between biotechnological science and the production of drugs, food enzymes and ingredients, and specialty products for industry and agriculture. Applied molecular biology is an important leading-edge technology that affects health/disease prevention, agriculture, and environmental regulation (fabrication of enzymes that degrade solid waste and toxic chemicals or clean up oil spills).

Aeronautics and surface transportation. Aeronautics embraces a diverse array of technologies that are key to the design, development, production, performance, and safety of aircraft. In terms of state power, the important technologies are those utilized by advanced aircraft, including large subsonic transports, high-performance military aircraft (both fixed and rotary wing), and supersonic and hypersonic aircraft. Key technological areas include propulsion, aviation materials and structures, aerodynamics, human factors engineering, aircraft manufacturing, and aeronautical testing. The importance of aeronautics as a component of state power is obvious: advanced military aircraft remain on the leading edge of technology. Moreover, aeronautics has feedback interactions with other key technological sectors, including information, electronics, and manufacturing.

Surface transportation technologies include attempts to create intelligent vehicle and highway systems that will use advanced technology to increase driver safety, increase system capacity, and reduce emissions, fuel consumption, and congestion. Also included in surface transportation technologies are various approaches to developing more energy-efficient vehicles, including those that rely on energy sources other than fossil fuels. Surface transportation technologies will enable states to upgrade their transportation infrastructures, which are vital to overall economic growth. Increases in fuel efficiency and development of alternative propulsion sources hold out the prospect of freeing the state from dependence on fossil fuels extracted from geopolitically unstable areas like the Persian Gulf.

Energy and environment. The present reliance of advanced industrial states, as well as newly industrializing states, on fossil fuels as a primary energy source raises both geopolitical and environmental
There are two broad technological approaches to meeting these problems. The first is the quest to develop renewable energy sources, including solar thermal power, wind turbines, photovoltaics, and biomass/alternative fuels. A second approach is to develop technologies that allow existing fuel sources to be utilized in a way that minimizes environmental damage. For example, improvements in combustion and catalytic processes could enable coal to be used without adverse economic effects. Advances are also being pursued in nuclear fission technology to make it safer and more reliable by employing light-water, gas-cooled, and liquid metal reactors. Technologies that enhance energy conservation are also important, as are advances in energy storage such as fuel cells and batteries. Energy and environmental technologies will be a vital component of state power. Not only are fossil fuel supplies finite, they force states to rely on suppliers in politically volatile regions. For states, energy security and economic growth in the future demand that advanced technology create new energy sources.

Assessing a country’s technology base clearly requires an assessment of its capabilities in each of the six areas identified above. Assessing its militarily-critical technology base requires an assessment of the eighteen broad technology areas mentioned earlier—work that is already under way within the U.S. government. In each of these areas, an adequate assessment requires information about a country’s skills at five levels: (i) whether a country has indigenous production capabilities in the technology area; (ii) whether a country has transplanted production capabilities deriving from its status as a host for foreign-owned facilities; (iii) whether a country has trade access to foreign capabilities in a given technology area; (iv) whether a country engages in basic and applied research and developmental work, even if not in commercial production; and (v) whether a country undertakes theoretical research in the technology area in question.

While the list of technologies identified here is neither precise nor exhaustive, it is nonetheless intended to indicate that science-driven...
capabilities constitute the first and among the most important kinds of resources in the postindustrial age. Because science and technology persists as a driver of change in modern civilization, the level of technology existing in a given country—especially insofar as it is manifested in cutting-edge instruments that exploit information technology today and other kinds of sophisticated technologies tomorrow—can be ignored only at our peril. No matter how sophisticated a country’s technology actually is, however, it does not exist in a vacuum. Its existence is often the product of complex—prior—societal and state choices, so any assessment of a country’s technological resources must inevitably shift its focus beyond a point from the concrete artifacts concerned to the entrepreneurial capabilities that produced them.

ENTERPRISE

Although the concept of “enterprise” usually has many shades of meaning, depending on the context in which it is used, we define it here as a collective expression for the level of invention, innovation, and the diffusion of innovation within a given society. Viewed in this way, enterprise is understood as the natural progenitor of technology in that it refers to the societal dimensions of capability that make technology—the critical engines of power in the postindustrial age—possible. By incorporating the notion of enterprise as a component of national power, this framework seeks to emphasize that technology does not subsist autonomously but is always a product of prior societal and state choices in other areas like education and health, investments in human capital, and communications and infrastructure. While this fact cannot be ignored, the quality of entrepreneurial capabilities nonetheless remains an immediately important variable because it provides a country with the only means of overcoming the scarcities inherent in nature. Since capital and labor are essentially limited, national growth would inevitably hit a ceiling as a country progressively exhausts its finite pool of resources. This outcome of stagnation and, eventually, decay—the nightmare of classical economics—can be arrested only by technological progress, which at its core consists of nothing other than new and better ways to use existing resources. The ability to generate technological
progress is, in turn, a function of the entrepreneurial capacity of a society that is very often both stimulated and directed as a result of deliberate state choices. Irrespective of what the source of such entrepreneurship may be, the capacity to invent, innovate, and diffuse innovations is critical because it creates a multiplier effect that serves to overcome many of the disadvantages of a limited, even poor, natural resource endowment.

### Indicators of Entrepreneurship

Assessing a country’s level of entrepreneurship as a component of its national power, then, requires a systematic scrutiny of both its potential and actual capability to invent, innovate, and diffuse its innovations, and each of these three dimensions, which were first elaborated by Schumpeter in 1912,\(^1\) will be briefly described in turn.

**Capacity for invention.** The concept of invention generally refers to the advancement of any new idea, sketch, or model for a new or improved product, process, or system. Invention in this sense does not necessarily imply demonstrating the feasibility of the new product or process, or even the creation of a prototype, but it must embody a reasoned justification that the idea or model proposed will actually work and often includes some preliminary test to demon-

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strate that it actually does.\footnote{J. Jewkes, D. Sawers, and R. Stillerman, *The Sources of Invention* (London: Macmillan, 1958).} What exactly the sources of invention are is an interesting, but difficult, question to answer. Clearly, the stock of scientific knowledge possessed by a society at any given moment in time is a crucial factor, since this knowledge provides the base from which all inventions come. However, human creativity, inspiration, and genius all play a vital role as well, though these are by definition the idiosyncratic elements of the process. The causes of any given invention, therefore, are many and varied: invention may simply be a chance event characterized in fact by many prior failures; it may be the result of the superior knowledge and abilities of certain inventors; given the necessary background knowledge, it may arise from sufficient and appropriate private and public investment in science and technological activity; or it may be rooted ultimately in economic incentives, often provided by the state, that are aimed at producing specific scientific discoveries and inventions.\footnote{P. Stoneman, *The Economic Analysis of Technological Change* (New York: Oxford University Press, 1983).} Early studies seemed to suggest that individual inventors and small firms played a significant role where inventions were concerned, but whether this is true even today, when large-scale private and public investments in basic and applied research are often necessary for the creation of new products and processes, is unclear.\footnote{Jewkes, Sawers, and Stillerman, op. cit.}

In any event, assessing a country’s capacity to produce useful inventions, especially in the core technology areas identified in the last subsection, may be captured by a variety of measures. To begin with, the levels of investment in research and development provide a useful first cut that depicts how seriously a country pursues the benefits of technical change. Government expenditures on R&D as a percentage of GNP are a particularly important index because studies suggest that the annual rate of return from R&D to society as a whole may be close to 50 percent, a value assessed to be twice the private return to an individual firm.\footnote{Pam Woodall, “The World Economy: The Hitchhiker’s Guide to Cybernomics,” *The Economist*, September 28, 1996, p. 44.} The level of government R&D expenditures in the core technology areas identified previously rep-
resents another more focused measure of inventive potential. Government-level expenditures alone, however, may not be sufficient to assess the potential for invention because these values are crucially affected by the character of state-society relations within a given country. Strong states presumably will spend more on R&D (both generally and in specific technology areas) than weak states might, but strong societies may in some instances spend as much if not more on R&D both generally and specifically in comparison to some strong states. Consequently, aggregate private R&D expenditures as a function of GNP, as well as more focused expenditures on critical technology, should also be assessed as a complementary measure of the inventive potential of a country.

Where actual inventive performance is concerned, however, patenting activity appears to provide the best measure of national inventiveness.\textsuperscript{16} Examining the record of patents applied for and secured helps to assess the productivity of a country’s resident inventors and by implication may even provide an intuitive measure of the quality of a country’s education and science and technology (S&T) base. The first specific measure that might be appropriate for measuring a country’s actual inventiveness therefore consists simply of identifying the level of domestic patenting activity both generally and in the specific technology areas mentioned previously.\textsuperscript{17} But because patenting systems and the laws governing intellectual property rights vary across countries, a useful complementary measure of inventiveness consists of measuring not just domestic patenting but patents actually sought and secured by inventors in foreign countries, especially the United States. Patenting in the United States is actually an appropriate numeraire for assessing the inventiveness of all other countries, since the United States not only has an excellent and well-organized patent office but is also the wealthiest country, whose...


\textsuperscript{17}Since patenting can also reflect activity associated with foreign licensed production in a given country, however, information about the \textit{origins} of the product or processes patented would be a useful corrective to aggregate data on patent activity. Information about the origins of a new product or process is usually available to patent examiners in every case, but it is unclear whether aggregate data identifying the origins of patented products or processes are available.
vibrant economic system attracts leading-edge technologies that for-
eign inventors would seek to protect for purposes of revenue genera-
tion both in the United States and abroad.¹⁸ These foreign patents
secured within the United States should again be measured in aggre-
gate terms as well as in disaggregated form, focusing on activity in
the high-technology fields identified earlier.

**Capacity for innovation.** While inventiveness certainly remains at
the root of technical change in any society, it is but one element in
the larger measurement of enterprise as a variable in national power.
For inventions to become valuable they must be transformed eventu-
ally into innovations, or else they remain merely novel ideas of no
economic consequence. Schumpeter, insistently pointing to the dis-
tinction between invention and innovation, used the latter concept
to structure his entire theory of economic development insofar as he
posited the entrepreneur-as-innovator to be the prime mover of all
technological change. The Schumpeterian emphasis on innovation
is critical because while inventions may occur idiosyncratically at
various places and times, the ability to innovate—which includes the
issue of receptivity to other people’s inventions and creations—
provides the motive force that transforms the existing economic and
technological order. Innovation in this context is defined not simply
as the generation of a new idea or product but rather the **first intro-
duction of a new product, process, method, or system into the national
economy.** The process of innovation thus refers to the development
or the exploitation of an invention insofar as it is actually used or
produced as an economic good within the economy, and here
Schumpeter distinguished between five kinds of innovations: the
introduction of a new good (or dramatic improvements in the quality
of existing goods), the introduction of new methods of production,
the opening of new markets, the securing of new sources of supply of
raw materials or intermediate goods, and the creation of new forms
of industrial organization. Schumpeter used this typology to indicate
that the innovator was, therefore, necessarily neither the inventor of
a product nor the risk-bearer, since risk-bearing remains the prove-
nance of the capitalist who advances the requisite funds to the inno-
vator.

¹⁸K. Pavitt, “Patent Statistics as Indicators of Innovative Activities: Possibilities and
The innovator thus remains “merely” a decisionmaker, but one whose attentiveness to the potential profitability of new inventions and whose willingness to make judgments about product choices in the face of uncertainty makes him a critical element in the process by which new ideas, methods, and goods actually reach the marketplace and, thereby, become valuable commodities which can eventually contribute to a country’s national power. Because innovation hinges on risky judgments about a product’s potential economic value and because transforming an invention into a marketable commodity may require the application of great resources—due in part to the problems of scaling laboratory products for mass production and debugging inventions of potential defects prior to mass manufacture—it is not surprising to find fewer innovators than inventors in any society. In part, this is simply because although most inventions are patented, few ever make it to commercial production, since many, if not most, patents are used primarily as bargaining counters for the sake of revenue sharing.19

Schumpeter himself argued that because of the complexity, cost, and risks attending any efforts at innovation, large firms—enjoying the benefits of size and possibly other monopolies—would be advantaged in the struggle to innovate. Since the publication of his work in 1934, this claim has provoked a good deal of debate and dissension, and while important new insights have been gained into what accounts for the success and failure of private efforts at innovation, it is still unclear as to which government policies are more likely to encourage national innovation and promote eventual economic success. Rothwell and Zegveld correctly argue that this uncertainty arises mainly because it is difficult to isolate any single measure like a tax incentive, development subsidy, or procurement initiative from the more general economic influences on the behavior of the firm and the numerous factors which may be specific to any individual firm.20 These difficulties, unfortunately, impose certain limitations on how a country’s potential capacity to innovate may be evaluated, but at least two measures relating to the actual level of innovation suggest themselves: compiling data relating to the number of prod-

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19C. Freeman, The Economics of Industrial Innovation (Cambridge: MIT Press, 1982).
uct or process patents adopted for manufacture and the percentage of prototypes actually line produced either across the economy as a whole or within the critical technology areas identified earlier. Either or both of these measures would help to indicate the level of innovation witnessed within a given country and thereby contribute to a qualitative assessment of the entrepreneurial capacity exhibited within the country as a whole.

**Diffusion of innovation.** The third and last dimension of enterprise measures focuses on the diffusion of innovations within a productive system. This dimension is crucial for the creation of national power because the diffusion of innovations—be they products or processes—represents the process by which productivity gains can be dispersed throughout society at large. Because new production techniques as well as products can be imitated by firms other than their creators, it is possible for goods and services not only to be produced at lower costs but also in an expanded variety and range. Moreover, the diffusion of such artifacts could lead to further invention and innovation insofar as the emergence of a single product, especially in a competitive market system, often gives rise to competitive efforts at either improvement or substitution, as well as to the creation of other complementary products that increase the value of the original good. The diffusion of innovations is thus critical because, by bringing in its wake a multiplier effect, it ensures the dissemination of technical change throughout the economy, helping to offset the limitations imposed by the natural scarce supply of capital and labor.

To be sure, the process of diffusion is often difficult to trace out because the innovated products are often altered as they are disseminated throughout the economy. Yet it is important to try to capture this dimension of enterprise, because several studies have convincingly demonstrated that the technological distinctiveness of innovations more than any other variable (like price distinctiveness, for example) accounts for a country’s comparative advantage in the international economic system.\(^{21}\) The ability to diffuse innovations

\(^{21}\)This finding was first demonstrated in 1966 by Gary Hufbauer in his study, *Synthetic Materials and the Theory of International Trade* (London: Duckworth, 1966), where it was shown that innovation in the production of synthetic materials increased the comparative advantage of producers more than other variables, like price or factor
effectively must therefore be seen as deriving from two broad but different kinds of sources. The first source, which must be tapped as a measure of diffusive capacity, is simply the degree of connectivity of different firms with the rest of the national economy. Connectivity is a good indicator of a firm’s capacity to exchange information and ideas, attract customers, advertise products, and eventually spawn competition as well as improvements to its product line. Furthermore, connectivity is also a prerequisite for businesses to be able to exploit information and data in their competition for market share. A simple indicator of connectivity would consist of data relating to (i) the percentage of businesses either throughout the economy or in the critical technology sectors specified earlier that use electronic mail, have their own Web pages, and advertise on the World Wide Web; and (ii) the volume of e-business as a percentage of total business within the economy. A second indicator in this regard might simply be the usage of information technologies within a given country measured by the number of computers, Internet connections and bandwidth, and communication devices available per 1,000 individuals.

The second source, which must be tapped as a measure of diffusive capacity, is the number of specialized national or industrywide research institutes that play a role in building up cumulative technological capability. Because evidence suggests that technical know-how, skills, and innovative capacity do account for the differences in national economic performance, the number of national or industrywide research institutes existing in a country provides a good insight into how well a given society can disseminate technical knowledge in order to secure the multiplier effects that stem from innovation at large. It has, for example, been cogently argued that German advantages in the chemical and engineering industries have been related to the “Technische Hochschulen” set up since the 19th century, and that Japanese excellence more recently also owes its robustness to similar institutions.

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proportions, which were deemed to be important by standard models like the Heckscher-Olin theory of trade.

Enterprise, understood as the capacity to invent, innovate, and diffuse innovations, thus remains the motor of technological change. The ability to promote and sustain rapid technological change, in turn, functions as the foundation upon which national power is built. The discussion above clearly suggests that enterprise, like technology, does not exist as a natural building block of national power. Rather, it emerges from within the human capital stock of a given society, since the ability to invent, innovate, and diffuse innovations is little other than an extended product of the national investments—both private and state sponsored—made in human resources. The next section, therefore, examines human resources as an independent building block of national power.

HUMAN RESOURCES

While the most visible elements of the postindustrial age are the myriad information technologies visible throughout society, the most critical component of this era—though manifested in technology and the innovations that give rise to it—is the individuals who create its various artifacts. Since knowledge has become the new “axial principle”\(^{23}\) on which the postindustrial age is built, the resources invested in human beings for the creation, codification, and assimilation of knowledge become critical not only for the maintenance of a given society but also for the production of national power and political control. A sophisticated framework for measuring national capabilities must therefore concentrate on assessing the productive capacities of human beings as income-, wealth-, and technology-producing agents precisely because the production of actionable knowledge, including that which eventually enables the efficient creation and employment of an effective military force, constitutes the foundation on which national power is built today.

In some sense, the insight that human resources are important for national power is not new. It dates back to Adam Smith, who argued in *The Wealth of Nations* that the improvement of workers’ skills constituted the main source of economic progress and increased economic welfare. In the same work, Smith in fact demonstrated

\(^{23}\)Bell, op. cit., p. 20.
how investments in human capital not only affect an individual’s personal income but also transform the structure of wages in the marketplace. Almost a century and a half later, Frank Knight contended that investments in human capital were the key to improving a society’s stock of productive knowledge in order to stave off the effects of diminishing returns in a growing economy.24 The basic ideas about the relationship between human capital and economic growth were thus understood and recognized by economists for a long time, but the decisive demonstration of the importance of human resources came only in the 1950s and 1960s, when the availability of detailed national income data revealed that aggregate national output grew at a more rapid pace than aggregate factor inputs. Although many explanations for this divergence had in fact been offered, the most persuasive hypothesis seems to have been the presence of hitherto unexplained technical change, and it fell to Theodore Schultz and Edward Denison to explicate how “human capital”—meaning the secular improvements in worker skills as a function of education, training, and literacy—accounted for the improved quality of factor inputs which, in turn, resulted in the disproportionate increase seen in aggregate output.25

The recognition that investments in human capital have disproportionate effectiveness, thus, predates the postindustrial age. But at a time when economic growth and national power are increasingly driven by the ability to create and apply the “actionable knowledge” that produces high-technology and higher-value-added products, investments in human capital take on a specific coloration and meaning. Because knowledge per se is not scarce in the traditional sense of the term—that is, its quantity diminishes as it is used—but the ability to understand and use knowledge certainly is—in that not all individuals can use a society’s knowledge base with equal skill and dexterity, not to mention contribute by expanding it—any useful measure of national power must focus its attention primarily on those kinds of human capital which concern “the directing of inno-

In other words, they must measure the human capital that, relating directly to the acquisition, codification, and application of scientific knowledge, not only drives the specific character of the postindustrial age but also increases the skills and productivity of labor both within and across countries.

**Indicators of Human Capital Resources**

The most general measure of human capital that captures this dimension is a country’s expenditure on education and its number of educational institutions. Both education expenditures and the number of institutions—private and public—must be disaggregated to capture the relative emphasis on primary, secondary, tertiary, and vocational and continuing education. Such data convey the importance levied on improving the quality of a country’s potential work force, and, to equalize for disparities in the size of population, this information should also be structured on a per-capita basis in addition to data about gross totals. Information of this sort should identify, at least as a first cut, the size of a country’s educational infrastructure and the importance placed on fostering knowledge-based strategies for increasing economic growth and national power.

While information about the size and balance of the educational infrastructure is vital, it is not sufficient. It must be supplemented by information about enrollment at all educational levels, with special attention paid to the tertiary level, since the net analytic capacity of the work force will be of a higher caliber in direct proportion to the

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26 Bell, op. cit., p. 20.
percentage of the population that attends university, and higher still according to the percentage that actually receives an associate’s, bachelor’s, master’s, or doctoral degree. With the increasing access to international education, the number of students receiving an education abroad at all levels (but especially the tertiary level) should also be accounted for. An important derivative indicator here would be enrollment and attainment data pertaining to foreign students (especially by area of study) receiving an education in the United States. Assessing the emphasis placed on secondary and more importantly tertiary education is crucial for evaluating a country’s capacity to participate in and exploit the postindustrial economy. This is because secondary and tertiary education in particular place a premium on analytic capability: the ability to formulate a problem, gather information, recognize patterns, and synthesize information. These skills become particularly relevant in the knowledge-based economy, where the process of asking the right questions, finding the data necessary to answer those questions, processing that data to create meaningful answers, and synthesizing those answers to create the knowledge required to resolve the initial problem remains the foundation on which the technology invent-and-innovate cycle can proceed uninterruptedly.

The information pertaining to the enrollment in higher education needs to be further refined if it is to capture certain critical dimensions of human capital that are relevant to the postindustrial age. Among the most important such refinements is the composition of specializations among the highly educated subset of the populace. The British historian Correlli Barnett has illustrated the crucial role that the composition of education plays in the production of national power by comparing the very different German and English approaches to higher education at the turn of the century. While England’s elite universities stressed a curriculum based on the classics, the Germans stressed science (both pure research and applied science), engineering, and administrative and organizational tech-

27The Harbison-Myers Skills Index is one example of such an index that measures the attainments in secondary education and beyond as a measure of national capacity. See The World Bank, World Development Report 1992 (New York: Oxford University Press, 1993) for its application.

niques. Reviewing the data, Barnett concluded that to a large extent, the early 20th century contest for economic and, hence, geopolitical supremacy between Germany and Britain "was lost in the schoolyards and quadrangles of Britain"29 long before its effects were ever made manifest in terms of the decline in English power. Measuring human capital as a contributor to national power therefore requires disaggregated information about the composition of specialization in five general areas: mathematics and physical sciences, biological sciences, engineering, social and behavioral sciences, and the arts and humanities. While the last specialization is necessary for the preservation of culture and humanity, it is less relevant in comparison to the first three disciplines for the production of national power; the social and behavioral sciences fall in between. In any event, the data about the composition of specialization should indicate the extent to which a country places a focused emphasis on the production of actionable knowledge pertinent to the postindustrial age.30

Finally, the last measure of a country’s human capital consists of assessing the quality of a country’s system of higher education and the levels of recognized excellence that may exist in its knowledge-production complex, especially in the key areas of mathematics-physical sciences, biological sciences, and engineering. Quality and excellence merit evaluation because they provide an important indicator of a nation’s ability to renew its knowledge base and thereby increase its relative power. The objective of the indicators here must be to measure the quality of scholarship and research, the system’s effectiveness in training new scholars and researchers, and the extent and value of research productivity. Such assessments are generally difficult to produce, and most traditional efforts in this regard consist almost exclusively of “reputational ratings” derived entirely from peer evaluations.31 Such ratings are useful, but they are afflicted by multiple difficulties that cannot be easily overlooked.32

30 This information would obviously be supplemented by the data relating to enrollment and attainment data of foreign nationals receiving an education in the United States.
31 The history of reputational assessments in the United States is briefly explored in A. Granbard, "Notes Toward a New History," in J. Cole, E. Barber, and A. Granbard, *The
For this reason, educational quality, especially between countries, is best compared using a few additional objective criteria, even though these criteria are by no means exhaustive and are in fact quite modest. To begin with, it must be recognized that “there is no single agreed index of a unitary attribute called ‘quality’ [but only] several ‘qualities,’ and the importance of them is largely a function of the needs of the [observer].” Further, quality cannot be measured across the education system as a whole but only within disciplinary boundaries; accordingly, the analyst must select those disciplines which are most relevant for the production of power and judge national quality within those specific research areas. And, finally, it is worth remembering that it is always easier to assess quality about the strongest and weakest educational programs, but much more difficult to assess programs in the middle range. Bearing these caveats in mind, there are several objective criteria of educational quality worth exploring as indices of national performance in a given disciplinary area. These include (i) the number of published articles and books emerging from a given research area; (ii) the estimated “overall influence” of published articles and books; (iii) the number of recognized national and international grants awarded to researchers in a given discipline; (iv) the number of recognized awards and honors earned by researchers in a given research area; and (v) the number and quality of advanced research institutes focusing on key science and technology areas of importance to the production of national power.

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34 An elaborate methodology for evaluating “overall influence” has been developed in Francis Narin, Evaluative Bibliometrics: The Use of Publications and Citations Analysis in the Evaluation of Scientific Activity, Report to the National Science Foundation, March 1976.
There is no doubt that measuring the quality of a country’s human capital stock is a difficult but at the same time necessary undertaking. A comprehensive measure would require accounting for direct improvements in human productive ability not simply through education but also through more remote investments in health and human welfare. Accounting for such remote investments, however, would complicate considerably the measures of national power proposed here, so they are excluded. Besides the practical concerns deriving from the need for parsimony and manageability, such an exclusion can also be justified at the theoretical level on the grounds that it is reasonable to presume that individuals who appear in the educated subset of the population already have minimal access to health care and a hospitable social environment. Thus, concentrating on education not only provides the benefit of focusing on the measure that directly relates to the effectiveness of the work force—which is after all a stock of skills and productive knowledge embodied in people—but it also, arguably, serves as a reasonable proxy for other more remote measures relating to health and welfare. It is also worth recognizing in this connection that more extensive measures about education itself could be supplied for purposes of assessment: these could include, for example, the access of the labor force to retraining and continuing education, the skills and qualifications of managers, and the like. Such measures too have been avoided because they are in some sense implicit in the measures of access to education proposed above and, more important, because the overall skills and training of the population provide a better guide to the quality of a country’s human capital than the access to specific kinds of educational opportunity enjoyed by one subgroup or another.

Resources in the form of human capital arguably remain one of the most critical inputs for the production of national power. The quality of this capital is directly responsible for the entrepreneurial character visible in a country, and this in turn creates the technology base that fundamentally affects the national power a country can produce. While human capital is thus further responsible for the production of actionable knowledge, it is—like all the other inputs examined before it—also an artificial building block of national power. That is, it is owed to prior human decisions and in particular to the non-human-capital stocks possessed and created within a country. These non-human-capital stocks, usually subsumed by the locution “economic
power," will be examined as one more critical—but artificial—input in the production of national power.

FINANCIAL/CAPITAL RESOURCES

The concept of nonhuman capital occupies a central position in neoclassical theories of production and distribution, but it is nonetheless one of the most hotly contested concepts in modern economics.\(^{35}\) The conventional definition of capital is that it is a stock of produced commodities essential for production, commodities that are subject, more or less, to wear and tear depending on the extent and the methods of their use. This view embodies an understanding of capital as a stock of “capital goods,” that is, a series of heterogeneous goods each having specific technical characteristics. The heterogeneity of capital goods, however, creates particular problems that prevent them from being aggregated in terms of a single uniform yardstick. One solution to this difficulty has taken the form of arguments for better or more appropriate indices to aggregate heterogeneous capital goods in terms of some scalar measure.\(^{36}\) Another solution, which derives from a distinct tradition in economic analysis dating back to Adam Smith, has been to avoid aggregating capital goods altogether but rather to focus on aggregating their value. Treating capital as a sum of values sidesteps the problem of aggregation, but it does create other problems of its own: by reducing a stock of real goods to a bookkeeping valuation of those assets, it opens the door to the possibility that capital values could change even though the stock of real goods itself remains unaltered. The relationship between real capital goods and their expressed value, even when stated in money terms, therefore remains problematic, though some economists have suggested that real counterparts to capital values can be constructed in principle, though not without difficulty.\(^{37}\)


\(^{37}\)Hicks, op. cit., p. 151ff, and H.A.J. Green, p. 120.
Such fundamental disagreements about the notion of capital and how to account for it are only complemented by continuing disputes about whether, and in what sense, capital may be treated as a productive element in economic growth. These debates, while fascinating, cannot be surveyed here, much less resolved, so the notion of capital employed in this analysis is drawn largely from the work of economists like John Clark and Frank Knight mainly because of its utility for the purpose of assessing national power. Although Clark clearly distinguished between material capital and capital as a “quantum of productive wealth,”38 the development of his views by Knight and others over time resulted in capital being depicted essentially as a homogenous mass created by savings decisions, which can be easily transferred from one industry to another. Although consisting ultimately of heterogeneous goods, it came to be visualized as a fund of resources which could be switched between multiple uses and is productive in the sense that “it has a non-negative marginal product if used properly” and “which guarantees higher productivity if employed in larger amounts in relation to other factors of production.”39 This Clark-Knight conception of capital—though highly controversial in economics—has been adopted in some form or another by most political theorists, for example Klaus Knorr, who argued that the importance of wealth or capital for politics derives precisely from its fungibility, that is, its easy convertibility into “virtually all types of power and influence.”40

While the fungibility of capital may be valuable from a political perspective because it implies a certain flexibility of allocation with respect to power political ends, the value of capital from an economic perspective derives from more fundamental considerations relating to the nature and processes of growth. The desirability of capital here derives primarily from its ability to enhance an economy’s capability to satisfy a greater range of human needs than before

38 Clark, p. 119.
and, as A. K. Cairncross explained, it does so in three ways.\footnote{The discussion in this paragraph is drawn from A. K. Cairncross, “The Place of Capital in Economic Progress,” in L. H. Dupriez (ed.), \textit{Economic Progress} (Louvain: International Economic Association, 1955), pp. 235–248.} First, a greater abundance of capital enables the institutionalization of more “roundabout” methods of production. This implies that societies with higher stocks of capital can use more capital instruments in the production of any given good, and this results not only in increased productivity but also in greater consumption and enhanced incomes accruing to a larger range of productive agents in the economy. Second, a greater accumulation of capital enables broader economic expansion than might be possible otherwise. This process is generally referred to widening—as opposed to deepening—the structure of production, and it arises when new productive activities are undertaken as a result of more easily available capital; or when changes in the balance between industries makes additional demands on available resources; or when markets extend as a result of population growth, more favorable terms of trade, or the discovery of natural resources. Third, a greater accretion of capital enables the pursuit of rapid technical change. It finances the discovery of what was unknown before or the adaptation of existing knowledge for purposes of commercial exploitation; it underwrites the costs of restructuring organizational changes as well as provides for investment in new human capital. For all these reasons, capital becomes the principal avenue through which all other determinants, whatever those may be, condition the long-run development and prospects facing a country’s power.

**Indicators of Financial/Capital Resources**

While capital enables growth through the three mechanisms identified in Figure 7, it should be obvious by now that it is not an “original” factor of production (in the sense that uncultivated land and raw labor are usually taken to be), but only an outcome resulting from prior economic activity. Consequently, the processes resulting in the creation of capital take on a special importance from the perspective of producing national power. Here, at least, the simple dynamics of capital accumulation are easy to explain, even if they are difficult to undertake in practice: capital increases by investment,
and more investment requires either greater domestic savings or foreign assistance. Domestic savings, carried out by individuals, households, firms, or government, can be generated either voluntarily through a reduction in consumption or involuntarily through taxation by, or compulsory lending to, the government. The absorption of underemployed labor into more productive work also constitutes a form of saving, though this is difficult to measure by standard indices. Savings from external sources can be garnered in the form of foreign direct assistance and direct and portfolio investments, the restriction of a country’s imports (provided these are not substituted by increased domestic consumption), or an improvement in the terms of trade (assuming, of course, that the increased revenues are saved and not consumed). Measuring the sources of capital formation as a means of understanding a country’s ability to provide usable investment resources must, therefore, focus on just the variables identified above. This includes measuring the overall rates of saving in the economy (disaggregated by source if needed), the ratio of taxes to GNP, and the economy’s access to external resources in terms of official direct assistance, and foreign direct and portfolio investments.

When capital is accumulated through some combination of means such as those described above, the processes of growth produce a chain reaction that can be sustained only to the degree that a fraction of the growing incomes—generated either by increasingly roundabout consumption, greater economic widening, or faster technical change—is itself saved and plowed back into profitable enterprises.
so as to sustain the cycle indefinitely. Because this cycle occurs at different rates in different countries—given the wide disparity, inter alia, in levels of knowledge, rates of saving, and the character of technical change—the processes of capital accumulation produce different effects when measured by both the size and the growth rates of countries. Both these variables are important and need to be assessed when considering national power.

The size of a country in terms of its economic output is critical because output, in the first instance, represents a mass of resources that can be utilized for various purposes by a nation’s political authority. Because national power is always relative, however, the size of a country’s gross national product functions as a useful yardstick for how its capital stocks stand up to those of its competitors; a country with larger capital resources is not only afforded greater autonomy to choose its own preferred course of action but, ceteris paribus, also secures a greater measure of protection insofar as it can presumably produce larger and more effective military forces while simultaneously resolving the difficult tradeoffs involved in the production of such capabilities with greater flexibility than its less well-endowed neighbors. The size of an economy also brings other less well-recognized but equally critical benefits: because concentrations of economic power imply a concentration of capital resources, the wealthiest countries in effect possess the most “votes” in the global market economy. As a result, the global structure of production, the use and transfers of productive factors, and the exchange of raw materials, semifinished and finished goods, all comport with the pattern of preferences displayed by the largest group of consumers in the global economy, namely those economies with the largest capital resources or GNP. Larger economic size, therefore, not only bequeaths greater freedom of action but also structures the pattern of investment decisions in the global economy to its own advantage; it defines the nature and the extent of the bargains that can be struck in the international arena; and it affects the patterns of global access to resources because of the disproportionate weight of its own domestic consumers and investors.42

While size of capital resources in a gross sense is thus an important index of power, it must be refined in two ways. First, it is important to assess how the value of accumulated outputs or capital stacks up in the face of the size of the existing population. The measure of per-capita GNP thus becomes important because it describes a country’s level of internal development in notional terms, while simultaneously providing some sense of the balance between internal and external demands on the country’s resources. Per-capita GNP describes the size of the capital stocks per individual and thereby depicts the relative access to wealth and consumption within a country. It could therefore serve as a corrective measure in some cases insofar as it relates a stock measure of wealth to the number of people who must be supported by it.

Second, it is important to assess what proportion of a country’s output derives from certain activities that are particularly important in the knowledge-based postindustrial age. Both GNP and per-capita GNP describe the levels of capital resources in aggregate and distributed terms respectively. They do not identify, however, how these capital resources are produced. In an age where the levels of actionable knowledge have become the yardstick by which power in general and effective coercive power in particular is produced, understanding whether a country’s overall growth derives from certain leading-edge sectors as supposed to “sunset” sectors is important for assessing its power capabilities. As William R. Thompson points out, the link between relative power and dominance in the “leading sectors” of the global economy is critical. The leading sectors in any given age are created by radical technological breakthroughs achieved in certain countries, and these sectors are crucial because in their early developmental stages, their positive impact on a country’s economic growth is disproportionate to their size in relation to the overall economy. Moreover, dominance in the leading sectors is important to a country’s ability to contend for geopolitical leadership in the international system. Thompson describes this link thus:

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Major technological innovations are not only discontinuous in time and space, but the lead in innovational development . . . tends to be confined to a single national economy. This lead helps establish a commanding position in the pace of commercial, industrial, and economic growth. It also facilitates the development of the lead economy’s commercial and financial centrality to the system. The movement toward increasingly productive commercial and financial centrality encourages the development of two other essential ingredients: the gradual ascendency of a globally oriented, domestic ruling coalition and the creation of a politico-military infrastructure of global reach capabilities.44

Because the leading sectors today remain information and communications, understanding where the sources of accumulation lie in these areas provides a qualitative profile of the structure of capital generation in a country. Unfortunately, the standard division of the economy into the primary, secondary, and tertiary sectors hides more than it reveals in the postindustrial age. In large part, this is because the customary distinction between manufacturing and services is increasingly breaking down on one hand, while on the other hand the value of even traditional tangible goods is increasingly being lifted by the embedding of knowledge-based artifacts.45 Thus, while it is useful to know the things national leaders traditionally worried about, like the share of manufacturing in both the GNP and the global product, today their ability to both know these things and assess their significance has dropped dramatically.46 One solution to this problem might be to decompose the tertiary sector further into quaternary and quinary sectors, as Daniel Bell attempted in 1973.47 Or it might be more useful to simply try to understand the extent of capital accumulation occurring in the knowledge-producing sectors of the economy as a means of appreciating the character of a country’s GNP. There have been several efforts made at concep-

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44Ibid., p. 224. As Thompson notes, historically, victory in global (or hegemonic) war has also been a stimulus to leading sector dominance and its concomitant effects.


47Bell, op. cit., p. 117ff.
ualizing the structure of the knowledge-producing sectors of the economy: these include Bell at one end with three simple categories, Machlup and the OECD in the middle with five different categories each, and Porat and Rubin with eight expansive categories at the far end.48 Some of these measures are better than others, but data organized on the basis of any of them would provide a useful comparative picture of how much of the GNP is owed to the knowledge-producing sectors of the economy.

Finally, the last measure of capital as a building block of national power must focus simply on the growth rate of GNP. This simple measure is important because it conveys information about the future size of the national economy (with all the benefits accruing to size), the changes in the balances of international power, and the ease with which a given country may be able to either increase its stock of coercive capabilities or change its factor endowments to garner the relatively greater increasing returns that may be accruing to certain critical sectors within the economy. Whether a country embarks on the latter choice, however, will be determined by its perception of the strategic value of certain sectors; the incremental capital-output ratio existing in that sector relative to others; and the rates of return accruing to investments in that sector in comparison to all other alternatives. In any event, GNP growth rates are important because they determine the choices that a country has with respect to developing its future national power.

On balance then, the value of capital, understood as a fund that represents a stock of capital goods possessed by a country, derives ultimately from its ability to make national sustained economic growth possible. To be sure, capital does not function as a “simple input” which when injected in “direct” form automatically produces increased productivity and rapid growth. Rather, its effectiveness derives in large measure from being a mediated input that often takes the form of better technical knowledge, improved human capital, more sophisticated machinery, and modernized forms of organi-

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zation in addition to its customary “raw” manifestation as money capital. Its contributions to increasing the stock of technical knowledge are particularly important from the viewpoint of national power, and in the postindustrial age this value will be increasingly manifested by the infrastructure that generates scientific and technological innovations within a given society.

**PHYSICAL RESOURCES**

The transformation of society from the agricultural age to the industrial age and beyond set into motion a process of economic change that resulted in new demands for various physical resources. Raw physical resources, in the form of land and national resources, had their greatest utility in the agricultural age. During the industrial age, energy sources acquired pride of place. In the postindustrial age, when knowledge-driven economic growth has become central to progress, the value of natural resources as a stock concept (with the exception of energy) appears to have decreased even further as technical knowledge provides new ways of utilizing existing natural resources more efficiently and, occasionally, even provides synthetic substitutes for depletable natural resources.

While the growth of knowledge has thus contributed to diminishing the importance of natural resources as inputs for economic growth, the rise of the international trading system has further reduced their relative significance. The existence of a fairly well institutionalized international trading system for primary commodities implies that countries need no longer be limited by the poverty of their natural endowments as far as their growth prospects and national power are concerned. This is all the more true because the number of absolutely critical raw materials has diminished over time, and even fewer of these materials are restricted in terms of single sources of supply. This is true today even for high-priority natural resources like energy.

**Indicators of Physical Resources**

Since natural resources in general are already lower-valued items in comparison to technology and human capital, it is unlikely that constraints with respect to both access and national endowments
would serve any more as real impediments to a nation’s growth in power so long as the international market for trade in primary commodities continues to function with reasonable efficiency. This, at any rate, is likely to be true at least as far as most candidate great powers of interest to the United States are concerned.

The only exceptions to this rule may be energy and food (and, over the very long term, water), and the significance of these resources is as much technical as it is political: because energy and food remain inputs necessary for the functioning of about everything else in a modern economy, countries in general are extremely sensitive to the potential for disruption and cut-off in supply. Consequently, fossil fuel resources like oil, coal, and natural gas will continue to remain important, as will artificial fuel resources like nuclear power.

Peculiar to the postindustrial age, however, will be nonfuel resources like jewel bearings used in sophisticated machine tools and beryllium used with copper in electrical and computer components. Light, but strong and flexible metals like titanium, vanadium, chromium, cobalt, aluminum, and columbium, the vital components of complex machines, especially in the aerospace industry, will also remain significant. A set of other similar resources have also become critical with the progression of the information revolution. For instance, platinum group metals (iridium, palladium, and platinum) are critical components of information age electronics like circuit boards and computer network connectors; platinum is also used in the production of optical fibers for telecommunications. Germanium, a by-product of zinc processing, has become important for its use in high-data-rate optical communication systems, lasers, night-
vision systems, and weapons guidance. The aluminum by-product gallium arsenide has also received heightened attention because of its role as a component of high-speed integrated circuitry, especially relied upon in military computing. Silicon is another element that has received heightened attention because of the information age. Widely abundant, as the backbone of computer chips and fiber optics, silicon should not be ignored as a necessary building material. Lastly, the inputs for sophisticated materials technologies round out the list of critical information technologies. These inputs include the components of composite materials (graphite, carbon, asbestos, and other fibrous materials), and of ceramics (rare earth elements; pure, inorganic, nonmetallic powders; and fibers for reinforcement). These materials are increasingly vital to the production of sophisticated machinery (again, especially aerospace and weaponry). In addition, they have sparked interest in the possibility that synthetic materials might replace many former mineral dependencies.

When considering these resources as inputs of power, however, it is important to go beyond stockpiles and supplies to consider the accessibility of these resources during times of crisis, when states must rely largely on their own inputs for power. To measure this accessibility, both the obvious domestic sources and the degree to which these resources originate from stable external sources, i.e., allies or neutrals with stable governments, ought to be considered. This provides an indicator of the extent to which countries are dependent on vulnerable sources for the basic physical building blocks of power.