William J. Baumol's Prize Lecture[1]
*2003 Award Winner**

ABSTRACT

The paper studies the principal influences accounting for the unprecedented growth and innovation performance of the free-market economies. It indicates that vigorous oligopolistic competition, particularly in high-tech industries, forces firms to keep innovating in order to survive. This leads them to internalize innovative activities rather than leaving them to independent inventors, and turns invention into an assembly-line process. The bulk of private R&D spending is shown to come from a tiny number of very large firms. Yet the revolutionary breakthroughs continue to come predominantly from small entrepreneurial enterprises, with large industry providing streams of incremental improvements that also add up to major contributions. Moreover, these firms voluntarily disseminate much of their innovative technology widely and rapidly, both as a major revenue source and in exchange for complementary technological property of other firms, including direct competitors. This helps to internalize the externalities of innovation and speeds elimination of obsolete technology. Some policy implications for industrialized and developing countries are also discussed.

Introduction

Entrepreneurship has long been valued as a key contributor to the growth of an economy. This view often refers to the entrepreneurial activity entailed in the original usage of the term—the mere organization or establishment of just any new firm, even one that merely duplicates something that has been done many times before. In the following discussion, it is natural and appropriate to emphasize instead the meaning that was assigned to the term by Joseph Schumpeter (indisputably the 20th century's prime contributor to the economic analysis of entrepreneurship and innovation), taking the entrepreneur as the partner of the inventor—as the businessperson who recognizes the value of the invention, determines how to adapt it to the preferences of prospective users and whose tasks include bringing the invention to market and promoting its utilization. It is widely believed that economies that are abundantly supplied with entrepreneurs will tend to grow far more rapidly than those in which entrepreneurial talent is scarce. Yet Schumpeter himself was led to conclude that the day of the entrepreneur was waning, that the expanding role of routinized innovation by big business was threatening to make the entrepreneur obsolete. I will argue here that part of the pertinent mechanism has been correctly discerned both by those who continue to have faith in the individual entrepreneur's critical role in economic growth and by any who follow Schumpeter in concluding that routinized innovation by giant enterprises is assuming a primary role. Yet each side here is telling only part of the story and, as a result, overlooks much of its essence. The entrepreneur continues to play a critical part in the growth process, and there is no reason to expect that role to disappear. But in the modern economy the entrepreneur, working alone in the marketplace, cannot carry out the task most effectively. Fortunately, the market mechanism has provided the partners that the entrepreneur needs for the purpose.

In seeking to explain the unprecedented and, indeed, miraculous

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It was not until 2003 that the Award Winners were formally requested to give a Prize Lecture in connection with the Award ceremony. Therefore, in cases where the lectures were missing the Award Winners were invited in 2008 to deliver a belated Prize Lecture in the form of a manuscript. This essay by Professor William J. Baumol was delivered in August 2008.

[1] As always, I must express my gratitude to my colleague, Sue Anne Batey Blackman, for her editing and contribution of sense to this paper. The discussion here is based upon, but goes beyond, the materials in my recent book, *The Free-Market Innovation Machine Analyzing the Growth Miracle of Capitalism* (Princeton 2002).

growth performance of the free-market economies, this paper focuses upon the difference in, but complementary relationship between, the characteristic innovative contributions of large and small entrepreneurial firms, pointing out that these two groups have tended to specialize in different components of society's innovation process. The major breakthroughs have tended to come from small new enterprises, while the invaluable incremental contributions that multiply capacity and speed, and increase reliability and user-friendliness have been the domain of the larger firms. Together, the two have contributed far more than either would have by itself.

In addition, important innovations continue to flow from two groups outside the market sector: the government and the universities. I will point out some of the truly astonishing contributions that have come from each of the four sectors. The implication is that to ensure that the pertinent arrangements and institutions are really effective in the promotion of economic growth, it is essential that each is provided with the appropriate incentives to undertake its role in the process. For any modern economy concerned with this issue, understanding of the roles of the four key sectors and of the requisites for effectiveness of their participation constitutes a road map for public sector growth policy.

Market Pressures for an Enhanced Large-Firm Role in Technical Progress

Free competition–that is, competition not handicapped by severe government regulations or tightly enforced customary rules, like those of the medieval guilds that prevented gloves-off combat among rival firms–has arguably played a critical role in the growth of the capitalist economies. Of particular significance here is rivalry among oligopolistic firms–those large firms in markets dominated by a small number of sellers. And crucial here is the fact that in today's economy many rival oligopolistic firms use *innovation* as their main battle weapon, with which they protect themselves from competitors and with which they seek to beat those competitors out. The result is precisely analogous to an arms race-to the case of two countries, each of which fears that the other will attack it militarily and therefore feels it necessary always at least to match the other country's military spending. Similarly, either of two competing firms will feel it to be foolhardy to let its competitor outspend it on the development and acquisition of *its* battle weapons. Each firm is driven to conclude that its very existence depends, at the least, on matching its rivals' efforts and spending on the innovation process. In an economy in which this is so, a constant stream of innovations can be expected to appear, because the giant warring firms to whom the story pertains do not dare relax their innovation activities.

The entrepreneur is naturally associated with the small, startup firm; indeed, as we know, widespread and long-employed usage simply *defines* entrepreneurs as the creators of new enterprises. This is relevant to investigation of their role in the economy's innovation process, because for the reasons just indicated, the apportionment of the task of supplying the resources invested in innovation has been changing materially. Increasingly, at least in the United States, the funding for innovation has been supplied by large oligopolistic enterprises, hardly the sort of firms that one associates with the entrepreneur.

Today some 70 percent of R&D expenditure in the U.S. is carried out by private business, and most of this is provided by the larger firms.[2] In these enterprises, innovative activities are carefully designed to prevent unwelcome surprises and to keep risks to a minimum. As a result, there is little of the free-wheeling, imaginative, and risk-taking approach that characterizes the entrepreneur. Instead, the large firm's top management often keeps a tight rein on the activities of the company's laboratories, with budgets determined by the upper strata of control within the firm, who also may determine how many persons and what sort of specialists at what levels will be employed on R&D endeavors. It is not even unusual for persons untrained or inexperienced in research to determine what new products and processes the laboratories should next seek to discover. Sometimes, large firms try to unleash their employees engaged in innovative activity by organizing a subsidiary operation that is more inviting to the free exercise of entrepreneurship, but often without much success.

The natural incentive system for a bureaucratically governed enterprise is to run research and development in accord with bureaucratic rules and procedures. All of this leads to the conjecture, voiced by Schumpeter, that the work responsibilities the economy assigns to the entrepreneur are narrowing and are destined to shrink even further. One can easily surmise what prompted Schumpeter to foresee a limited future for the entrepreneur where industry and its innovation processes are widely characterized in the manner just described. Yet, I will argue next that this is fundamentally a mischaracterization. Rather than being condemned to obsolescence, a vital role continues to be played by independent entrepreneurs.

Revolutionary Breakthroughs: A Small-Firm Specialty

It is convenient here to divide up inventions with the aid of two polar categories: revolutionary breakthroughs and cumulative incremental improvements. Of course, many new products and processes fall into neither extreme category, but are somewhere in-between. Still, it will become clear that the distinction is useful. Moreover, there are many examples that clearly fit into one of these categories or the other quite easily. For instance, the electric light, alternating electric current, the internal combustion engine, and a host of other advances must surely be deemed revolutionary, while successive models of washing machines and refrigerators–with each new model a bit longer-lasting, a bit less susceptible to breakdown, and a bit easier to use–arguably constitute a sequence of incremental improvements.

The relevance of the distinction should be evident, given what has been said about the working and organization of R&D in the large business organization. The inherent conservatism of the process naturally leads to the expectation that these firms will tend to specialize in the incremental improvements and tend to avoid the

[2] According to data gathered by the National Science Foundation (National Science Board, 2000, Chapter 2, p. 24), in the year 2000, 46 percent of total U.S. industrial R&D funds were spent by 167 companies with 25,000 or more employees; 60 percent of these funds were spent by 366 companies with at least 10,000 employees, and 80 percent was spent by 1,990 firms of 1,000 or more employees. At the other end of the spectrum, about 15 percent of total U.S. industrial R&D funds were spent by 32,000 companies with fewer than 500 employees each.

Table 1

Some Important Innovations by U.S. Small Firms in the Twentieth Century

Air Conditioning	Heart Valve	Portable Computer
Air Passenger Service	Heat Sensor	Prestressed Concrete
Airplane	Helicopter	Prefabricated Housing
Articulated Tractor Chassis	High Resolution CAT Scanner	Pressure Sensitive Cellophane
Artificial Skin	High Resolution Digital X-Ray	Tape
Assembly Line	High Resolution X-Ray	Programmable Computer
Audio Tape Recorder	Microscope	Quick-Frozen Food
Bakelite	Human Growth Hormone	Reading Machine
Biomagnetic Imaging	Hydraulic Brake	Rotary Oil Drilling Bit Biosynthetic
Insulin	Integrated Circuit	Safety Razor
Catalytic Petroleum Cracking	Kidney Stone Laser	Six-Axis Robot Arm Computerized
Blood Pressure	Large Computer	Soft Contact Lens
Controller	Link Trainer	Solid Fuel Rocket Engine
Continuous Casting	Microprocessor	Stereoscopic Map Scanner Cotton
Picker	Nuclear Magnetic Resonance	Strain Gauge
Defibrillator	Scanner	Strobe Lights
DNA Fingerprinting	Optical Scanner	Supercomputer
Double-Knit Fabric	Oral Contraceptives	Two-Armed Mobile Robot
Electronic Spreadsheet	Outboard Engine	Vacuum Tube
Freewing Aircraft	Overnight National Delivery	Variable Output Transformer
FM Radio	Pacemaker	Vascular Lesion Laser
Front-End Loader	Personal Computer	Xerography
Geodesic Dome	Photo Typesetting	X-Ray Telescope
Gyrocompass	Polaroid Camera	Zipper

Source: U.S. Small Business Administration (1995, p. 114.)

risks of the unknown that the revolutionary breakthrough entails. The latter, rather, is left most often to the small or newly founded enterprise, guided by its enterprising entrepreneur. Though that is to be expected, the degree of asymmetry in the apportionment of this specialized activity between large and small firms in reality is striking. The U.S. Small Business Administration has prepared a chart listing breakthrough innovations of the twentieth century for which small firms are responsible (reproduced here in *Table 1*), and as will be seen, its menu of inventions literally spans the range from A to Z, from the airplane to the zipper.

This remarkable list includes a strikingly substantial share of the technical breakthroughs of the twentieth century. Besides the airplane, it lists FM radio, the helicopter, the personal computer, and the pacemaker, among a host of others, many of enormous significance for our economy.

A very recent study, also sponsored by the U.S. Small Business Administration (2003), provides more-systematic and powerful evidence to similar effect[3]. This report examines technical change through patenting and defines "small firms" as "businesses with fewer than 500 employees." Perhaps most notably, the study finds that "…a small firm patent is more likely than a large firm patent to be among the top 1 percent of most frequently cited patents." Among other conclusions, in the words of its authors, this study reports that:

- Small firms represent one-third of the most prolific patenting companies that have 15 or more U.S. patents.
- Small firm innovation is twice as closely linked to scientific research as large firm innovation on average, and so is substantially more high-tech or leading edge.
- Small firms are more effective in producing high-value innovations–the citation index for small firm patents averaged 1.53 compared to 1.19 for large firms.
- Small patenting firms are roughly 13 times more innovative per employee than large patenting firms.
- A small firm patent is at least twice as likely to be found among the top 1 percent of highest-impact patents as a patent from a large firm (p. 2).

One is, then, led to the plausible conjecture that most of the revolutionary new ideas of the past two centuries have been, and are likely to continue to be, provided more heavily by independent innovators who, essentially, operate small business enterprises. Evidently, the small entrepreneurial firms have come close to monopolizing the portion of R&D activity that is engaged in the search for revolutionary breakthroughs.

But now we seem to have leapt to the opposite conclusion, that rather than likely disappearance of the innovative role of the entrepreneur and the small firm, little would appear to be left for the large enterprise to do. That, as we will see next, is also a very misleading conclusion.

[3] Quoting the release describing the study, "A total of 1,071 firms with 15 or more patents issued between 1996 and 2000 were examined. A total of 193,976 patents were analyzed. CHI [the firm that carried out the study] created a data-base of these firms and their patents. This list excluded foreign-owned firms, universities, government laboratories, and nonprofit institutions" (p. 2).

Revolutionary Consequences of Aggregated *Incremental* Improvements

As we have seen, the type of innovation in which the giant enterprises tend to specialize is primarily devoted to product improvement, increased reliability and enhanced user-friendliness of products and the finding of new uses for those products. The approach tends to be conservative, seeking results whose applicability is clear and whose markets are relatively unspeculative. As already noted, the bureaucratic control typical of innovative activity in the large firm serves to ensure that the resulting changes will be modest, predictable and incremental. These firms are not predisposed to welcome the romantic flights of the imagination, the entrepreneurial leaps of faith and plunges into the unknown that often lead only to disaster, but which alone are likely to open up new worlds.

However, having recognized the critical role of the smaller enterprises, one should not go to the other extreme and undervalue the incremental contribution of the routine activity that at least sometimes arguably adds even more to growth than do the more revolutionary prototype innovations. Though each such small improvement may be relatively unspectacular, added together they can become very significant indeed. Thus, consider how little computing power the first clumsy and enormously expensive computers provided, and what huge multiples of such power have been added by the many subsequent incremental improvements.

Table 1 provided a set of extreme examples of the contributions of the small, entrepreneurial firms. But one can easily obtain equally startling examples of the magnitude of the innovative contributions of the large companies, whose incremental contributions can add up and compound to results of enormous magnitude.

One such illustration is the progress in computer chip manufacture by the Intel Corporation, which is the leading manufacturer of these devices and has brought to market successive generations of chips and transistors, on which the performance of computers is so heavily dependent. According to a recent report (Markoff 2003), over the period 1971-2003, the "clock speed" of Intel's microprocessor chips–that is, the number of instructions each chip can carry out per second–has increased by some *3 million percen*t, reaching about 3 billion computations per second today. During the period 1968-2003, the number of transistors embedded in a single chip has expanded more than *10 million percent*, and the number of transistors that can be purchased for a dollar has grown by *five billion percent*. These are evidently no minor contributions. Added up, they surely contribute far more computing capacity than was provided by the original revolutionary breakthrough of the invention of the electronic computer. Of course, that initial invention was an indispensable necessity for all of the later improvements. But it is only the combined work of the two together that made possible the powerful and inexpensive apparatus that serves us so effectively today.

On the Role of Government and the University in Innovation

A revised analysis of the forces making for economic growth also must not overlook the public sector's role in promotion of economic output and its expansion. My writing on the free-market growth mechanism emphasizes the importance of oligopolistic competition and independent entrepreneurship, and has given less attention to the contribution of the public sector. Yet in that story the government plays two critical roles, one active and the other passive. The passive contribution is provided primarily through the legal infrastructure that encourages entrepreneurship, the formation of new firms and investment in the innovation process by larger competing enterprises. That entails well-recognized provisions such as property rights and enforceability of contracts. It also entails absence of government acts of interference in the exchange of technical information and access to patented intellectual property, as well as avoidance of rules on employment and rental that inhibit the formation of new firms. On the active side, government support of basic research has proven to be invaluable, since with its uncertainties and unpredictable beneficiaries, such research is not highly attractive to private enterprise, though it can be critical for innovation and growth in the long run.

There are, as a matter of fact, two key players that are not guided directly by market forces, the universities and the pertinent government agencies, which have also made direct contributions to technological progress themselves. Here, one need only mention the electronic computer once again, as well as the Internet. But the contributions of these institutions have also tended to be rather specialized and different from those discussed above. It is to them that we must look primarily for the results provided by basic research as distinguished from applied research. The reasons for this division of labor with private industry are well understood, and only a few words need be said on the subject here.

From the point of view of the unthinking market mechanism, expenditure on basic research is a "wasteful" expenditure, because the outlay promises no addition to the profits of the firm. By its very nature, it is nearly impossible to predict whether basic research will yield any financial benefit at all and, if so, who will ultimately be the beneficiary. Certainly, it need not be the enterprise that carried it out. That is why governments and universities have had to step in, if basic research of any magnitude was to be carried out. And as we know, it is important for growth in the long run that this be done, for so much of applied innovation is made possible or is at least stimulated by its results.

The importance for technological progress of this conjunction of academia, business, and public sector was dramatically confirmed in an American Philosophical Society symposium (2003) on recent and projected biomedical advances.[4] There, it was strikingly demonstrated that the contributions of universities, government (notably the military) and (apparently small) private firms have produced a truly mind-boggling array of medical breakthroughs, aptly summed up by one speaker in a quotation from Hollywood's Steven Spielberg: "There is no more science *fiction*." The outlook is, indeed, that there will be no break in the acceleration of innovation, and that the innovations in prospect will be as difficult for us to comprehend as those now thoroughly familiar to us would have been for our ancestors. Just a small sample indicates the nature of what was described at the symposium:

• Surgery carried out by computer-guided robots, with immediate and automatic restocking (without reordering or human intervention) of surgical equipment and medication (this is partly already in use), and remote surgery in which the operating surgeon (who guides the computer) may be thousands of miles from the patient during the

[4] For more on this, see also "A Futurist's View: An Interview with Richard M. Satava", M.D., Yale Medicine, Winter 2003, available at www.med.yale.edu.

procedure (this is already done successfully);

• Growth of replacement bodily organs in specially maintained groups of animals (pigs apparently favored currently) for use in human transplantation, promising to make shortages of transplanted organs a thing of the past (this is predicted to become available within one to three years);

• Artificially induced hibernation and what can only be described as "reversible pseudo-death" of patients as a substitute for anesthesia, eliminating the latter's undesirable side effects and other perils;

• Inducement of growth of new organs within patients, as a substitute for transplants, eliminating the difficult and dangerous problem of transplant rejection and the need for post-procedure anti-rejection medications, with their undesirable side effects, perhaps for the remainder of the patient's lifetime;

• Use of certain insects (notably butterflies, cockroaches, and sphinx moths with their very specialized and powerful senses) to transmit information about the presence of dangers such as buried land mines or anthrax spores (or to locate earthquake victims), with no human presence, making it possible to take countermeasures remotely.

This list, surely, must suffice to stir the imagination to overload, to indicate that the end of innovation is nowhere in sight, and to confirm that the large corporations cannot do it alone.

Dissemination of Invention and Rapid Termination of the Obsolete

There is another key activity for growth that is elicited by market forces but that has not yet been mentioned–the incentive for rapid dissemination and widespread utilization of new or improved products and processes. This would appear simultaneously both to help and to hinder growth, but as will be argued next, current practices by industry have tended to contain the hindering effects.

One of the attributes of an effective economic arrangement for the encouragement of beneficial technological change is the innovator's financial gain derived from the temporary acquisition of monopoly power through the improved product or process in his possession. However, encouragement of growth also requires rapid *dissemination* of any improved techniques and products and their widespread adoption by others beside the innovator. These two desiderata would, however, appear to be in conflict. After all, rapidity and ease of dissemination can threaten the innovator's reward. While the free market has hardly eliminated this conflict, it has nevertheless ameliorated the problem to a considerable degree. Though it is something of a digression, my discussion will turn briefly to this issue because it will play a substantial role in the possible programs that merit consideration for facilitation of an economy's growth.

As is to be expected, many business firms do guard their proprietary technology and strive with the aid of patents, secrecy and other means to prevent other firms, notably rivals, from using the new products and processes. This is unfortunate for economic progress because it means that consumers who purchase from other firms are forced to accept obsolete features in the items they buy.[5] Moreover, two firms that deny one another access to their proprietary improvements in the firms' common product can evidently both survive, marketing their somewhat differentiated outputs, each of which is rendered inferior in terms of what is currently possible technologically by the obsolete features that it is forced to provide. Happily, however, that is hardly the norm. On the contrary, voluntary licensing of access to proprietary technology is widespread in the economy. Many firms derive substantial incomes from the sale of such licenses. The logic is straightforward. Suppose firm A invents a new widget and expects to make a net profit of X dollars per widget of the new type that it produces. Then if rival firm B offers firm A a license fee of Y dollars (Y > X) for each unit of the new widget it is able to sell, then A obviously can be better off letting B do so, even if every widget sold by B means one less sale for A. Of course, B will generally be able to afford so high a fee only if it is a more efficient *producer* of widgets than A, even though it may be an inferior inventor. In this way the price mechanism will not only encourage licensing, but will, as usual, elicit efficient specialization: inventive activity will be undertaken primarily by the more effective inventor, while production of the resulting products will be undertaken predominantly by the more efficient producer. This sort of unreciprocated licensing does take place in practice, but it seems most frequently to entail the sale of licenses by large firms that are in a position to undertake extensive R&D activity, the licensees being smaller enterprises that cannot afford to carry out such activity and do not possess personnel qualified to do so.

There are a number of other incentives for such profitable and voluntary exchanges in the free market. For example, the most straightforward reason, and the one that seems most frequently offered by businesspersons, is the very high cost of R&D activity. By entering into some sort of sharing consortium this burden can obviously be divided and reduced for each participant. Given the public-good attribute of the resulting information, it is far less expensive (per user) to provide such information to several firms than only to supply it to one. Another reason is reduction of risk. In any given year, a single firm's R&D division may fail to come up with any significant breakthroughs. The fear by management of firm A that this will happen to it in a year when its rival, B, manages a significant breakthrough is a fear that is replicated in firm B. Since, as already emphasized, product and process improvement are a matter of life and death in the high-tech industries characterized by vigorous oligopolistic competition, technology-sharing agreements serve as effective insurance policies, protecting each participant from such catastrophes.

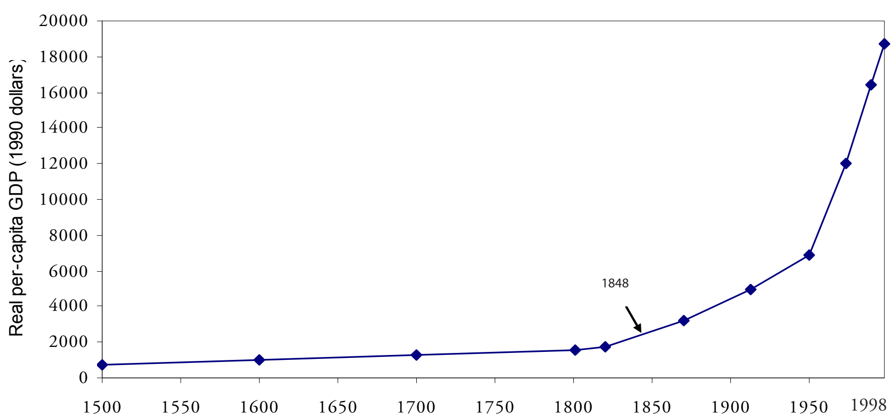
A further, and less obvious, reason for voluntary dissemination also entails trading of technology, but it is undertaken because it protects the firm from entry. To see how this works, consider, for example, an industry with 10 firms of identical size, each with an R&D division with similar staffing and similar funding to those of the others. Each firm in such a consortium will then have available to it not only the discoveries of its own R&D establishment, but those of nine other firms in addition. Now suppose an eleventh firm wants to enter the market, but is not invited to join the technology-sharing consortium. Having only the products of its own R&D division at its disposal, while the other firms each obtain the outputs of ten R&D establishments, the entrant can find itself at a severe competitive disadvantage.

[5] It is, however, not always recognized that patents are not designed to prevent the spread of information about novel technology. On the contrary, patent holders are required to make full information on their inventions public so that others can profit from the ideas even if they cannot replicate the patented products themselves without the patent holder's permission.

This type of arrangement evidently has its pros and cons. It can be shown to stimulate innovative effort (provided that anticompetitive conspiracy is absent). For it helps to internalize the externalities generated by the innovative efforts of each firm. Indeed, if as happens in practice, in such an exchange each firm undertakes compensation equalization payments to any other member of the consortium if the latter's innovations are of market value significantly superior to its own, then the firm has a direct incentive to come to the contract bargaining table with a menu of valuable innovations to offer. It can also be shown that the formation of such a consortium tends to be welfare-enhancing (Baumol 2002, Chapter 7).

Yet there are evidently dangers against which the authorities must be vigilant. Such consortia *can* serve as vehicles or as camouflage for anticompetitive behavior. For example, the contract discussions can conceivably serve as a disguise for price fixing by the competitors. Or they can enter into an agreement for mutual restriction of their R&D expenditures, each firm knowing that it can safely limit its innovative efforts if it can rely on its rivals to do the same. Or the contracts can be offered in a discriminatory manner that limit the benefits offered to entrants or denies them access altogether.

Figure 1
Real Per-Capita GDP in the United Kingdom, 1500-1998



Source: Maddison (2001).

Similar perils for the public interest arise in the last of the reasons for voluntary technology sharing–the problem of "patent thickets" and the widespread patent pools that have been formed to deal with the thicket problem. A complex piece of equipment, such as a computer, characteristically is made up of components each of which is covered by a surprisingly large number of patents, and the patents pertinent for such an item are often owned by a considerable number of different firms, many of them direct competitors in the final-product market. For example, Peter N. Detkin, vice president and assistant general counsel at Intel Corporation, estimates that there were more than 90,000 patents generally related to microprocessors held by more than 10,000 parties in 2002 (Federal Trade Commission 2002, p. 667). This puts many of these firms in a legal position that can enable each to bring the manufacturing process of the others to a halt. The most effective way to prevent the catastrophic consequences this threatens for each of them is the formation of a patent pool in which each makes use of its patents available to the other members of the pool, and even to outsiders (as a step to avoid intervention by the anti-monopoly authorities). There are many such pools in the U.S., with widely varying membership rules, license fee arrangements and other differences that are not germane here.

It is of some interest that in the U.S. the Department of Justice and the Federal Trade Commission have recognized the two sides of the issue, the benefits of coordination in the arena and the attendant danger of anticompetitive behavior. Their 2000 *Guidelines for the Licensing of Intellectual Property* very explicitly discuss the substantial pro-competitive benefits of licensing, coordination of research efforts and trading of proprietary technology. What is significant for us here is that licensing as the prime instrument for technology dissemination has become sufficiently important to merit this sort of attention by the antitrust agencies.

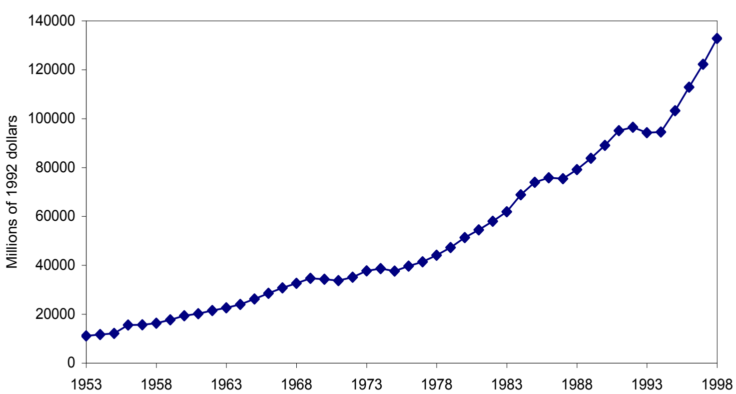
Indicators of the Magnitude of the Free-Enterprise Growth Miracle

But what has actually been accomplished by the components of the growth mechanism that have been reviewed here? The growth record of the free-market economies is generally recognized, though its magnitude seems often to be overlooked. It is seems worthwhile to pause and attempt to suggest the size of the accomplishment. The improvement in the growth performance of the industrial economies is, in fact, so enormous that it is difficult to comprehend. Average growth rates for about one and a half millennia before the Industrial Revolution are estimated to have been approximately zero, and while there was undoubtedly some growth starting around the tenth century, it proceeded at a snail's pace by modern standards. But in the 18th century, with the advent of capitalism in Great Britain, GDP per capita is estimated to have grown some 20 to 30 percent. In the 19th century, this figure rose, perhaps, tenfold, to some 200 percent. In the 20th century, growth in the U.S. has conservatively been estimated at about 700 percent, with some qualified observers arguing, with the aid of striking data, that this is a substantial *underestimate*. Elsewhere, the twentieth century growth rate was even more spectacular. The British record is described in *Figure 1*, which reports Angus Maddison's (2001) estimates of per capita income since the 16th century. The negligible rate of increase during the first three centuries reported in the graph is clear. The explosive growth path since that time must also be striking. It is also worth noting how early in the rising trajectory it was that Marx and Engels made their cogent observations: "The Bourgeoisie [i.e., capitalism] cannot exist without constantly revolutionizing the instruments of production.... Conservation of the old modes of production in unaltered form was, on the contrary, the first condition of existence for all earlier industrial classes.... The bourgeoisie, during its rule of scarce one hundred years has created more massive and more colossal productive forces than have all preceding generations together" (the arrow labeled 1848 marks the date of publication of these words).

Even the most well-off consumers before the Industrial Revolution had virtually no goods that were unavailable in ancient Rome. Clocks, hunting guns, window glass and paper virtually exhaust the list. Moreover, many choices available to affluent Romans–like hot baths–had long disappeared by the time of the Industrial Revolution. Since then, the pace of innovation has evidently grown into a flood. It has been said that the18th century was the period when the process first took off; that only in the 19th century did the change achieve widespread recognition and did the belief in continuing technical progress take hold; while in the 20th century, the arrival of new products and processes became so frequent and commonplace that it began to be taken for granted and hardly worth noticing. It is surely arguable that during the collapse of many of the communist regimes in the late 1980s and early 1990s, when even China turned toward capitalist enterprise, what the public wanted was to participate in the capitalist growth miracle just described.

Outlays on research and invention, like GDP per capita, have also been exploding. *Figure 2* shows real private (business) expenditures on research and development activity in the U.S. for nearly half a century after the Second World War. Here again, the near-exponential growth path is immediately observable. It is also worth observing how small was the effect of the recessions of the postwar period in holding back the growth in real expenditures on the invention process. The intervals of decline in R&D outlays are merely small deviations from what appears to be an inexorable rising path.

Figure 2
Real U.S. Private R&D Expenditures, 1953-1998



Source: National Science Board (2000); and Economic Report of the President (2001); expenditures are deflated using the GDP implicit price deflator.

The Invaluable Contribution of "Mere Imitation"

It is predictable that most of the innovation that a relatively small industrial economy can expect to introduce will not have been contributed by the country's own R&D activities, but by those of other countries. This is not to be regarded as a deficiency. In a world in which almost all major technological development takes place in some 25 countries, and in which technology licensing and trading is increasingly common, it is a tautology that if none of the countries falls significantly behind, then the average country should expect some 24/25ths of its new technology to come from abroad.

The imitation process that is evidently so important is the source of a significant misapprehension. The notion is that the imitation process has little or none of the attributes of a truly innovative activity. But that is simply incorrect. History is replete with examples of substantial improvements that were contributed by the imitators. In part, these improvements are elicited by the need to adapt the technology to local conditions, including differences in size of the market, in the nature of consumer preferences, in climatic conditions and in the character of available complementary inputs. Thus, there is nothing inherently inferior about a process of organized imitation of foreign technology. Indeed, as one historian who specialized in the history of innovation has observed, "…every invention contains some borrowing and every borrowing some invention" (De Camp 1963).

Moreover, as just noted, every economically advanced nation can be expected to do it and to run the risk of falling behind if it does not. Even the U.S. and Japan, the two leading contributor to the world's stock of new products and processes, derive a substantial proportion of their latest technology from elsewhere. For every advanced economy, innovation will continue to be of prime importance for economic growth. But one may well expect that a substantial proportion of that innovation will be obtained from foreign sources. And to be an effective user of such foreign technology, it is important for the country to ensure that it is a skilled imitator as well as an effective innovator.

On Governmental Policy for Promotion of Innovation and Growth

Given the four contributory sources that play critical roles in expanding an economy's innovation and growth–entrepreneurs and small firms, large firms with internal R&D capacity, universities, and government—one is driven to conclude that effective programs for facilitation and stimulation of entrepreneurship are important, but that there is more that can be done than is currently being done for this purpose. In this section, I offer a few illustrative suggestions that seem to merit consideration by the designers of policy. Of course, since the subject here is public policy, what will be said relates to the role of government–not the role of government as innovator on its own, but, rather, as facilitator of the innovative work of others. In particular, I will focus on one illustrative subject, the facilitation of the acquisition of foreign technology.

Funding and Execution of Basic Research.

As already noted, the universities and the pertinent government agencies have also made major contributions to technological progress, the electronic computer and the Internet providing striking examples. However, the contributions of these institutions have also tended, appropriately, to be rather specialized and different from those of private industry. I begin with just a few words about the character of those contributions.

It is to the public sector and universities that we must look primarily for the results provided by *basic research* as distinguished from applied research. The reasons for this division of labor with private industry are well understood and were laid out earlier in this paper. Basic research can contribute materially to the economy's growth, at least in the long run, but its questionable returns to the private investor makes it unattractive to business firms. What is clearly called for is governmental funding of basic research, to be carried out by its own agencies, or some appropriate outside agencies, most notably the universities, with the outstanding scientists and engineers to be found in their faculties. And indeed, specialization of the research activities funded by government have tended to focus on such basic research because that is the most effective and reliable way to elicit such activity that can be so important for long-run growth.

A Government Role in Acquisition of Foreign Technology.

Economists generally agree that government can play a useful role in the provision of certain socially valuable goods and services because private enterprises lack the incentive to supply optimal quantities of such outputs. Basic research, as just noted, is one important example. The encouragement of technology transfer from abroad is another significant case in point. In particular, it is important for an economy of smaller or medium size to recognize the contribution to its growth offered by rapid acquisition and absorption of technological information from elsewhere. But the transfer process has significant attributes that invite a role for the public sector. For example, the work of monitoring foreign technical journals and of providing translations of pertinent articles can be carried out nearly as cheaply for a multiplicity of firms, or even for a considerable number of industries, as it can on behalf of any single business enterprise.

Countries appear to have differed substantially in the quantity of resources they devote to this purpose. Edwin Mansfield (1990, p. 343) reports, on the basis of a survey of 100 American firms in 13 industries, that these respondents believed only 29 percent of U.S. firms spend as large a percentage of their sales on the monitoring of foreign technology as the average amount spent by the Japanese, only 47 percent as much as the Germans do, only 51 percent as much as the French do, and only 70 percent spend as much as the average British enterprises in the corresponding industries. Such disparities may well constitute an opportunity for a country to gain a differential advantage in its monitoring and adoption of foreign technology. For example, it may prove to be profitable socially for a government to establish a special Office of Technology Transfer, with a staff of specialists qualified to monitor, translate and disseminate pertinent materials in foreign publications. This, surely, constitutes a form of industrial policy that should make sense even to those economists who are most suspicious of public-sector intervention. More specifically, it is easy to describe some illustrative steps that can be taken in carrying out such a program:

a. Education and training.
The government can establish a set of well-funded scholarships for the study of engineering and other pertinent subjects by a smaller country's students studying in the U.S., Japan, Germany, and several other countries that are leading producers of innovation. This program would include funding of an intensive set of language courses that would prepare the students for their studies abroad. The students can be obligated, upon completion of their courses, to take suitable jobs in their home country's industry or government for a period of (say) five years after completion of their studies.

b. Immigration of foreign technicians and related personnel.
A fund can be established to provide subsidies for the immigration, permanent or temporary, of foreign scientists, engineers and technicians who can provide knowledge to their home-country industry about current foreign technological developments. It may be desirable to require such a prospective immigrant to be sponsored by a home-country firm, university or government agency, with the sponsor obligated to provide employment to the immigrant, and to make a case that the immigration of the individual in question will make a substantial contribution to absorption of useful technological information by native industry.

c. Establishment of observer staff in the country's embassies.
At several countries that are leaders in innovation, the embassy in such a leader country of any growth-seeking economy should be provided with a special technology monitoring staff of a size that can be deemed adequate to keep track of technical journals, company newsletters and other available published materials, and arrange for translations where desirable, making those translations available to home-country firms, and to provide such information from other legitimate sources. These specialists can also help to facilitate technology transfer agreements between those firms and home-country enterprises. Frequent contact between these embassy staff members and suitable representatives of home-country industry can ensure that the efforts of the embassy observer staff are directed in a manner that is as useful as possible.

d. Study of measures taken by governments in other countries to facilitate absorption of foreign technology by their
industry.
A suitable group in the universities or elsewhere can be given funds to support an extensive and systematic study of the programs of other governments to encourage the acquisition of foreign technology, with the study describing the programs, their working and their degree of success. Interviews with businesspersons in the countries in question can be used to provide analysis of the effectiveness and shortcomings of each of the programs. The study can provide a report and a set of recommendations based on foreign experience to the appropriate committees of the home government.

The preceding remarks are merely offered as examples of what sorts of measures are at least worthy of consideration. Reading of this article, and of the book upon which it draws, should readily suggest other promising avenues. Stimulation of such investigation is all that the preceding brief remarks on policy are meant to accomplish.

Concluding Comment

The primary lesson that follows from the discussion here is that the future prosperity of any economy depends to a considerable extent on its success in promoting entrepreneurship, innovation, and the effective and prompt importation of technological advance from abroad. It also follows that the incentives for these developments should not be left exclusively to chance and the natural spirit of enterprise to be found within a nation's population. There are measures that can be adopted to stimulate and facilitate them. This article's analysis of the mechanism underlying the free-market growth miracle should suggest promising directions for growth policy as well as actions that should be avoided because they are likely to impede progress in the economy.

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