George E. Pake
Xerox Corporation

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I shall begin with an analysis of the sequence of nouns in our topic, coupling my personal experience with each term.

I have, at one period of my life, actually done some *science*; and I have held tenured professorships in physics. Perhaps the greatest contribution I made to the academic world was that I resigned three different professorships thereby opening up opportunities for young people.

As to *economics*, I really know nothing about the subject. Although I have during my life been frequently buffeted about by the repercussions of economic events, I certainly have no scholarly credentials in economics. Perhaps my greatest claim to economic fame was once having the budgets of a major private university in my office; we stayed solvent in spite of selling every university product at a loss!

In the realm of *public policy*, I have been exposed to numerous "science and public policy" issues in my role on the President's Science Advisory Committee from 1965 through 1969, and now on some university boards of trustees and on a significant council of the National Academy of Sciences, called the Government-University-Industry Research Roundtable.

As I attempt to divine what was in mind in selecting the title of this panel discussion I am led to assume that another topic is implied, namely technology. It strikes me that the usual or normal link between science and economics is technology; I believe my experience in industrial research demonstrates that to be the case.

There is not always a hand-in-hand relationship between science and technology. What I have sometimes called the "standard model" has science or scientific understanding upstream of technology in a flow that is idealized to proceed from science to technology to engineering to manufacture to distribution to sales. Sales bring revenues and thereby a coupling to economics. I have seen several examples of that flow first-hand in my R&D responsibilities with Xerox. The model, which I see Mowery and Steinmueller label as the linear model, does have real manifestations, though it is not always followed.

Sometimes, imaginative engineers or technologists slap something together that works, and a useful product is marketed even though there is little understanding of the science underlying the technological events within the product. Several significant inventions have followed this course. Early builders of automobiles knew little of combustion theory, and the Wright brothers knew little aerodynamics. But by the time modern pollution controls via microprocessors characterized automobile engineering, or by the time jet planes began to dominate commercial skies, their critical technologies could be built upon strong and extensive science bases.

It seems to me that the circumstances where technology is likely to get out in front of science occur where necessity has mothered invention. I believe that these kinds of invention are from an era that has largely passed - perhaps one can say that they are from an era we would now characterize as "low tech": the automobile, the Wright flier, the telephone, the cotton gin all fit in that category. When we look at modern "high tech" inventions, they often seem to be close descendants from science: the laser, the transistor or the integrated circuit, recombinant DNA - none of these would have been likely to come from the inventive genius tinkering in his basement or garage. Instead, they spring to life out of the "primordial ooze" of the crackling scientific environment provided in the modern, well-instrumented, highly sophisticated research laboratory.

There are circumstances in these modern research laboratories where invention far precedes necessity. The laser is an example. For several years after its invention, people looked hard for applications of the laser. Indeed, many have been found by now; the laser-Xerographic printer that makes transparencies for speeches or prints thousands of pages per hour benefits greatly. I cannot imagine our Xerox invention of electronic printing without the laser already in existence. It is not conceivable to me that the need for an intense coherent light source for an electronic printer could have provided a powerful enough necessity to induce invention of the laser. Nor would the benefits for retinal surgery have provided sufficient impetus.

What I am driving at here has public policy implications. These sophisticated modern technologies grow out of this primordial ooze of modern research laboratories steeped in basic scientific understanding. Once that basic understanding is deep enough, imaginative scientists see that, here, coherent reinforcement and amplification of radiation can be made to occur, or, there, it has become possible to splice genes. Many of our recent opportunities for economic growth rest on these new capabilities.

The public policy implication is that, the nation requires many first-rate science and research laboratories abounding in the fertile primordial ooze. In order to have a continuing genesis of the new high-tech opportunities for consequent economic growth, the nation also requires a substantial population of bright, well-funded scientists to wallow in this ooze - even to mud-wrestle each other.

A combination of demographic and political events now puts the U.S. at a critically important juncture. As a matter of public policy, our universities and their laboratories have been allowed, through inattention, to stagnate with obsolescent equipment and ever tighter budgets. Scholarship and fellowship support for the few bright ambitious students we have has been curtailed. The primary and secondary school systems that should feed the universities have been allowed to deteriorate - particularly in science education. Ironically, much of this current starvation of education is associated with short term efforts to feed a gargantuan military establishment whose future technological requirements depend critically upon a large supply of trained scientists and technologists and upon a steady flow of new sophisticated technology.

But this supply of technically educated personnel and advanced technology is equally essential for maintaining the U.S. position in the international marketplace - and thus for the economic health of the nation. The warfare for economic survival is a contest in which it is certain we shall have to engage. The current expenditures for the arms race are building an inventory that, hopefully, a skillful foreign policy will avert any need to use. How strange that we are taking almost certain steps toward a longer term economic subservience in order to have a short-term defense against military and political subservience!

I mentioned demographics earlier. We are now missing opportunities to train potential scientists and engineers whom our future economic growth will require - because our public educational system is in disrepair, and we threaten our universities with a similar fate. But the demographic patterns offer very little prospect for making up these lost opportunities during the '90s. In a very real sense, every scientist or engineer we fail to train in the '80s is an irreplaceable loss to our techno-economic engine for future national prosperity. The deterioration of our public educational system, and the incipient erosion of our university system's strength, are critically vital public policy issues.