G000205

# general purpose technologies

Economists have come to use the term 'general purpose technology' (GPT) to describe technological advances that pervade many sectors, improve rapidly, and spawn further innovations. This article addresses the concept of a GPT by example, showing the extent to which electricity and information technology might qualify as members of this special class of inventions, as opposed to more ordinary ones.

Economists have long been interested in how technological change affects long-run growth and aggregate fluctuations, yet it remains most often treated as incremental in nature, adding only a trend to standard growth models. History tells us, however, that such change can appear in bursts, with flurries of innovative activity following the introduction of a new core technology. This observation leads economists to reserve the term 'general-purpose technology' (GPT) to describe fundamental advances that drive these flurries, which in turn transform both household life and the ways in which firms conduct business. Over the past 200 years or so, steam, electricity, internal combustion, and information technology (IT) seem to have served as GPT-type technologies. They affected entire economies. Earlier, the very ability to communicate in writing and later to disseminate written information via the printed page also appears to fit well into the idea of a GPT.

The notions that GPTs differ from the more incremental refinements that occur in between their arrivals and that they represent real-side shocks that permanently change the nature of production and preferences provide the basis of a potentially useful way to organize thinking about long-run economic fluctuations and growth. But to support such a view with anything more than casual observation, it is necessary to establish criteria for determining just what features a technology must possess in order to be a GPT rather than a more ordinary invention. This article defines GPTs in terms of a number of tangible criteria, and then uses two candidate GPTs, electrification and IT, to demonstrate how identification of a GPT might proceed. Attention then turns to other indicators that may signal the start of a GPT era.

## Dating a GPT's arrival

Associating a point in time with a GPT's 'arrival' depends on what exactly one means by this term. If defined with a measure such as, in the case of electrification, attaining a one per cent share of horsepower in the manufacturing sector, then some time around 1895 might be appropriate. This coincides roughly with the start-up of the world's first large scale hydroelectric power facility at Niagara Falls, New York, in 1894. It would be reasonable to argue, however, that electricity arrived earlier, perhaps in 1882 when Thomas Edison brought the first centralized electricity system online at the Pearl Street station in lower Manhattan. For IT, it is true that mainframe computers had existed for two decades before the invention of the 4004 chip in 1971, and had even been used to project the winner of the 1952 US presidential election. Yet, if measured by the attainment of a one per cent share in the industrial sector's stock of equipment, 1971 remains the most likely candidate for dating IT's 'arrival'.

Whether electricity and IT arrived in 1895 and 1971, respectively, or some time prior to these dates, one characteristic noted by David (1991) is that neither delivered productivity gains immediately. Indeed, productivity growth as measured by output per man-hour seems to have been relatively high in the 1870s, when steam was the dominant power source for industry, but fell as electrification arrived in the 1880s and 1890s. It was only in the period after 1915, which also saw the diffusion of secondary motors and the widespread establishment of centralized power distribution systems, that measured productivity numbers began to rise. (This can be seen in the series for output per man-hour in the non-farm business sector from US Census Bureau, 1975, Series D684, p. 162.) Further, Intel's 1971 invention of the 4004 microprocessor (the key component in the first generation of personal computers), if taken to be the start of the IT era, did not reverse the decline in productivity growth that had begun more than a decade earlier.

## Identification of a new core technology as a GPT

Once the arrival date of a new technology has been established, identification of that technology as a GPT can proceed by considering characteristics associated with its diffusion. One set of criteria, proposed by Bresnahan and Trajtenberg (1995), suggests that a GPT should have the following three characteristics:

1. *Pervasiveness:* the GPT should spread to most sectors.
2. *Improvement:* the GPT should get better over time and, hence, should keep lowering the costs of its users.
3. *Innovation spawning:* the GPT should make it easier to invent and produce new products or processes.

Most technologies possess each of these characteristics to some degree, and therefore a GPT cannot differ qualitatively from them. But the extent to which technologies have all three characteristics should determine which ones are likely to be GPTs.

For example, both electrification and IT were pervasive, and so might qualify as GPTs under the first criterion, yet had quite different absorption paths across sectors. Figure 1 shows the shares of total horsepower electrified in manufacturing sectors at ten-year intervals from 1889 to 1954 in percentile form, with the shaded area highlighting the period of electricity's most rapid diffusion. Figure 2 shows the spread of IT, measured as the share of IT equipment in the capital stock at the two-digit standard industry classification level. The striking difference between the two figures is that electricity diffused uniformly across sectors while the adoption of IT was not as widespread. On this count, then, electricity would be the stronger GPT candidate.

Presumably, the second characteristic – improvement – would show up in a decline in prices associated with the technology, an increase in quality, or both. How much a GPT improves can therefore be measured by how much cheaper a unit of quality gets over time. If the new technology is embodied in capital and begins to account for an increasing share of the net capital stock, capital should on the whole be getting cheaper faster during a GPT era, but especially capital that is tied to the new technology.

Figure 3 plots the price of the components of the aggregate capital stock tied to the two GPTs. Because deflators for electrically powered capital are not available in the first half of the 20th century, the figure compares the declines in relative price of electricity itself with the quality-adjusted price of computers, both relative to the consumption price index. The use of the left-

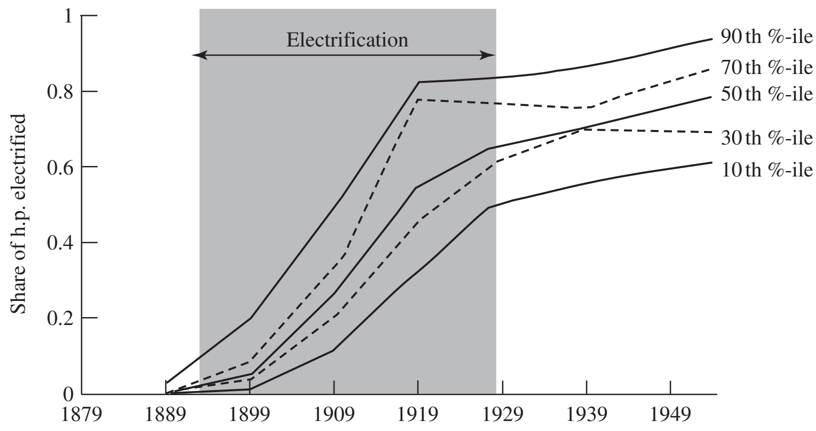


Figure 1 Shares of electrified horsepower by manufacturing sector in percentiles, 1890–1954. *Source*: DuBoff (1964, Tables E-ll and E-12–12e).

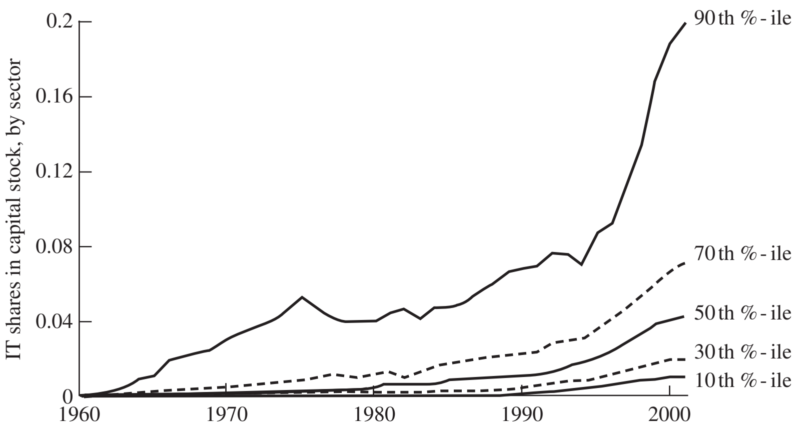


Figure 2 Shares of IT equipment and software in the capital stock by sector in percentiles, 1960–2001. *Source*: Detailed non-residential fixed asset tables in fixed 1996 dollars made available by the US Bureau of Economic Analysis (2004).

hand scale for electricity and the right-hand scale for computers underscores the extraordinary decline in computer prices since 1960 relative to electricity. While electricity prices fall by a factor of 10, the computer price index falls by a factor of 10,000!

It can be said that the electricity index, being the price of a kilowatt hour, understates the accompanying technological change because it does not account for improvements in electrical equipment, and especially improvements in the efficiency of electrical motors. Based on the price evidence in Figure 3, however, both electricity and computers might qualify as GPTs, with computers clearly more revolutionary.

With respect to the ability to generate further innovation, it is reasonable to assume that any GPT will affect all sorts of production processes, including those for invention and innovation. Some GPTs will be biased towards helping to produce existing products, others towards inventing and implementing new ones. Electricity and IT have both helped reduce the costs of making existing products, and they both spawn innovation. The 1920s especially saw a wave a new products powered by electricity, and the com-

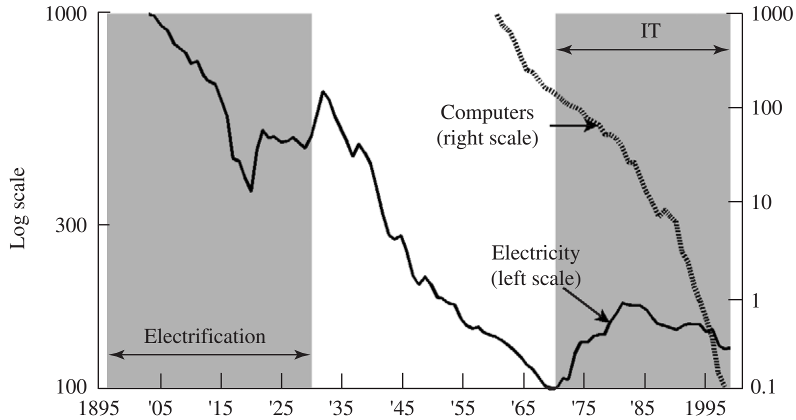


Figure 3 Price indices for products of two 'GPT eras', 1895–2000. *Sources*: The quality-adjusted price index for IT is formed by joining the 'final' price index for computer systems from Gordon (1990, Table 6.10, col. 5, p. 226) for 1960–78 with the pooled index developed for desktop and mobile personal computers by Berndt, Dulberger and Rappaport (2000, Table 2, col. 1, p. 22) for 1979–99. Electricity prices are averages of all electric energy services in cents per kilowatt hour from US Census Bureau (1975, series S119, p. 827) for 1903, 1907, 1917, 1922, and 1926–70, and from the US Census Bureau, *Statistical Abstract of the United States*, for 1971–89. For 1990–2000, prices are US city averages (June figures) from the US Bureau of Labor Statistics. Both indices are set to 1000 in the first years of the samples (that is, 1903 and 1960).

puter is now embodied in many new products as well. But the evidence suggests that IT has contributed more to furthering innovation.

In particular, patenting should be more intense after a GPT arrives and while it is spreading due to the introduction of related new products. US patent data confirm this, showing two surges in the annual number of invention patents issued per capita from 1890 to 2000 – one between 1900 and 1930, and the other after 1977. At the same time, the surge during the IT period was stronger than that observed during electrification. Interestingly, the slow rate of patenting during the Second World War years and the acceleration immediately thereafter suggests that there is some degree of intertemporal substitution in the release of new ideas away from times when they might be more difficult to popularize and towards times better suited for the entry of new products.

Of course, patent data may reflect fluctuations in the number of actual inventions or may simply reflect changes in the law that raise the propensity to patent. The distinction is important because, over longer periods of time, patents may reflect policy rather than invention. Kortum and Lerner (1998) analyse this question and find that the surge of the 1990s was worldwide, but not systematically related to country-specific policy changes, and they conclude that technology was the cause of the surge.

## Other characteristics of GPTs

In addition to the three basic qualities of a GPT, there are other, less direct signals implied by various theoretical models that deal with GPTs. These models predict the following:

1. *New ideas should come to market faster*. If a new technology has the potential for large productivity gains, firms will spend less time perfecting ideas associated with the new technology in order to realize the gains sooner (see, for example, Jovanovic and Rousseau, 2001).
2. *Entry, exit and mergers should rise*. New technologies may require some relocation of assets from firms that are unable to adopt them effectively to others with managements better equipped for their deployment (see, or example, Jovanovic and Rousseau, 2002).
3. *Young and small firms should do better*. The ideas and products associated with the GPT will often be brought to market by new firms. The market share and market value of young firms should therefore rise relative to old firms.
4. *Stock prices should initially fall*. The value of old capital should fall in anticipation of the new and more productive technology. How fast it falls depends on the way that the market learns of the GPT's arrival (see, for example, Hobijn and Jovanovic, 2001).
5. *Interest rates and the trade deficit should be affected*. The rise in desired consumption relative to output should cause interest rates to rise or the trade balance to worsen.
6. *The skill premium should rise*. If the GPT is not user-friendly at first, skilled people will be in greater demand when the new technology arrives, and their earnings should rise compared with those of the unskilled.

The available evidence suggests that predictions 1–3 hold for both the electrification and IT eras, but that a stock market decline (4) occurred only at the start of the IT period. Interest rates (5) rose in both eras, but the electrification period was associated with a trade surplus due to the First World War. It also appears that the skill premium (6) has risen over the IT period, but evidence of a rise in the electrification era is weaker.

To sum up, based upon the criteria chosen and the available evidence, both electricity and IT were pervasive, improving, and innovation-spawning, and thus seem to qualify as GPTs. At the same time, electricity was more pervasive, affecting sectors faster and more evenly than IT, while IT improved more dramatically, with computer prices falling more than 100 times faster than the price of electricity. IT also seems to have generated more innovation than electricity, and the initial productivity slowdown was also deeper in the IT era. All this would lead one to regard IT as the more 'revolutionary' GPT.

This is not to say that the differences between electrification and IT, or indeed between any two candidate GPTs, are unimportant. At the same time, the GPT paradigm emphasizes the commonalities, namely, that technological progress is uneven, that it does entail the episodic arrival of new core technologies, and that these GPTs bring on turbulence and lower growth early on and higher growth and prosperity later. Interestingly, the IT era has already outlasted that of electrification, but even six decades after what Field (2003) has called the 'most technologically progressive decade of the century' (that is, the 1930s), electricity has yet to become obsolete. Given the multitude of firms and households that have not quite yet adopted IT, its continuing price decline and the widespread increases in computer literacy among children and adults worldwide suggest that perhaps the most productive period of this GPT still lies ahead.

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## See also

<xref=D000122> diffusion of technology;
<xref=E000242> electricity markets;
<xref=I000275> information technology and economic growth;
<xref=xyyyyyy> technical change.

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## Index terms

diffusion of technology
electricity
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growth, models of
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innovation

intertemporal substitution
patents
productivity growth
skill premium
technical change

## Index terms not found:

diffusion of technology
growth, models of
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