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FOOTNOTES

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INNOVATION AND ECONOMIC GROWTH: LESSONS FROM THE STORY OF ENIAC

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Of all the various ideas that have been advanced on how to revive the U.S. and world economies, one of the most dominant is that of ingenuity, innovation, and the creation of new products and industries.

What is innovation; and what are the factors that lead to success?

We can't teach people to innovate--if we could, we could write an expert or artificial intelligence program that would innovate. But we can encourage it, provide funding, and promote adoption of new ideas. We can and should establish the environment to encourage innovation and innovators and recognize and reward innovation.

Innovation means a new way of doing something. It may refer to incremental, radical, and revolutionary changes in thinking, products, processes, or organizations.[1] Essentially there are three types of innovation: (1) radical--e.g., vaccination, fuel cell; (2) incremental--aluminum instead of chrome on a car, cell phones, the internet, satellites; and (3) revolutionary--leading to disruptive technologies (the digital computer, nuclear power, asymmetric warfare, and innovative explosive devices).

One of the greatest innovations in history, ENIAC--the Electronic Numerical Integrator and Computer--happened over sixty years ago in Philadelphia. The world's first general purpose electronic computer, it encompassed radical, incremental, and revolutionary innovations. It is the grandfather of the computer and of the information transformation of our world. It was the first machine ever invented that amplified the mind rather than physical strength.

FACTORS INFLUENCING INNOVATION

Newton saw an apple fall, Einstein knew there was a problem with speed of light experiments, and Mauchly wanted to predict the weather and the stock market. All had an idea. They nurtured it, they chewed on it, wondered about it, and went about solving the problem.

There are a number of factors involved in innovation. There is the environment of need (war, depression, epidemic, poverty); capability (industry, Babbage, Lister); and funding (government, private, corporate) support, both psychological and financial.

There is "passion": the guts and "fire in the belly." There is little chance of a breakthrough with a revolutionary/disruptive innovation without intestinal fortitude. Bill Gates slept in a knee hole of a desk, Steve Jobs worked in a garage with Steve Wozniak until the first showing of the Apple Computer. Bill Hewlett and David Packard built their devices in a garage until they moved into a factory and launched the Hewlett Packard Instrument Company. John Mauchly bought used gas tubes with his own money, soldered circuits, and built counters from 1936-41 until he convinced J. Presper Eckert to join him in building a computer in 1941. There was no funding until they won a government contract in 1943.

There has to be an idea: disruptive (cell phones, iPod, video, IED), incremental (wing design, FM, laptop, internet); or revolutionary (jets, antibiotics, atomic energy, the computer, personal medicine, nanotechnology).

Financing is needed. This often comes from the government (SBA, R&D, DOD, CIA, Energy) for basic science, and was the initial source for computer efforts. Government funding can be cautious, slow, and bureaucratic. There is also corporate

[1] Wikipedia.org.

support, which is success-oriented, profit-motivated, and also cautious, sometimes political, and product oriented, often covering applied research. Academic research relies heavily on government support, along with individual (angel and venture capitalist) support, which is success oriented, return oriented, adventuresome, and has supported the major breakthroughs of the last fifty years (Microsoft, Apple, Oracle, Google, Yahoo).

Of course, an innovation must have impact--it must be worth doing. In particular, a truly revolutionary innovation will be highly disruptive, creating new products, industries, and redirection to political and economic ways of doing things. It must be focused--buckshot often misses, but a well-aimed rifle in the hands of a marksman usually hits its target. Much time, treasure, and energy is lost in the absence of focus

ENIAC

February 14, 1946, saw the first public demonstration of ENIAC. It was the first such computer that worked, and it continued to work productively for almost ten years, finally ceasing operations on October 2, 1955.

ENIAC was the "wheel" of the new industrial revolution, ushering in a tidal wave of change, enterprise creation, and disruption to the status quo--significant change in the way we worked, played, communicated, and organized ourselves. The computer revolution has created vast new industrial infrastructures, new giant companies, and unbelievable wealth for many.

ENIAC not only paved the way for the development of computer technology and information systems, but it provided a global impetus to that initiative. Following this success strategy can do the same for us today.

ENIAC was the brainchild and work product of a team of engineers and scientists at the University of Pennsylvania. The intellectual force behind the invention was Mauchly, a 38-year old professor at Penn's Moore School of Electrical Engineering; Eckert was the creative engineering genius, who teamed with Mauchly as a 22-year-old graduate student to spearhead the birth of the computer and information age.

One has to consider the nature of ENIAC in the scientific world at the time. When the government contract to develop ENIAC was signed in 1943, the concept behind it was contrary to the prevailing wisdom of the day in the U.S. MIT and Harvard were heavily involved in extending the capability of "differential analyzers", mechanical analog computer designed to solve differential equations by integration, using wheel-and-disc mechanisms to perform the integrations, and Dr. John Atanasoff at the University of Iowa was concerned with creating a special purpose computing machine capable of solving systems of simultaneous equations. The concept of a true general purpose digital electronic computer was a quantum leap beyond these efforts.

The idea of a machine to do calculations is not new. Around 2700 BCE the "counting board" (later, "abacus") was invented. In about 1300 BCE the Greeks invented a machine to plot the course of the stars. In the seventeenth century, Napier Bones developed logarithmic tables. In the nineteenth century, Charles Babbage built mechanical difference engines. Vannevar Bush at MIT began work on the differential analyzer in 1927.

Mauchly began thinking about calculating machines around the same time, and in 1935 he started tinkering with circuits. His models still exist. In 1936 a brilliant mathematician at Cambridge University, Alan Turing, wrote a paper on how to solve numerical problems with a machine. His primary objective was to establish methodology for breaking codes. His work pointed the way to building machines that could then apply algorithms--arithmetic procedures for solving complex problems--to decoding encrypted messages.

The British effort was heavily concerned with that need, and extensive work proceeded with the building of ten Colossus computers that operated at the British decoding facility at Bletchley Park. There is no doubt that these machines were a significant factor in the thwarting of the German bombing offensive against Britain in 1940-1941, and then throughout World War II. But Turing never built any computers; he never built a single circuit, nor did he design any. While brilliantly conceived and executed, the Colossus machines were special purpose machines with the limited purpose--at which they were very effective--of decoding Enigma messages. There is a world of difference between a special purpose machine and a general purpose computer. For example, an electric drill is a special purpose machine used in drilling holes as part of some process; whereas a lathe is a general purpose machine tool that can be used in making just about anything.

Atanasoff and Charles Berry began building their "ABC" (Atanasoff-Berry Computer) in the late '30s at the University of Iowa. ABC data storage was a magnetic drum; ABC was a special purpose machine to solve simultaneous equations; it never completely worked as envisioned (solving up to 27 simultaneous equations in 27 unknowns)--even when a prototype was rebuilt in 1972; but a replica built in the 1990s could solve two equations in two unknowns. ABC was single purpose, was not totally electronic, and was slower than a rotary calculator.

Remember, Mauchly started building computing circuits in 1936. Communication in the 1930s was not that of today. There was no internet, no instant messaging, and travel was difficult. Besides, nobody had any money. Mauchly bought used radio tubes to build his circuits with his own money.

Hence the idea and desire for a computer was not new, but he went about solving that problem in a total system concept approach. He conceived it, designed it, and then found someone to build it.

ENIAC was an outgrowth of Mauchly's efforts at building counting circuits in the 30s and his concept of a fully integrated, fully electronic computing machine that could be applied to any type of mathematical problem. His pet peeve was to eliminate the need to reenter intermediate results as a problem solution proceeded. The concept, design, and creation of ENIAC was so directed. ENIAC succeeded. Mauchly convinced a young graduate student, Eckert, to join him in this effort in 1941. Their work together created the Information Age as we know it today. Mauchly provided the vision; Eckert created the circuits to make it happen.

As a young boy, Mauchly strove to understand how things worked. A natural tinkerer, he took apart locks and studied the components of telephones. Climbing into a telephone company ditch outside his home in Chevy Chase, Maryland, he would hook up wires from the trunk line to his room, and even fashioned an intercom system for his pals. To read past his bedtime, he furtively placed a sensor under the steps leading to his room, alerting him of his parents' approach.

His interests were broad, he was good natured, and he was an honest man. But Mauchly was stubborn beyond all belief. When he locked onto an idea, he wrestled with it until he had it solved. I was privileged to work closely with him in the 1950s and early 1960s. He always had time to answer any question and examine any possibility. John sought unlimited capability in his machines, totally general purpose, including branching, conditional logic, and subroutines.

One story about Mauchly from his teaching days summarizes him. He wanted to demonstrate Newton's Third Law of motion to prove that every force has an opposite force that is set up--for example, the recoil of a cannon or rifle. John illustrated this law by wearing roller skates on top of the desk in the front of the room. He threw a weight forward and just managed to keep from falling off the end of the table. He proved his point.

Eckert was a methodical slave driver who swept away difficulties in his drive for perfection. His circuits had to be perfect, never go down, and meet all of Mauchly's visions, and more. While Eckert attributed many of the novel ideas in ENIAC, and later BINBAC and UNIVAC, to Mauchly, he was the prime mover in building the circuits and auxiliary components such as storage devices, printers, self-checking circuits, and high-fidelity circuits--all common place today, but previously unknown when he created these capabilities. Eckert put all the pieces together and made it all work; and all within the plan and schedule he kept almost entirely in his head. Eckert suffered fools badly.

AN OPPORTUNITY

I asked Bill Mauchly, John's son, to comment on ENIAC. Commenting on how it could do any math problem 1000 times faster, he said "Imagine what that means. It would be as if one day you could only walk, but the next day you could fly, anywhere, at 3000 mph… This was a bold challenge--to be able to compute any problem, at electronic speeds."

"*The*" problem, which was known to anyone who was in the field of computation in the '30s, was how to perform a sequence of various different operations on numbers very quickly. The answer, that we can see from hindsight, was straightforward: Use only electricity; do not use any moving parts in the mechanisms that *store* the numbers, *or* that control the operations.

ENIAC worked at the electronic speed of 5000 operations a second. It could do this because the numbers were "stored" in electrons, not paper tape, rotating drums, or punch cards. The calculation units all worked at that speed, with no moving parts. And perhaps most important, the *next* operation could proceed immediately, without waiting for paper tapes or human intervention; or branch logically. It took some smart people, an urgent need, and government money to solve that problem. (Other machines of the time used slower storage: Colossus used a giant loop of paper tape and a bank of mechanical relays, while ABC used a spinning magnetic drum that was regenerated with each revolution. Such systems are much slower than electronic memory.)

Bill Mauchly also commented on Philadelphia's place in the electronic world--then and now. In the 1930s and 1940s the Delaware Valley was often referred to as "tube alley" since so much of the electronic tube manufacture and design occurred in this region. Most of the TV sets manufactured in the United States came from this area. Philco and RCA were major forces in the field and in the country. Now they are manufactured overseas.

Taking these two major foundation stones into account, why isn't Philadelphia the computer capital of the world today? For a short period of time it was.

After Mauchly and Eckert left the University of Pennsylvania, they started the Electronic Control Company, and many of the engineers who had worked on ENIAC joined them. They used borrowed money from family and friends to get started, principally a $ 25,000 loan from Eckert's father. The team was enthusiastic, working long hours, their salary sometimes reduced and occasionally completely deferred. Astonishingly, not a single bank or investment company was willing to lend them money, much less invest.

Eckert and Mauchly conceived of a true commercial oriented computer which they termed and called UNIVAC--for UNIversal Automatic Computer. When they secured contracts with the Army, Navy, and Air Force for UNIVAC machines, they changed the name of the company to the Eckert Mauchly Computer Company--EMCC , and sought additional funding. Mauchly was President--and salesman--and Eckert was Vice President and Chief Engineer. The objective of the company was to design, build and market commercial computers. Despite their experience, knowledge, and ability, this was very difficult for a start-up company in that era. Problems concerning fallacious concerns about military security and the hostile attitude of certain academic advisors to the military made Eckert and Mauchly's goals infinitely more difficult to achieve. Contracts were

pursued to build the first commercially available completely programmable electronic computer. The first UNIVAC was delivered to the Census Bureau in 1951. Ultimately 46 UNIVAC I machines were built and delivered in the period ending in 1956. They were built in Philadelphia.

For a brief period, UNIVAC captured the majority of the market for digital electronic computer systems. These systems functioned for years, with a life averaging over nine years. The last machine was still in useful productive work as late as 1970 at Life and Casualty of Tennessee. The Census Bureau used its 1951 machine for twelve years; and a second one for nine years. A UNIVAC was installed at the Franklin Institute in Philadelphia which I used in the mid and late 1950s. Remington Rand donated a UNIVAC to the University of Pennsylvania in 1957.

Funding was always a problem for EMCC. When Mauchly approached IBM, the story was circulated that Tom Watson, Sr., then the virtual dictator of IBM, did not foresee a large market for computers. John told me the real story. Watson was concerned about antitrust and restraint of trade problems if IBM were to acquire the Eckert Mauchly Corporation. When subsequently Remington Rand bought the company, IBM launched an aggressive program of "catch-up" which ultimately succeeded.

Remington Rand bought EMCC in February of 1950 in a complex negotiation that Mauchly ultimately accepted because he had no choice. The net proceeds for inventing the computer for each of Eckert and Mauchly were $ 34,000 plus 25% of any future royalties on the patents and know-how. They ended up with 2.5%.

The computer industry in Philadelphia ultimately died. Venture capital was late in making investments in the new industries. The center of gravity shifted westward. Today the computer capital of the world is the Silicon Valley in California. Silicon Valley was a verdant pasture of orchards when 46 UNIVAC I machines were being built in Philadelphia. It wasn't until 1971 that the term Silicon Valley began to appear in newspaper stories as silicon-based chip and computer companies such as Intel, Fairchild, and others began to flourish in the area. Soon, Steve Jobs earned billions from his creation of Apple; and slightly to the north, near Seattle, Bill Gates became the richest man in the world by licensing software. The growth of technology was firmly in place.

FOSTERING ECONOMIC GROWTH BY WAY OF INNOVATION

Eckert and Mauchly created a revolution that propelled this nation--and the world--forward over the past sixty-three years. We need more men and women like them to once again bring us out of the chaos into which our bureaucratic think-inside-the-box attitudes have led us.

But we also need a highly focused system of support that enables people of vision and drive to succeed. These people are America's best hope. To succeed, we must get back to the work of creating the proper support system for innovation, while we still have time.

We may or may not be at war with an evil empire like we confronted in 1942, but regarding our standard of living, we have a great battle on our hands and like Pogo, I believe that "we have seen the enemy and he is us".

As a nation we are at a crossroads. Our economy, and that of the entire world, is in a shambles. People are comparing today's world to that of the Great Depression of the 1930s. That is one view. But another view is to compare ourselves to the world that existed after World War II, when many world economies were destroyed or nonexistent and untold cities lay in ruins.

In the 1930s we attempted to spend our way out of trouble. Stimulus packages were devised to put people back to work on government works programs. Bureaucracies were created that knew better than others how to solve the problem. The result was a continuing depression that lasted until World War II. While the message and rhetoric of the Roosevelt years were beacons of hope for the people, in reality the tax, spend, and protect policies of the administration did not completely succeed in restoring economic growth to the country. Initiative was stifled, and innovation was certainly not funded. The economy languished.

World War II is distinct from our own situation. Victory at any cost was the primary motivation then, not billions in set-asides on an $825 billion stimulus package. If you're going to stimulate the economy, you cannot stifle it with pay-back and pork-barrel politics. Tax and spend does not create success. The needs of warfare in 1941 swept away much of the stultifying impact of the blanket of bureaucracy created during the '30s. Innovation was sought, encouraged, and followed. True stimulus programs were enacted; lend-lease during the war, for example, and the Marshall Plan afterwards. The United States became the arsenal of democracy, with entirely new concepts of engineering and manufacturing replacing inefficient methods in shipbuilding, aircraft production, and research and development. The concepts of operations research came to the fore--the idea that a team of people with different disciplines could tackle problems--and solve them. Radar, jets, antibiotics, and atomic energy were born of this drive for innovation, investment, and the solution of problems by dedicated teams of people without bureaucratic blankets that may have protected but often smothered. This solution oriented approach led the U.S. Army Ballistics Research Laboratory to invest in a machine to calculate artillery trajectories. While this investment of about $486,804 did not produce a solution during the war, it did usher in the postwar innovation explosion, resulting in the greatest creation of wealth in history. That innovation was the first general purpose electronic digital computer--ENIAC.

In World War II, victory at any cost was the primary motivation. We need the same kind of approach now. Business as usual will take us further down the economic ladder.

Our current government must develop a conscious strategy to enable a Mauchly-type person to achieve his dream--to predict the weather, even if it is supported by the need to calculate artillery trajectories.

The financial meltdown of the present is a barometer of what the future could bring. Success in countering this downturn can only come from creating jobs, igniting the spark of American ingenuity, and creative thinking. Let's look for an economic renaissance, a new ENIAC.

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