How Important Will the Information Economy Be?: Some Simple Analytics

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How important will the information economy—the sectors and industries that have extremely rapid productivity growth driven by the enormous and ongoing technological revolutions in data processing and data communications—turn out to be? Will this wave of innovation and technological development have consequences similar to the trio of steam power, metal forging, and automatic machinery that powered the original British Industrial Revolution and transformed economies and societies beyond recognition? Or will it turn out to have a much smaller impact on long-run economic growth, as did previous leading sectors like civil aviation, illumination, and chemical engineering—leading sectors that produced astonishing leaps in productivity in their relatively narrow sectors, but that had little long-run influence on the structure of the rest of the economy or the rate of overall productivity growth?

The analytics of the effect of a leading sector on overall productivity growth are simple and straightforward. If total factor productivity growth in the rest of the economy is growing at a rate π_R, and if total factor productivity in the leading industries and sectors is growing at a faster rate π_L, then total factor productivity growth in the economy as a whole will be equal to:

(1) $\pi = \sigma(\pi_L) + (1-\sigma)(\pi_R)$

where σ is the share of total expenditure on the goods produced by the economy's fast-growing technologically-dynamic leading sectors.

As the process of innovation and technological revolution in the leading sectors proceeds, we would not expect the leading sector share σ of total expenditure to remain constant. If the goods produced by the leading sectors are superior (or inferior) goods, the share σ will rise (or fall) as economic growth continues: only if the income elasticity of demand ε_I for its products is one will changes in the overall level of prosperity leave the leading sector share unchanged. If the goods produced by the leading sector have a high (or low) price elasticity of demand, the falls over time in their relative prices will boost (or reduce) the share of total expenditure σ: only if the price elasticity of demand ε_P is one will the fall in the relative price of leading sector products produced by the technological revolutions leave the leading sector share unchanged.

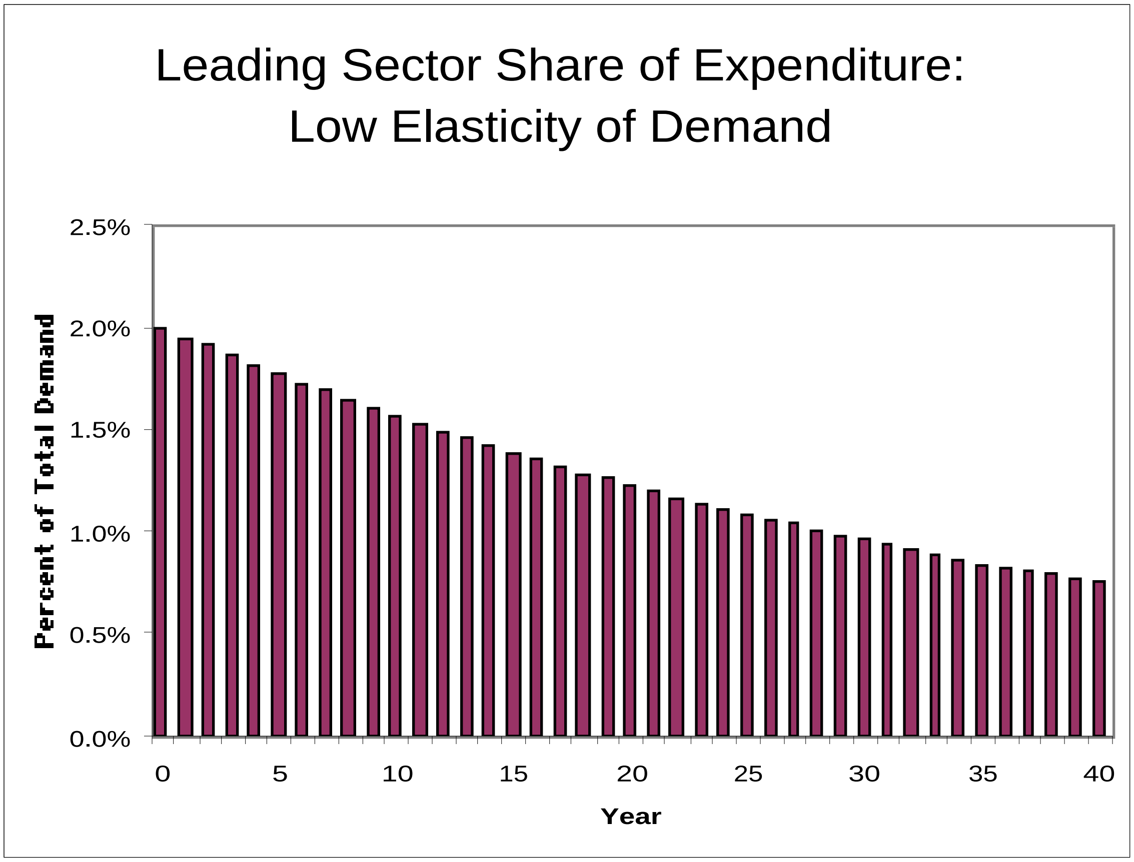
Moreover, the leading sector share of total expenditure σ matters only as long as the leading sector remains technologically dynamic. Once the heroic phase of invention and innovation comes to an end and the rate of total factor productivity growth returns to the economy's normal background level π_R, the rate of productivity growth in the economy as a whole will return to that same level π_R and the leading sector share of expenditure σ will no longer be relevant.

Thus five pieces of information are necessary to assess the aggregate economic impact of an explosion of invention and innovation in a leading sector:

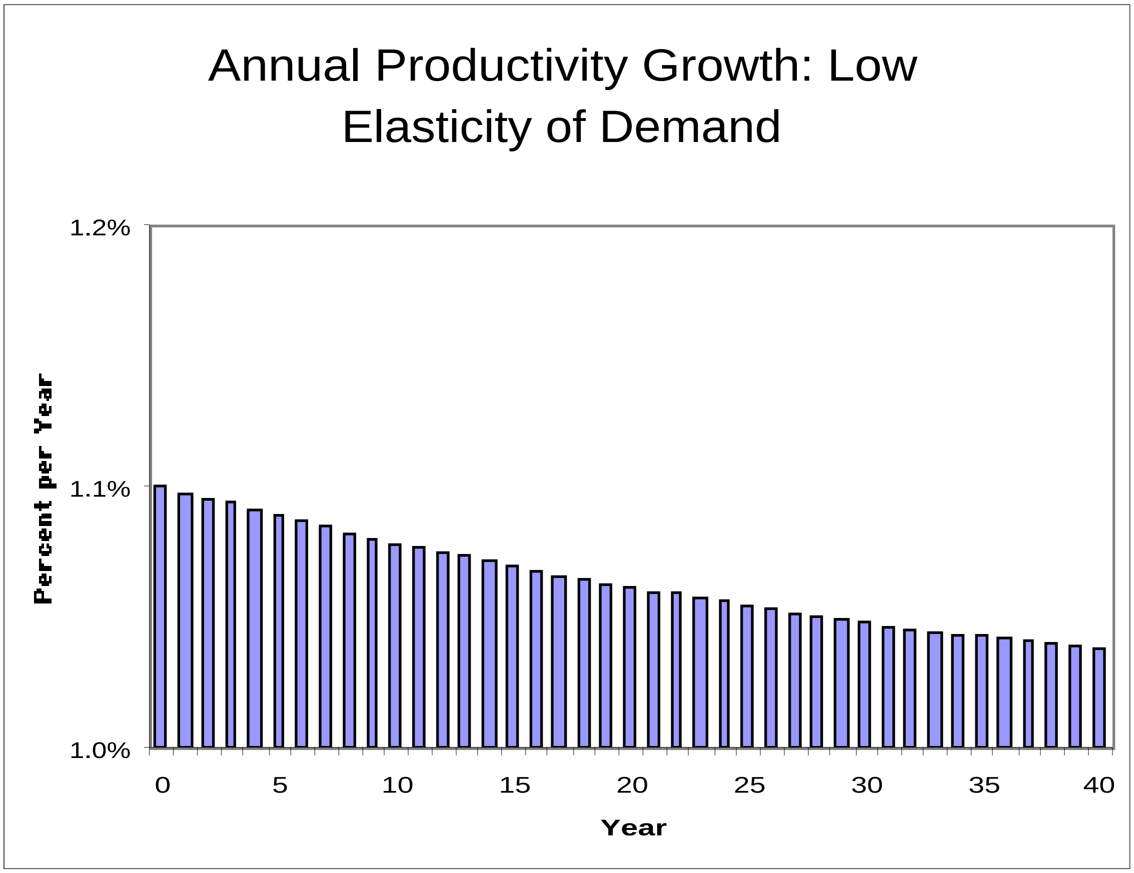
- The initial share of expenditure on the leading sector's products, σ_0.
- The magnitude of the relative pace of cost reduction, $\pi_L - \pi_R$, during the leading sector's heroic age of invention and innovation.
- The duration of the leading sector's heroic age of invention and innovation.
- The income elasticity of demand ε_I for the leading sector's products.
- The price elasticity of demand ε_P for the leading sector's products.

To gain a sense of the importance of these factors, let's consider a few simulations with sample parameter values. For simplicity's sake, set the initial share of expenditure on the leading sector's products σ_0 equal to 0.02, set the income elasticity of demand for the leading sector's products ε_I equal to 1.0, set the heroic age of invention and innovation to a period 40 years long, and set the background level of total factor productivity growth π_R to 0.01 per year, one percent per year. Consider three values for the price elasticity of demand ε_P: 0.5, 2.0, and 4.0. And consider two values for the wedge in the annual rate of technological progress between the leading sector and the rest: 0.03, and 0.05.

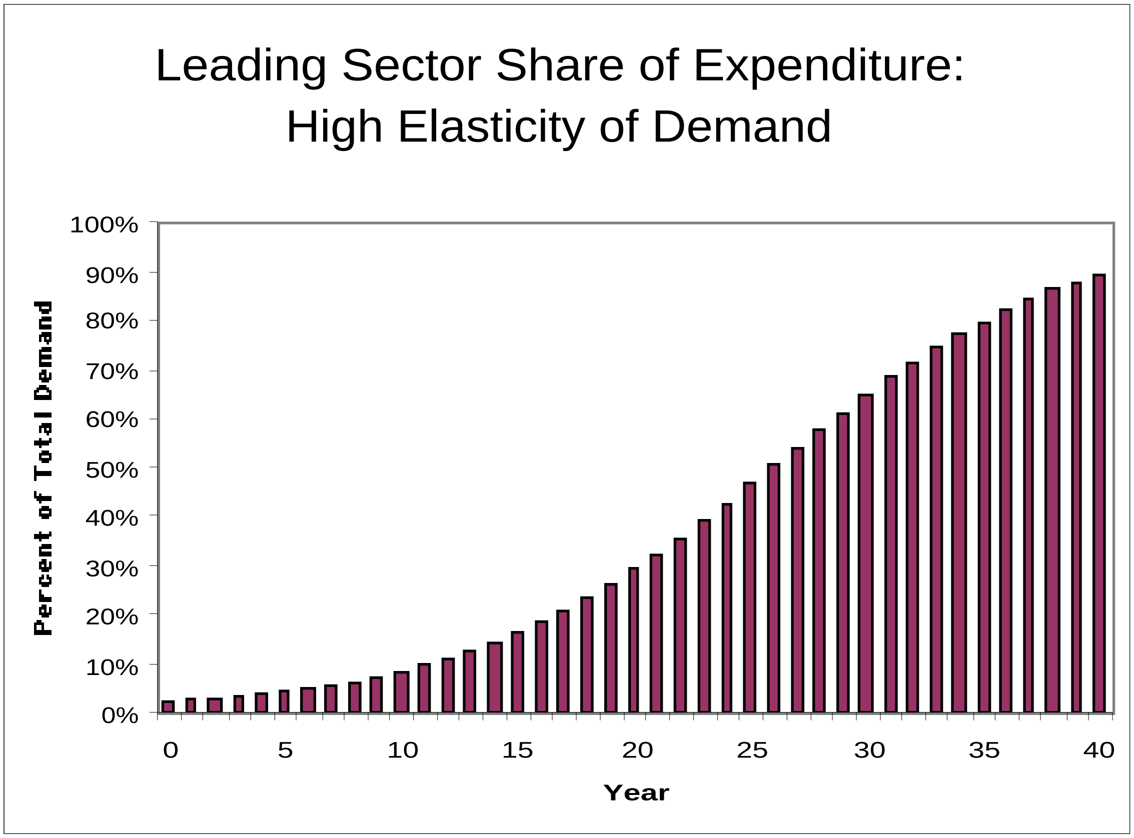
With a price elasticity of demand of 0.5, the expenditure share of the leading sectors declines from its original value of 2% as technology advances and the prices of leading-sector goods fall. With a productivity wedge of 5% per year, the initial rate of growth of economy-wide productivity growth is 1.1% per year—1% from the background growth of the rest of the economy, and an extra one-tenth of a percent from the faster productivity growth in the one-fiftieth of the economy that is the leading sector. By the twelfth year the expenditure share on leading sector products has fallen below 1.5%. By the twenty-eighth year the expenditure share has fallen below 1.0%. By the fortieth year the expenditure share has fallen to 0.7%.



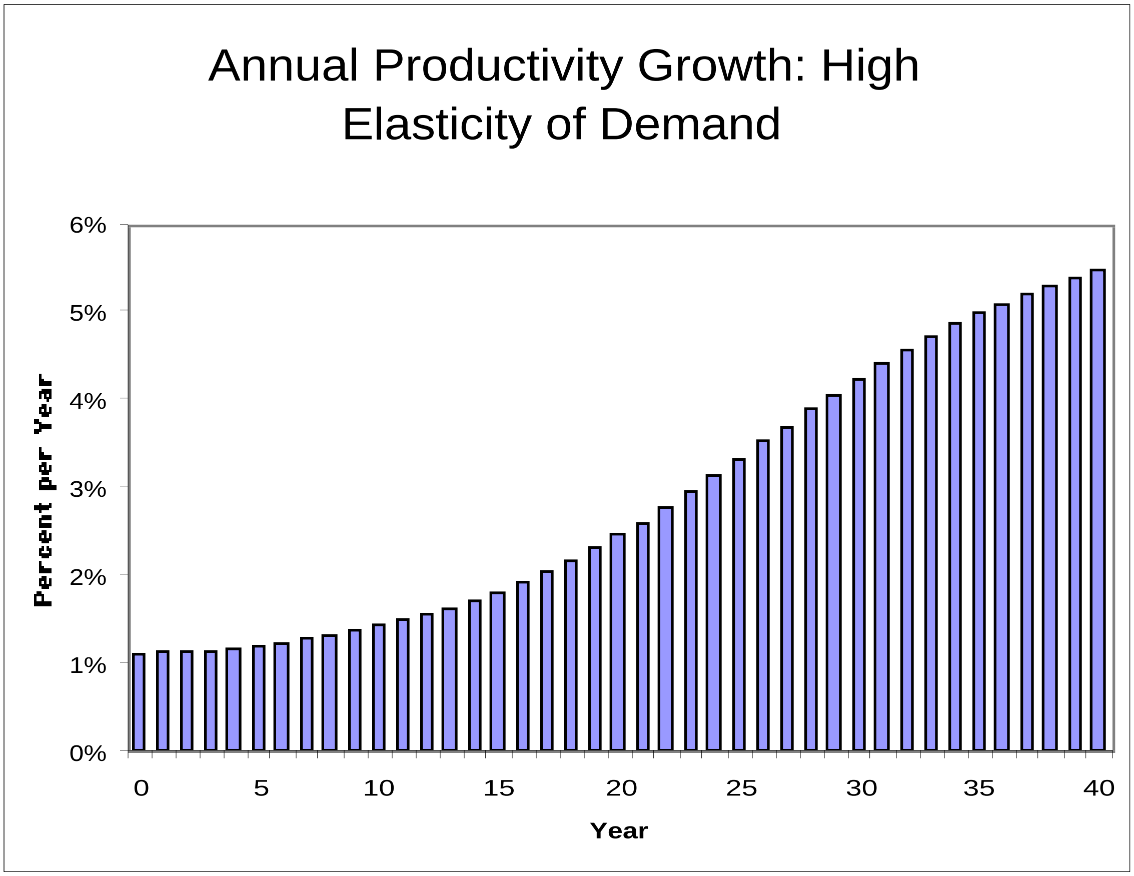
The low initial and declining share of the leading sector in total expenditure means that 40 years of 6% per year productivity growth in the leading sector has only a very limited impact on the total economy. After forty years total productivity in the economy as a whole is only 2.54% higher than had the leading sector not existed at all. Rapid productivity growth in the leading sector has next to no effect on productivity growth in the economy as a whole because the salience of the leading sector falls, and the salience of other sectors resistant to productivity improvement rises as technology advances. This is Baumol and Bowen' (1966) "cost disease" scenario: innovations become less and less important because the innovation-resistant share of the economy rises over time. Indeed, as time passes the rate of aggregate growth converges to the rate of growth in the productivity-resistant rest of the economy.



By contrast, with a price elasticity of 4 the expenditure share of the leading sectors grow rapidly from their original value of 2%. With a productivity growth wedge of 5% per year, the leading sector share of spending surpasses 10% by year 12, 30% by year 20, and reaches 89% by year 40. As the spending share of the leading sectors rise, aggregate productivity growth rises too: from 1.1% per year at the start to 1.4% per year by year 10, 2.4% per year by year 20, 4.2% per year by year 30, and 5.4% per year by year 40. The impact on the aggregate economy is enormous: total factor productivity after 40 years is 113% higher than it would have been had the leading sector never existed.



In these simulations, there is only one reason for the sharp difference in the effects of innovation in the leading sector: the different price elasticities of demand for leading-sector products in the two scenarios. The initial shares of leading sector products in demand, the rate of technology improvement in the leading sector, and the duration of the technology boom are all the same. But when demand for leading sector products is price-elastic, each advance in technology and reduction in the leading sector's costs raises the salience of the leading sector in the economy and thus brings the proportional rate of growth of the aggregate economy closer to the rate of growth in the leading sector itself. By the end of the 40 year period of these simulations, the scenario with the price elasticity of 4 has seen the leading sectors practically take over the economy, and dominate demand. This is the "economic revolution" scenario: not only does productivity growth accelerate substantially and material welfare increase, but the structure of the economy is transformed as the bulk of the labor force shifts into producing leading-sector products and the bulk of final demand shifts into consuming leading-sector products.



What determines whether demand for a leading sector's products is price-inelastic—in which case we are in Baumol and Bowen's "cost disease" scenario in which technological progress in the leading sector barely affects the aggregate economy at all—or price-elastic—in which case we are in the "economic revolution" scenario, and everything is transformed? What determines the income and price elasticities of demand for the high-tech goods that are the products of our current leading sectors?

The more are high-tech products seen as "luxury" goods, and the greater is the number of different uses found for high-tech products as their prices decline, the larger will be the income and price elasticities of demand--and thus the stronger will be the forces pushing the expenditure share up, not down, as technological advance continues.

Modern silicon and fiber-based electronics technologies may well fit Bresnahan and Trajtenberg's (1995) definition of a "general purpose technology"--one useful not just for one narrow class but for an extremely wide variety of production processes, one for which each decline in price appears to bring forth new uses, one that can spark off a long-lasting major economic transformation. Such general purpose technologies are, as Bresnahan and Trajtenberg say, “engines of growth”: precisely because they have a wide range of potential uses, and are complementary to a large proportion of other inputs, their price elasticity of demand is likely to be high.

The possibility of the demand-side externalities called “network effects”—Metcalfe’s law, the idea that the value of any network is proportional to the square of the number of connected nodes—raises the likely elasticity of demand still further. (However, offsetting the point that value is proportional to the square of the size of the network is the point that the most valuable nodes are likely to be connected to the network first—a point that Paul Krugman (2000) has made and called “DeLong’s law.”)

The wide potential domain of use of information technology is one sign that it is truly a high-elasticity general purpose technology. Selling plastic doghouses in warehouse stores in middle America is not usually thought of as a high-tech enterprise. Yet Wal-Mart’s extraordinary efficiency advantage over other retailers in the 1980s and 1990s can be credited in large part to its early investments in modern information technology, and to careful thought and skilled execution of how modern information technology can achieve economies of distribution. As Wal-Mart founder Sam Walton (1992) wrote in his autobiography:

> Nowadays, I see management articles about information sharing as a new source of power in corporations. We've been doing this from the days when we only had a handful of stores. Back then, we believed in showing a store manager every single number relating to his store, and eventually we began sharing those numbers with the department heads in our stores. We've kept doing it as we've grown. That's why we've spent hundreds of millions of dollars on computers and satellites--to spread all the little details around the company as fast as possible. But they were worth the cost. It's only because of information technology that our store managers have a really clear sense of what they're doing most of the time.

In addition, the history of the electronics sector suggests that the income and price elasticities tend to be high, not low. Each successive generation of falling prices for computers, switches, and cables has produced radically new uses for computers and communications equipment.

The first, very expensive, computers were seen as good at performing complicated and lengthy sets of arithmetic operations. The first leading-edge applications of large-scale electronic computing power were military: the burst of innovation during World War II that produced the first one-of-a-kind hand-tooled electronic computers was totally funded by the war effort. The coming of the Korean War won IBM its first contract to actually deliver a computer: the million-dollar Defense Calculator. The military demand in the 1950s and the 1960s by projects such as Whirlwind and SAGE [Semi Automatic Ground Environment]--a strategic air defense system--both filled the assembly lines of computer manufacturers and trained the generation of engineers that designed and built.

The first leading-edge civilian economic applications of large--for the time, the 1950s--amounts of computer power came from government agencies like the Census and from industries like insurance and finance which performed lengthy sets of calculations as they processed large amounts of paper. The first UNIVAC computer was bought by the Census Bureau. The second and third orders came from A.C. Nielson Market Research and the Prudential Insurance Company. This second, slightly cheaper, generation was of computers was used not to make sophisticated calculations, but to make the extremely simple calculations needed by the Census, and by the human resource departments of large corporations. The Census Bureau used computers to replace their electro-mechanical tabulating machines. Businesses used computers to do the payroll, report-generating, and record-analyzing tasks that their own electro-mechanical calculators had previously performed.

The still next generation of computers--exemplified by the IBM 360 series--were used to stuff data into and pull data out of databases in real time--airline reservations processing systems, insurance systems, inventory control. It became clear that the computer was good for much more than performing repetitive calculations at high speed. The computer was much more than a calculator, however large and however fast. It was also an organizer. American Airlines used computers to create its SABRE automated reservations system, which cost as much as ten airplanes (see Cohen, Delong, and

Zysman (2000)). The insurance industry automated its back office sorting and classifying.

Subsequent uses have included computer-aided product design, applied to everything from airplanes designed without wind-tunnels to pharmaceuticals designed at the molecular level for particular applications. In this area and in other applications, the major function of the computer is not as a calculator, a tabulator, or a database manager, but is instead as a what-if machine. The computer creates models of what-if: would happen if the airplane, the molecule, the business, or the document were to be built up in a particular way. It thus enables an amount and a degree of experimentation in the virtual world that would be prohibitively expensive in resources and time in the real world.

The value of this use as a what-if machine took most computer scientists and computer manufacturers by surprise. None of the engineers designing softare for the IBM 360 series, none of the parents of Berkeley UNIX, nobody before Dan Bricklin programmed Visicalc had any idea of the utility of a spreadsheet program. Yet the invention of the spreadsheet marked the spread of computers into the office as a what-if machine. Indeed, the computerization of Americas white-collar offices in the 1980s was largely driven by the spreadsheet program's utility--first Visicalc, then Lotus 1-2-3, and finally Microsoft Excel.

For one example of the importance of a computer as a what-if machine, consider that today's complex designs for new semiconductors would be simply impossible without automated design tools. The process has come full circle. Progress in computing depends upon Moore's law; and the progress in semiconductors that makes possible the continued march of Moore's law depends upon progress in computers and software.

As increasing computer power has enabled their use in real-time control, the domain has expanded further as lead users have figured out new applications. Production and distribution processes have been and are being transformed. Moreover, it is not just robotic auto painting or assembly that have become possible, but scanner-based retail quick-turn supply chains and robot-guided hip surgery as well.

In the most recent years the evolution of the computer and its uses has continued. It has branched along two quite different paths. First, computers have burrowed inside conventional products as they have become embedded systems. Second, computers have connected outside to create what we call the world wide web: a distributed global database of information all accessible through the single global network. Paralleling the revolution in data processing capacity has been a similar revolution in data communications capacity. There is no sign that the domain of potential uses has been exhausted. So far there are no good reasons to believe that the economic salience of high-tech industries are about to decline, or that the pace at which innovation continues is about to flag.

There is room for computerization to grow on the intensive margin, as computer use saturates potential markets like office work and email. But there is also room to grow on the extensive margin, as microprocessors are used for tasks like controlling hotel room doors or changing the burn mix of a household furnace that few, two decades ago, would ever have thought of.

Thus the balance of probabilities is that the elasticity of demand for the products of our current high-tech computer and communications leading sectors is high, not low. Because of the general purpose nature of the technology, it has an enormous number of potential uses, many of which have not yet been developed. The way to bet is that our new economy will have not a limited but an enormous impact on how we live.

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