The Next Industrial

Information Technology makes a difference – finally.

By Stephen S. Cohen, J. Bradford DeLong and John Zysman

Is the recent acceleration of American economic growth likely to persist? Could the next generation see its material standard of living rise at something like 3 percent per year, rather than the 1 percent or so we have grown used to since the slowdown of the early 1970's? And will the next generation see other countries join the world economy's wealthy core not one by one – as Italy joined in the 1960's, Japan in the 1970's, and Korea hopes to join in the next decade – but in battalions?

Maybe. The next generation might see a return of productivity growth to the levels present before 1973, but that is not inevitable. What happens will largely turn on the answers to two questions: are the changes profound – and if they are, will we provide the proper resources and rules to nurture them?

Yes, Virginia, there is a New Economy

Many see a shift in the economic landscape, and different people call it by different names: the post-industrial society, the innovation economy, the knowledge economy, the network economy. We prefer a new term: the e-conomy. The other

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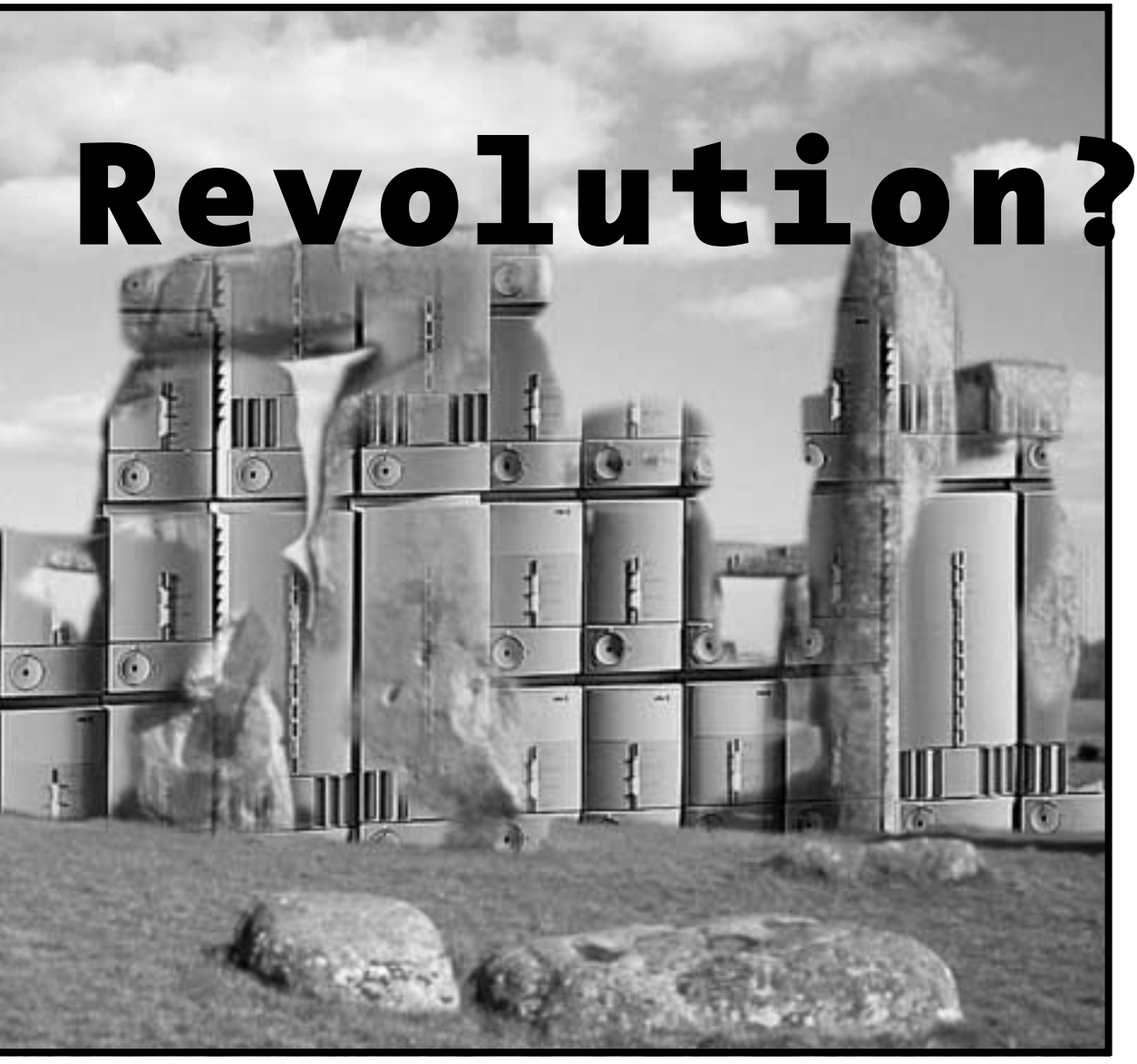

labels seem vulnerable to misinterpretation and focus attention in the wrong direction. The term "network economy" is too narrow. "New economy" is too broad; it can carry anything anybody wants to put into it. The term "e-conomy" centers on the idea that today's shift is driven by the development and diffusion of information technology. The e-conomy is a structural shift, bringing transformation and disruption. But it is not about soft macroeconomic landings, smooth growth, permanently rising stock prices, government budget surpluses, or permanently low rates of unemployment, interest and inflation.

What, then, is the e-conomy about? There are eras when advancing technology and changing organizations transform not just one production sector but the whole economy and the society on which it rests. Such

moments are rare. But we may well living in the middle of one driven by information technology.

THE TECHNOLOGICAL TSUNAMI: MOORE'S LAW

Back in 1965, Gordon Moore, the founder of the Intel Corporation, projected that the density of transistors – electronic switches – on a silicon chip would double every 12 months. He was somewhat overoptimistic: transistor density has been doubling every 18 months. But his forecast of the pace of technological improvement, immortalized as Moore's Law, was largely correct. The astounding growth of productivity in the design and manufacture of integrated circuits underpins modern computing and communications.

Information processing power grows along with transistor density. Today's computers deliver 66,000 times more power per dollar spent than the computers of 1975 did. And the best guess now is that Moore's Law has another ten years to run along its present technological trajectory before reaching limits dictated by physics or cost. Hence computers in 2010 are likely to have ten million times the processing power of circa-1975 computers.

How does the information-processing revolution compare to previous waves of innovation? Contrast the past 40 years of progress in information technology with another technical leap, the replacement of the steam engine with the electric motor. In 1869, America's steam engines produced 1.2 million horsepower for manufacturing. By 1939, electric motors were delivering 45 million horsepower. This was roughly a fortyfold increase in 70 years – a 5 percent annual increase in mechanical muscle.

At the end of the 1950's, there were roughly 2,000 computers up and running in the world – machines like Remington Rand Univacs, IBM 650's and 702's, and DEC PDP-1's, with processing power averaging perhaps 10,000 instructions per second. Forty years later, there are approximately 200 million computers in use worldwide, with processing power that averages approximately 100 million instructions per second. That is a millionfold increase in 40 years – a 35 percent per year increase in information-processing power. Meanwhile, labor productivity growth in all non-farm businesses was not especially impressive in the 1990's, increasing only 1.6 percent annually.

But the price of computing power has fallen by 99.99 percent in a single generation, and the price of semiconductors has fallen even faster. By no coincidence, the productivity performance of the industries that produce information technology goods – semiconductors, fiber optics, and so forth – has been astonishing. In this one sector, labor productivity has been rising at nearly 25 percent per year.

THE TECHNOLOGICAL TSUNAMI: THE NETWORK

Back in the early days of networking – the 1960's and 1970's – it was thought that high-speed data communications would require special data-friendly phone lines. POTS – plain old telephone service – would be capable of carrying data transmissions at 300 bits per second or, if we were lucky, a turbocharged 2,400 bits per second. Hardly any-

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one dreamed of the 40,000-plus bits per second typically achieved by the latest generation of computer modems.

The wave of innovation in data communications has allowed the rapid creation of the worldwide data network on top of the existing phone network. To put it another way, technology made it possible to leapfrog the decades that would normally have been needed to wear out the hundreds of billions of dollars' worth of telephone lines in place – the time it would otherwise have taken to rewire the United States for the Internet. Today the United States houses one computer connected to the Internet for every 15 citizens. And more than 60 million computers are now linked to the Net worldwide.

The best is yet to come. At least half the phone lines in the country are capable of handling high-speed DSL service, permitting perhaps another fiftyfold increase in data transmission capacity. Approximately three-quarters of the households that are not close enough to telephone switching offices to get DSL service are potential customers for cable modems – high-speed links using existing cable television wiring.

Whether the first generation of high-bandwidth connections will be cable modem, DSL, or wireless connections will be decided by a market heavily influenced by regulation. But the connections will arrive quickly. And still higher-bandwidth connections are on the horizon. Kim Maxwell, the author of *Residential Broadband: The Battle for the Last Mile*, forecasts video-on-demand beginning in 2003 and fiber-optic cable to the home starting around 2015.

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Internet Service Provider? What's that?

JUST A LEADING SECTOR?

Nothing that we have said so far is the story of an e-conomy. Indeed, it looks more like the standard story of a leading sector – explosive innovation in a corner of the economy that revolutionizes productivity in a narrow range of goods and services. There have been many such leading sectors in the past – air transport in the 1960's, television in the 1950's, automobiles in the 1920's, organic chemicals in the 1890's, railroads in the 1870's. They did not change the standard dynamic of economic growth: they were the standard dynamic of growth. So what, if anything, is different this time?

TOOLS AND GADGETS

One way to think about that question is to draw a distinction between "gadgets" that

make life easier or industry more productive but that can be slotted into the existing industrial organization, and more profound shifts we call "tools." The automatic transmission, for example, is a gadget: it allows you to tune the radio or to talk on the phone while driving, even if you are a klutz with a gearshift and clutch. But a car with an automatic transmission still does what a car does.

By contrast, the electric motor is a tool. Among other things, it made the modern assembly line possible. Factory floors no longer had to be arranged to allow each machine to be connected to the network of belts and shafts that transferred energy from a central steam engine. Paul David, an economic historian at Stanford, notes that it took 40 years for industry to figure out how to reorganize itself to take advantage of the decentralizing potential of electric motors. We call that reconfigured system mass production. And the long-run consequences – industrial, organizational, social – were enormous.

So are the revolutionary improvements in computer and communications technology gadgets? Do they merely allow us to add prettier graphs to reports and learn about the weather without waiting until 25 minutes past the hour? Or are they tools that fundamentally change industrial organization?

We think there is a chance – a very good chance – that 100 years from now, people will look back at the current wave of innovation and conclude the latter. The tools of the Industrial Revolution amplified muscle power: you didn't have to rely on a human or a horse anymore. The tools being forged today amplify the power to acquire and analyze information: you no longer have to rely on human memory or human eyes to manage the task.

Thus, it could be a very big tool, indeed. But even if it is a monster, there is no guarantee that we will do a good job of nurturing the industrial, organizational, and social transformations needed to take full advantage of its potential.

AN ANALOGY: THE GILDED AGE

Consider the coming of the large corporations to late-19th-century America. It needed more than the improvements in production technology to make large-scale industrial organization possible. Indeed, with hindsight, it apparently required five things:

- Limited legal liability for corporations.
- Liquid markets for trading of fractional ownership shares.
- Investment bankers to serve as intermediaries for capital markets.
- The federalization of regulation to insure free interstate commerce.
- An antitrust policy with some teeth.

The legal and institutional changes – limited liability, liquid markets and investment banking – made it possible to assemble the capital to build factories on the scale to serve a continental market. Political changes – antitrust policy – insured that the enormous economies within the grasp of the large corporation were not achieved at the price of replacing competition with monopoly. And centralization of the regulation of commerce allowed the new corporations to serve all the states.

Think of Swift and Armour. Their businesses were based on the idea of slaughtering beef in Chicago, shipping it dressed to, say, Boston, and undercutting the prices charged by small-scale local slaughterhouses by a third. This was a very good business plan. It promised large profits for investors and a better deal for carnivores.

But what if the Massachusetts Legislature had required that all meat sold in Massa-

When trustbusting was fun.

THOMAS NAST/ARCHIVE PHOTOS

chusetts be inspected on the hoof in the state? Swift's and Armour's businesses could not have existed. Without the right system of governance – in this case, the federal pre-emption of health and safety regulations affecting interstate commerce – you would never have seen the rise of America's efficient mass production of meat.

By contrast, Europe was Balkanized by national tariffs: without a continent-spanning market, fewer economies of scale were attainable. In Britain, with next to no development of investment banking prior to World War I, you didn't get assembly of the pools of capital needed to build large factories. British businesses stayed smaller – and much less efficient – than their American counterparts.

In Germany, with no antitrust policy worthy of the name, there was no brake on the cartelization of modern industry. Theories that German industrial cartels poisoned Germany's politics in the first half of the 20th century are now out of favor. But there's no denying that cartel-driven restrictions on output and innovation made Germany a poorer place in economic terms.

Because institutions in the United States changed to support, nurture and manage the coming of mass production and the large-scale business enterprise – and because European institutions did not – America led the world at the start of the 20th century. The United States was, in the words of Leon Trotsky, "the furnace where the future was being forged."

FUMBLING THE FUTURE?

What could truncate the possibilities opened up by new technology? It is possible that the potential productivity change from data-processing and communications technology just isn't as great as we have supposed. Perhaps the most important invention for the distribution of information will turn out to have been television rather than the Internet. Perhaps the most important invention for corporate organization will turn out to have been the filing cabinet. However, we're believers: the evidence is mounting that the information era is all that it's cracked up to be.

Second, we might fail to support the new technologies with the proper "social infrastructure." Consider, again, 19th-century Britain. But this time, compare it to Germany rather than to the United States. Manchester, the heartland of British manufacturing in 1850, showed both the potential and the dangers of the Industrial Revolution. The potential, of course, was the enormous increase in productivity and output. The dangers were found in the slums – for the British govern-

ment was not then investing in the infrastructure needed to keep its rapidly expanding urban population healthy, let alone to provide education for its children.

Few in Manchester noticed that the British government was not building schools for children of workers migrating from the countryside to the jobs in the new factories. Yet it should have been clear even then that industrial technology was becoming increasingly sophisticated and dependent on skilled labor. By the end of the 19th century, the lack of a well-schooled workforce meant that the post-steam-engine technologies of electricity, metallurgy, and chemistry found more fertile ground in Germany. Thus Britain entered the 20th century and its death struggle with German authoritarianism having squandered an initial edge in technology.

RESOURCES

Just as the second industrial revolution displacing steam power required a mechanically literate workforce, so the American economy of the early 21st century will require a computer- and communications-literate workforce. It will need inventors and innovators to push out the envelope of the possible in the use of these technologies. It will need engineers and technicians to staff the industries – and to manage the interfaces between information technology and the rest of the economy. It will need a public with sufficient knowledge to use the great network and its computers productively.

Our educational system does not seem up to the task. One consequence of increasing income inequality in America in the past quarter-century has been a decline in effective political support for public services that are paid for by the rich and used by all. By the same token, we seem indifferent to the possibilities of recruiting talent abroad. As Berkeley faculty members, we look at our students who come from outside the United States and think that America's immigration policy is shortsighted. Your average Berkeley grad is going to be a valuable asset to whatever society he or she lives in, yet America's politicians do not seem to be fighting hard to keep such people.

There are other resource-related questions as well. What is going to keep money flowing to research and development after stock market values return to earth? Who is going to provide the basic research to keep the pipeline of new technologies filled? In the generation and a half after World War II, the Federal government – along with a handful of private institutions like Bell Labs and Xerox PARC – did amazing things to support research and development. But in recent decades that commitment has eroded. What will fill the gap?

RULES

Last but hardly least is the matter of rules – the private and public governance to keep innovation coming. Silicon Valley has turned out to be an enormously fertile industrial ecology for nurturing this techno-economic revolution. How can we make it work better? What must we guard against that could make it work not very well?

The e-conomy is plainly a work in progress, and the rules will have to change along with the game. But creating new rules for a new era will require real choices and decisions, not just casual tinkering. The new circumstances, often involving qualitative changes in business and social life, will force painful changes in the social contract. But anyone who believes that we are on the threshold of an extended period of productivity growth should remember that institutions could make or break the golden age. M