Innovation, Components and Complements

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Every now and then a technology, or set of technologies, comes along that offers a rich set of components that can be combined and recombined to create new products. The arrival of these components then sets off a technology boom as innovators work through the possibilities.

This is, of course, an old idea in economic history. Schumpeter (1934), p. 66 refers to "new combinations of productive means." More recently, Weitzman (1998) used the term "recombinant growth." Gilfillan (1935), Usher (1954), Kauffman (1995) and many others describe variations on essentially the same idea.

The attempts to develop interchangeable parts during the early nineteenth century is a good example of a technology revolution driven by combinatorial innovation.[1] The standardization of design (at least in principle) of gears, pullies, chains, cams, and other mechanical devices led to the development of the so-called "American system of manufacture" which started in the weapons manufacturing plants of New England but eventually led to a thriving industry in domestic appliances.

A century later the development of the gasoline engine led to another wave of combinatorial innovation as it was incorporated into a variety of devices from motorcycles to automobiles to airplanes.

As Schumpeter points out in several of his writings (e.g., Shumpeter

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[1]See Hounshell (1984) for the fascinating history of technological development during this period.

(2000)), combinatorial innovation is one of the important reasons why inventions appear in waves, or "clusters," as he calls them.

> ... as soon as the various kinds of social resistance to something that is fundamentally new and untried have been overcome, it is much easier not only to do the same thing again but also to do *similar* things in different directions, so that a first success will always produce a cluster. (p 142)

Schumpeter emphasizes a "demand-side" explanation of cluster of innovation; one might also consider a complementary "supply-side" explanation: since innovators are, in many cases, working with the same components, it is not surprising to see simultaneous innovation, with several innovators coming up with essentially the same invention at almost the same time. There are many well-known examples, including the electric light, the airplane, the automobile, and the telephone.

A third explanation for waves of innovation involves the development of complements. When automobiles were first being sold, where did the paved roads and gasoline engines come from? The answer: the roads were initially the result of the prior decade's bicycle boom, and gasoline was often available at the general store to fuel stationary engines used on farms. These complementary products (and others, such as pneumatic tires) were enough to get the nascent technology going; and once the growth in the automobile industry took off it stimulated further demand for roads, gasoline, oil, and other complementary products. This is an example of an "indirect network effect."

The steam engine and the electrical engine also ignited rapid periods of combinatorial innovation. In the middle of the twentieth century, the integrated circuit had a huge impact on the electronics industry. Moore's law has driven the development of ever-more-powerful microelectronic devices, revolutionizing both the communications and the computer industry.

The routers that laid the groundwork for the Internet, the servers that dished up information, and the computers that individuals used to access this information were all enabled by the microprocessor.

But all of these technological revolutions took years, or even decades to work themselves out. As Hounshell (1984) documents, interchangeable parts took over a century to become truly reliable. Gasoline engines took decades to develop. The microelectronics industry took 30 years to reach its current position.

But the Internet revolution took only a few years. Why was it so rapid compared to the others? One hypothesis is that the Internet revolution was minor compared to the great technological developments of the past. (See, for example, Gordon (2000).) This may yet prove to be true—it's hard to tell at this point.

But another explanation is that the component parts of the Internet revolution were quite different from the mechanical or electrical devices that drove previous periods of combinatorial growth.

The components of the Internet revolution were not physical devices as all. Instead they were "just bits." They were ideas, standards specifications, protocols, programming languages, and software.

For such immaterial components there were no delays to manufacturer, or shipping costs, or inventory problems,. Unlike gears and pulleys, you can never run out of HTML! A new piece of software could be sent around the world in seconds and innovators everywhere could combine and recombine this software with other components to create a host of new applications.

Web pages, chat rooms, clickable images, web mail, MP3 files, online auctions and exchanges . . . the list goes on and on. The important point is that all of these applications were developed from a few basic tools and protocols. They are the result of the combinatorial innovation set off by the Internet, just as the sewing machine was a result of the combinatorial innovation set off by the push for interchangeable parts in the late eighteenth century munitions industry.

Given the lack of physical constraints, it is no wonder that the Internet boom proceeded so rapidly. Indeed, it continues today. As better and more powerful tools have been developed, the pace of innovation have even sped up in some areas, since a broader and broader segment of the population has been able to create online applications easily and quickly.

Twenty years ago the thought that a loosely coupled community of programmers, with no centralized direction or authority, would be able to develop an entire operating system, would have been rejected out of hand. The idea would have been just too absurd. But it has happened: GNU/Linux was not only created online, but has even become respectable and raised a serious threat to very powerful incumbents..

Open source is software is like the primordial soup for combinatorial innovation. All the components are floating around in the broth, bumping up against each other and creating new molecular forms, which themselves become components for future development.

1 Financial speculation

Each of the periods of combinatorial innovation referred to in the previous section was accompanied by financial speculation. New technologies that capture the public imagination inevitably lead to an investment boom: Sewing machines, the telegraph, the railroad, the automobile . . . the list could be extended indefinitely.

Perhaps the period that bears the most resemblance to the Internet boom is the so-called "Euphoria of 1923," when it was just becoming apparent that broadcast radio could be the next big thing.

The challenge with broadcast radio, as with the Internet, was how to make money from it. *Wireless World*, a hobbyist magazine, even sponsored a contest to determine the best business model for radio. The winner was "a tax on vacuum tubes" with radio commercials being one of the more unpopular choices.[2]

Broadcast radio, of course, set off its own stock market bubble. When the public gets excited about a new technology, a lot of "dumb money" comes into the stock market. Bubbles are a common outcome. It may be true that it's hard to start a bubble with rational investors—but not it's not that hard with real people.

Though billions of dollars were lost during the Internet bubble, a substantial fraction of the investment made during this period still has social value. Much has been made of the miles laid of "dark fiber." But it's just as cheap to lay 128 strands of fiber as a single strand, and the *marginal* cost of the "excess" investment was likely rather low.

The biggest capital investment during the bubble years was probably in human capital. The rush for financial success led to a whole generation of young adults immersing themselves in technology. Just as it was important for teenagers to know about radio during the 1920s and automobiles in the 1950s, it was important to know about computers during the 1990s. "Being digital" (whatever that meant) was clearly cool in the 1990s, just as "being mechanical" was cool in the 1940s and 1950s.

This knowledge of, and facility with, computers will have large payoffs in the future. It may well be that part of the surge in productivity observed in the late 1990s came from the human capital invested in facility with spread-

[2]See Smulyan (1994) for a detailed history and Hanson (1998) for a useful overview of this period.

sheets and web pages, rather than the physical capital represented by PCs and routers. Since the hardware, the software, and the wetware—the human capital—are inexorably linked, it is almost impossible to subject this hypothesis to an econometric test.

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