UNIVERSITY OF OXFORD

Discussion Papers in Economic and Social History

Number 31, September 1999

GENERAL PURPOSE TECHNOLOGIES AND SURGES IN PRODUCTIVITY: HISTORICAL REFLECTIONS ON THE FUTURE OF THE ICT REVOLUTION

PAUL A. DAVID AND GAVIN WRIGHT

Abstract

The phenomenon of recurring prolonged swings in the total factor productivity (TFP) growth rate is approached in this paper by examining a particular episode in earlier twentieth century economic history. A marked acceleration of productivity growth in U.S. manufacturing occurred after World War I, and was the main driver of the absolute and relative rise of the private domestic economy's TFP residual. This discontinuity reflected the elaboration and adoption of a new factory regime based upon the electric dynamo, a general purpose technology (GPT) that brought significant fixed-capital savings while simultaneously raising labor productivity in a wide array of manufacturing operations. But, rather than offering a purely technological explanation of the productivity surge of the 1920s, a more complex conceptualization of the dynamics of GPT diffusion is proposed. This highlights both the generic and the differentiating aspects of U.S. industrial electrification in comparison with that of the contemporary UK. Explicit historical contextualization of the GPT concept also sheds further light on the puzzling late twentieth century productivity slowdown, and it points to some contemporary portents of a future phase of more rapid total factor productivity growth.

General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution

by

Paul A. David and Gavin Wright
All Souls College & Stanford University

Presented to the Symposium on

ECONOMIC CHALLENGES OF THE 21ST CENTURY
IN HISTORICAL PERSPECTIVE

Oxford, England, 2nd-4th July, 1999

Celebrating the Scholarly Career of Charles H. Feinstein, FBA

Contact Authors: P. A. David <paul.david@economics.ox.ac.uk>
G. Wright <write@leland.stanford.edu>

HISTORICAL REFLECTIONS ON THE FUTURE OF THE ICT REVOLUTION

In this essay we reflect on the relevance of early twentieth century experience for understanding the more general phenomenon of recurring prolonged swings in the TFP growth rate in advanced industrial economies. Our discussion builds upon our recent re-examination of the marked acceleration of the pace of total factor productivity growth that occurred in U.S. manufacturing following World War I (David and Wright 1999). After a 'productivity pause' of some three decades, during which gross manufacturing output grew at less than one percent per annum relative to inputs of capital and labor, TFP in this sector expanded at more than five percent per annum between 1919 and 1929. This remarkable discontinuity has often been overlooked by modern productivity analysts and economic historians alike; yet it contributed substantially to the absolute and relative rise of the US domestic economy's TFP residual, and in many respects launched the high-growth era that persisted into the 1970s.

Upon closer scrutiny, this implied shift in the prevailing technological regime can be traced to critical advances in the electrification of industry, which we interpret as a phase in the diffusion of a general purpose technology (GPT) that made possible significant fixed-capital savings while simultaneously increasing labor productivity as well. But a purely technological explanation of the productivity surge is inadequate. It would neglect the concurrence of these developments with important structural changes in US labor markets, and the interrelationships that appear between managerial and organizational innovations and the new dynamo-based factory technology, on the one hand, and between both forms of innovation and the macroeconomic conditions of the 1920s on the other hand. We explore this more complex formulation of the dynamics of GPT diffusion by considering the generic and the differentiating aspects of the US experience with industrial electrification in comparison with that of the UK. The cross-national perspective brings to light some differences between leader and follower economies in the dynamics of GPT diffusion and its relationship to the strength of surges in productivity growth. It also serves to underscore the important role of the institutional and policy context with respect to the potential for upgrading the quality of the workforce in the immediately affected branches of industry.

The concluding sections of the essay offer some reflections on the analogies and contrasts between the modern experience of the information and communications technology (ICT) revolution, and the historical case of a socio-economic regime transition involving the electric dynamo. Contextualizing the GPT concept in explicitly historical terms enables us to shed further light upon the paradoxical phenomenon of the late twentieth century productivity slowdown, and also to point to some contemporary portents of a future phase of more rapid total factor productivity growth.

1. A Brief Recapitulation

In his introduction to John Kendrick's (1961) study of productivity trends in the United States, Solomon Fabricant noted (p. xliii):

> A distinct change in trend appeared some time after World War I. By each of our measures, productivity rose, on the average, more rapidly after World War I than before...The change in trend...is one of the most interesting facts before us. There is little question about it. It is visible not only in the indexes that Kendrick has compiled for the private domestic economy....It can be found also in his figures for the whole economy, including government, as well as in his estimates for the groups of industries for which individual productivity indexes are available.

The historical break was heavily though not exclusively concentrated in the manufacturing sector. Kendrick's estimates put the decadal growth of TFP at approximately 22 percent for the whole of the private domestic economy, while the corresponding figure for manufacturing was 76 percent, and for mining 41 percent. TFP growth in transportation, communications and public utilities exceeded the private domestic average by lesser amounts, while the farm sector was in last position with a relatively low gain of 14 percent. At the heart of the story was manufacturing, where the discontinuity was particularly marked (Figure 1).[1]

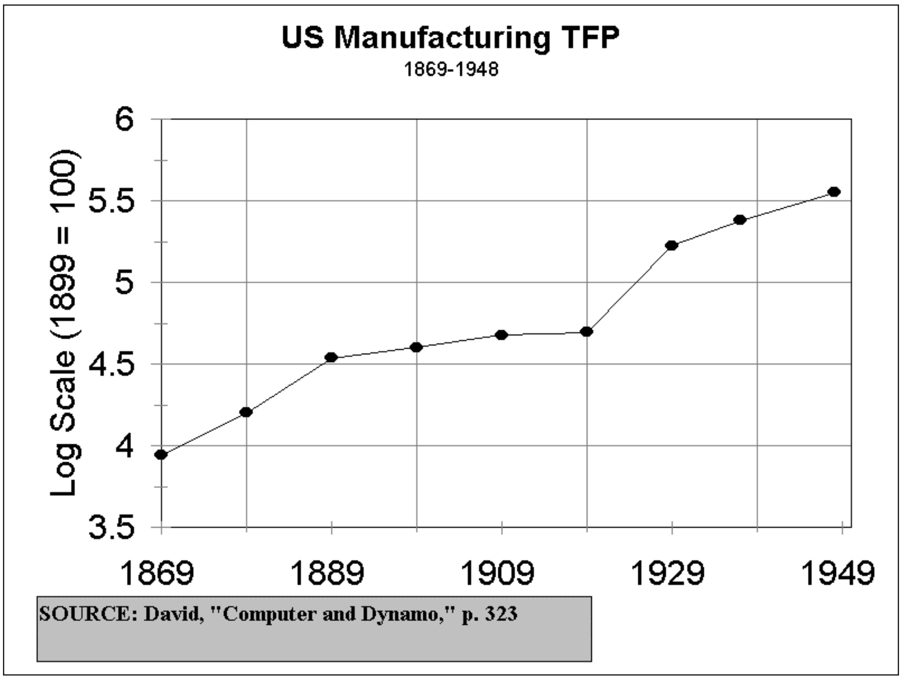

Figure 1

Having pinpointed manufacturing, our analysis proceeded to ask whether the productivity surge of the 1920s was broadly based within that sector, reflecting common forces at work in the economy; or whether instead it was concentrated in small number of rapidly changing industries. The distinction may be illustrated with the terms deployed by Arnold Harberger in his Presidential Address to the American Economic Association (1998): 'yeast'-like processes expand uniformly under a common fermenting agency, whereas 'mushroom' innovations reflect 'real cost reductions stemming from 1001 different causes', and tend to be highly localized and idiosyncratic to particular industries and even to individual firms. Although Professor Harberger finds that the 'mushroom' metaphor better describes the distribution of TFP growth among industries in the modern (slow productivity-growth) US economy, we find in contrast that the 1920s was a decade of yeast-like growth.

When manufacturing industries are grouped into standard groups, it may be seen that 13 of the 14 major categories experienced an acceleration in the growth of multifactor productivity between 1909-19 and 1919-29.[2] When the categories are further disaggregated,

[1] The discontinuity in decadal measures was not an artefact of cyclical fluctuations accentuated by wartime and postwar demand conditions. Although we do not have annual TFP data, logarithmic regressions using data on labor productivity show that trend growth jumped from 1.5 percentage points per annum during 1899-1914, to 5.1 during 1919-1929. See David and Wright (1999), Figure 3.

[2] The lone exception, Transportation Equipment, was deviant only because of its exceptional productivity growth during the previous decade, not because it was below average for the 1920s. These findings, previously

to identify the fastest-growing individual industries in terms of real net output per manhour, we find that the high-fliers were broadly dispersed among nine larger industry groups; six of these aggregates boasted two or more high-growth members. The flat Lorenz-like diagram displayed in Figure 2 (developed using Harberger's method) makes immediately apparent the contrast between the 1920s and the 'pro-mushroom' findings presented by Harberger for the 1970s and 1980s. Evidently the post-1919 industrial productivity surge reflected broad, generic developments that were impinging widely upon US manufacturing activities.

What sort of forces were sufficiently pervasive and potent as to have these far-reaching effects? Our analysis identified two: first, the culmination of the dynamo revolution that had been underway as a technological trajectory since the nineteenth century, but which did not realize its engineering potential for major productivity gains until the 1920s; and second, the restructuring of US manufacturing labor markets, in the wake of the closing of mass European immigration after 1914. Each of these developments had its own prior history; but the productivity surge reflected the confluence of these two largely independent streams of development.

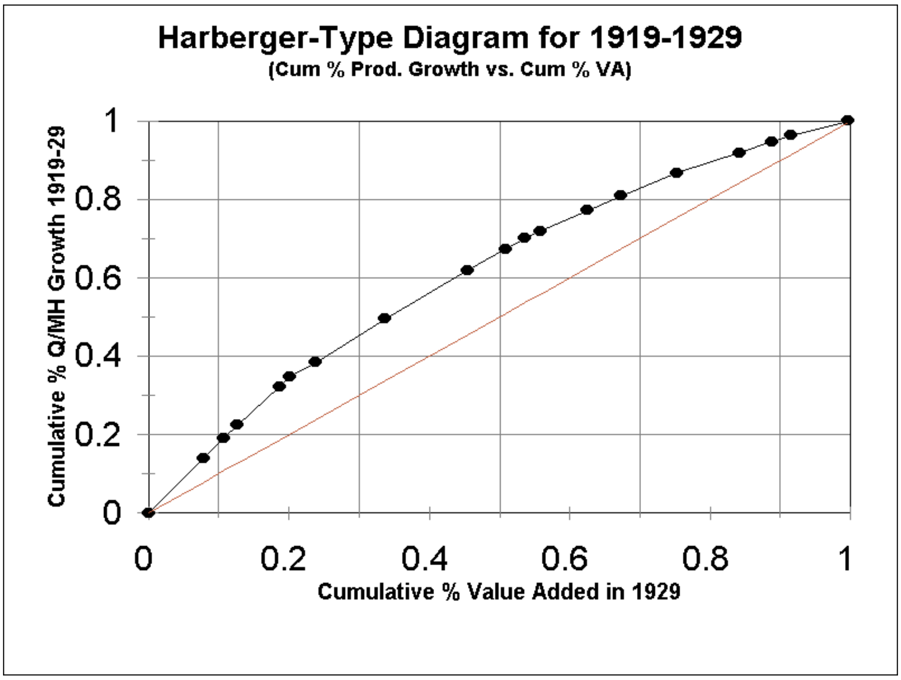

Figure 2

As recounted in earlier studies (David 1991), the transformation of industrial processes by the new electric power technology was a long-delayed and far from automatic business. It did not acquire real momentum until after 1914-1917, when the rates charged consumers by state-regulated regional utilities fell substantially in real terms, and central station generating capacity came to predominate over generating capacity in *isolated* industrial plants. Rapid efficiency gains in electricity generation during 1910-1920 derived from major direct investments in large central power plants, but also from the scale economies realized through integration and extension of power transmission over expanded territories. These developments were not simply matters of technology, but also reflected political and

reported by David (1991), account for purchased energy inputs in the multi-factor productivity measurement. This is appropriate, especially in view of the substitution of purchased electricity for the services of on-site capital equipment in the form of prime movers, which was taking place during the era in question.

institutional changes that allowed utilities largely to escape regulation by municipal and town governments, and facilitated the flow of investment capital into holding companies presiding over centrally managed regional networks. Together these supply-side improvements propelled the final phase of the shift to electricity as a power source in US manufacturing, from just over 50 percent in 1919 to nearly 80 percent in 1929 (David and Wright 1999, Figure 1, derived from DuBoff 1979).

But it would be a mistake to attribute the protracted delay in electrification exclusively to problems on the supply side. The slow pace of adoption prior to the 1920s was largely attributable to the unprofitability of replacing still serviceable manufacturing plants embodying production technologies adapted to the old regime of mechanical power derived from water and steam. Coexistence of older and newer forms of capital often restricted the scope for exploiting electricity's potential. Prior to the 1920s, the 'group drive' system of within-plant power transmission remained in vogue (Devine 1983). With this system in which electric motors turned separate shafting sections, so that each motor drove related groups of machines primary electric motors often were merely added to the existing stock of equipment. When the favourable investment climate of the 1920s opened up the potential for new, fully electrified plants, firms had the opportunity to switch from group to 'unit drive' transmission, where individual electric motors were used to run machines and tools of all sizes. The advantages of the unit drive extended well beyond savings in fuel and in energy efficiency. They also made possible single-story, linear factory layouts, within which reconfiguration of machine placement permitted a flow of materials through the plant that was both more rapid and more reliable. According to the surveys of American manufacturing directed by Harry Jerome (1934), rearrangement of the factory contributed to widespread cost savings in materials handling operations, serializing machines and thereby reducing or eliminating 'back-tracking' (pp. 190-91).

The package of electricity-based industrial process innovations that has just been described could well serve as a textbook illustration of *capital-saving* technological change. Electrification saved fixed capital by eliminating heavy shafts and belting, a change that also allowed factory buildings themselves to be more lightly constructed, because they were more likely to be single-story structures whose the walls no longer had to be braced to support the overhead transmission apparatus. The faster pace of material throughput amounted to an increase in the effective utilization of the capital stock. Further, the frequency of downtime was reduced by the modularity of the unit drive system and the flexibility of wiring; the entire plant no longer had to be shut down in order to make changes in one department or section of the factory (Schurr 1991, esp. pp. 29-30 and 292-93). Notice too that Henry Ford's transfer-line technique and the speed-up of work that this permitted was contributory element of the high throughput manufacturing regime, as were the new continuous process technologies that grew in importance during this era. These effects are confirmed by the sharp fall in the capital-output ratio during the 1920s, reversing the long-term trend. As with TFP growth, this pattern was pervasive: All but two of the seventeen major industry groups show a fall during this decade, whereas the ratio had been rising in every one of these groups during 1899-1909, and in twelve of seventeen during 1909-1919. A simple scatter plot demonstrates that this increase in capital productivity was directly associated with the electrification of primary horsepower, a correlation that strengthened across the 1920s (Figure 3).

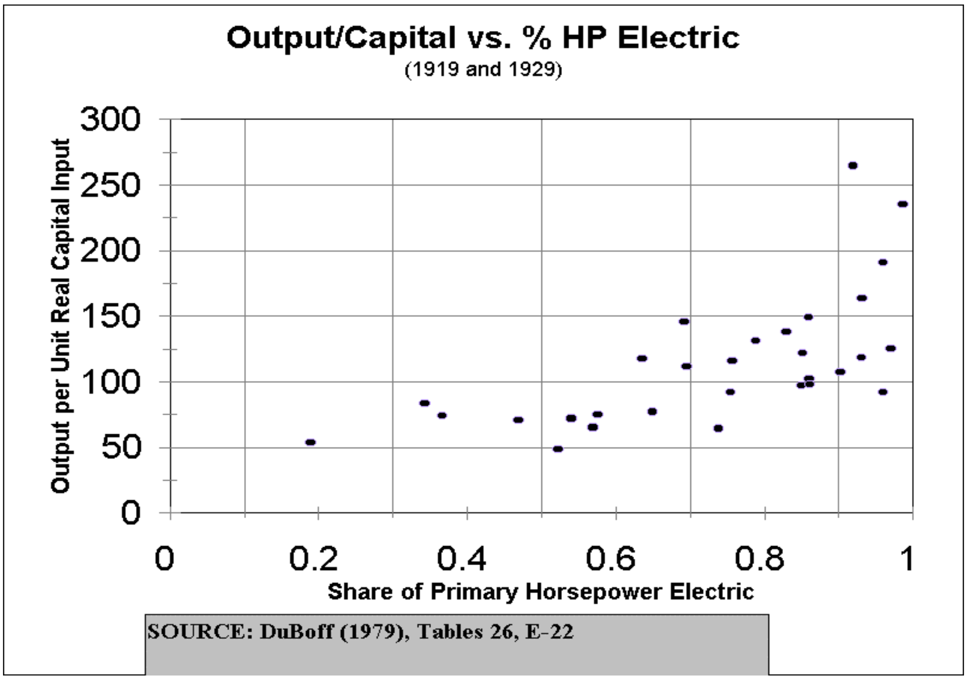

Figure 3

A proper historical account of the 1920s productivity revolution, however, cannot be confined to examining the implications of the cluster of manufacturing techniques that were diffusing into use in that decade. Equal notice must be taken of a second broad force operating on the U.S. economy at that time, namely the sharp increase in the relative price of labor. Relative to the general price level, the hourly wage of industrial labor was 50 to 70 percent higher after 1920 than it had been a decade before (Figure 4).

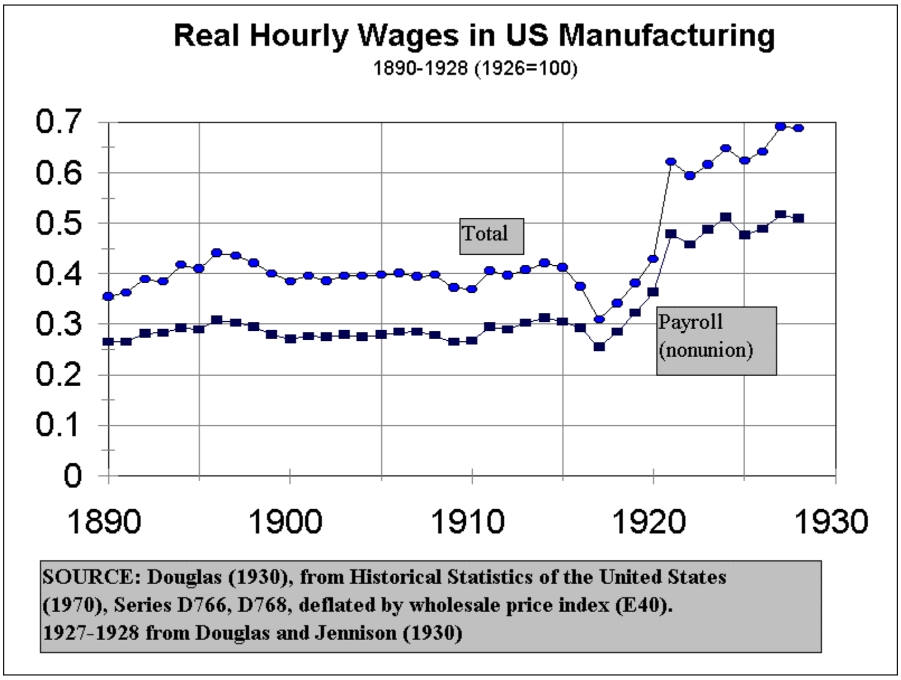

Figure 4

This change was most immediately associated with the end of mass European immigration, which had averaged more than one million per year during the decade prior to 1914, but was blocked during the war and then decisively closed by legislation in 1920 and 1924. The rise in real wages ushered in a sweeping change in the functioning of labor markets, reflected in a fall in turnover and an upgrading of hiring standards. As we interpret these events (in David and Wright, 1999), reinforcing changes on both sides of the labor market generated a 'regime transition', towards a new set of relationships that we may call the High Wage Economy.

Although this history was largely independent of electric power technology, it was the confluence of these two streams that gave the decade of the 1920s its truly extraordinary character. Both were facilitated by favourable macroeconomic conditions, including the high rate of investment in new plant and equipment; the new flexibility in plant location and design facilitated the reorganization of job assignments and labor systems as well as physical arrangements. Indeed, we would go further, suggesting that there were positive micro-level interactions between electrification and rising labor productivity. Another scatter diagram, relating the growth of capital and labor productivity across the array of industries during the decade, shows that there was a *positive* correlation between the two – not the negative association that one would expect using a simple factor substitution model (Figure 5).

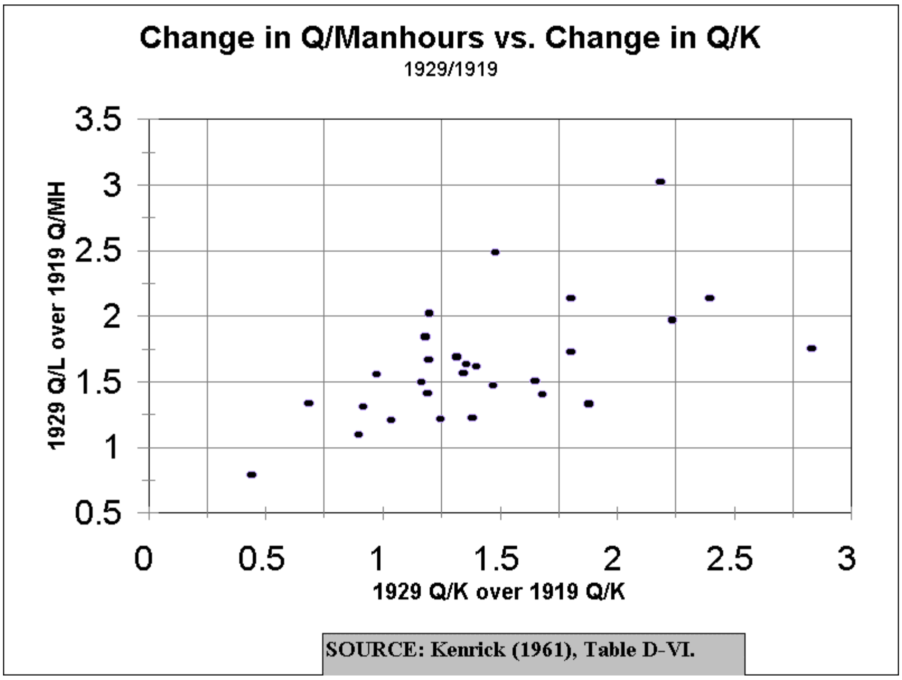

Figure 5

We argue that the technological and organizational changes just reviewed also exerted a positive influence on the efficiency of labor inputs, through at least three channels: (a) an increase in the effective utilization of labor capacity, by improving the speed and reliability of materials transmission; (b) a higher premium on mature, reliable, longer-term employees, because of the vulnerability of electrified plant systems to disruption; (c) increased scope for individual specialization and the exercise of discretion, made possible by the localization of power supply under the unit drive system.

2. Generalizing the Dynamo: Generic Features of General Purpose Technologies

The diffusion of the dynamo has served as something of a paradigmatic example for economists working in the spirit of the new growth theory who have sought to generalize the idea of 'general purpose technologies' with applications in diverse sectors of the economy. As formulated by Bresnahan and Trajtenberg (1995):

> Most GPTs play the role of 'enabling technologies', opening up new opportunities rather than offering complete, final solutions. For example, the productivity gains associated with the introduction of electric motors in manufacturing were not limited to a reduction in energy costs. The new energy sources fostered the more efficient design of factories, taking advantage of the newfound flexibility of electric power. Similarly, the users of micro-electronics benefit from the surging power of silicon by wrapping around the integrated circuits their own technical advances. This phenomenon involves what we call 'Innovational complementarities' (IC), that is, the productivity of R&D in a downstream sector increases as a consequence of innovation in the GPT technology. These complementarities magnify the effects of innovation in the GPT, and help propagate them throughout the economy.

The interest in generalization has in turn stimulated efforts to consolidate our understanding of the defining features of GPTs, and to extend the list of historical examples. According to the most carefully developed criteria proposed by Lipsey, Bekar, and Carlaw (in Helpman 1998, pp. 38-43), GPTs are technologies that share four characteristics:

(1) Wide scope for improvement and elaboration;
(2) Applicability across a broad range of uses;
(3) Potential for use in a wide variety of products and processes;
(4) Strong complementarities with existing or potential new technologies.

Using these criteria, Lipsey and his co-authors identify an extensive list of historical and contemporary GPTs, from power delivery systems (waterwheel, steam, electricity, internal combustion) and transport innovations (railways and motor vehicles) to lasers and the internet. They also extend the concept to such 'organizational technologies' as the factory system, mass production, and flexible manufacturing. In the same volume, Nathan Rosenberg extends the application still further into the institutional structure of knowledge itself, arguing that the rise of Chemical Engineering in the U.S. may be usefully viewed as a GPT (see Helpman 1998, pp. 167-192).

One has only to consider the length of such proposed lists of GPTs to begin to worry that the concept may be getting out of hand. History may not have been long enough to contain this many separate and distinct revolutionary changes. On closer inspection, it may be that some of these sweeping innovations should be better viewed as sub-categories of deeper conceptual breakthroughs in a hierarchical structure. Alternatively, particular historical episodes may be fruitfully understood in terms of interactions between one or more GPTs on previously separate historical paths. Quite clearly, an important aspect of the 'dynamo revolution' was the technological confluence, or convergence, of electrification with other trajectories of industrial innovation, each of which might be considered a species of GPT.

Three among these are especially notable in the present connection:

(a) the fixed transfer-line layout of assembly operations that came into full fruition in the Ford Highland Park plant on the eve of WWI diffused rapidly and widely during the 1920s, because, as Hounshell (1984) points out, Ford was deliberately open in promoting the logic and engineering specifics of this system of mass production by means of interchangeable parts. Electric power transmission by wire, rather than by drive-shafts was better suited to this new manufacturing regime (as one can see from the use made of group and unit drive set-ups at Highland Park itself).

(b) automated materials handling was a generic labor-saving development that featured prominently among the new innovations of manufacturing mechanization reported in Jerome's survey; these too did not require electrification, although in some cases such as the use of battery powered fork-lifts, the availability of cheap purchased power for recharging was important.

(c) continuous process chemical technologies, which as Rosenberg emphasizes implemented the unit system principles of A.D. Little, made extensive use of electro-mechanical and electro-chemical relays for control, and many of these processes were heat-using, and so were dependent upon purchased electricity for large-scale operations.

For the sake of brevity and the thematic unity provided by considering the dynamics of the diffusion of a broad GPT, however, we prefer to regard the foregoing streams of technical development as subsidiary, or perhaps 'tributary'. Hence, we focus our discussion on the productivity impact of electric power technology and its applications, regarding the dynamo technology as a GPT of a higher order, and more pervasive and transformative agent than the others.

But we do see the explosive productivity growth of the 1920s as the result of a confluence between the dynamo GPT and the clustering of electricity-based or enhance manufacturing process technologies, on the one side, and the emergence of a new organizational regime that created what might be called that High Wage Path for the mid-twentieth century US. economy. This latter development was triggered by a particular conjunction of macroeconomic and labor market conditions, and insofar as it became institutionalized in the practices and expectations upon which the strategies of major US industrial corporations were premised, it might itself have a certain claim to be regarded as a GPT. But we think otherwise. Generalized formulations of the GPT concept cannot be burdened with this degree of historical specificity, but we hold to the view that appropriate *applications* of the concept should be explicitly historical in this sense.

Inevitably, some of the sense of historical context is lost in the more abstract theoretical treatments. In the recent collection of essays edited by Helpman (1998), GPTs are variously characterized in terms of inter-industry linkages, R&D investments, scale economies, coordination problems, spillover, and other structural features, often applied to perfect-foresight, general-equilibrium models that seem to deny the premise of historical technological trajectories. But this may be a necessary phase in the early diffusion of a concept within the discipline of economics. And it is noteworthy that even in models that are stripped-down and simplified, GPT phenomena readily generate alternating phases of slow and rapid productivity growth, and corresponding phases of slowed or accelerated real wage growth. Depending on the formulation, the 'output slowdown' phase may be attributed to the diversion of resources into knowledge investment during the gestation of a new GPT; to increased rates of obsolescence in the older capital stock and in labor force skills; to measurement problems with respect to both the capital stock and to new goods and services; to the need for industry-specific adaptations, which have to wait upon progress in the GPT itself; or to risks and uncertainties facing adopters of the new technology, which decline only with improvements and cost reductions by suppliers.[3]

Virtually all of these aspects of discontinuity may be observed in our historical case of American electrification. We would add to this list, however, the need for organizational and above all for *conceptual* changes in the ways tasks and products are defined and structured. And because major technological revolutions can be expected to have social and distributional consequences, very likely political adjustments will also be required, if the full potential of the new technology is to be realized. Changes of this sort are intrinsically subject to delay and discontinuity. As noted above, the historical U.S. episode saw such transformations in immigration policy in education, and in the recruitment and retention policies of industrial employers.

3. Was this Phenomenon Uniquely American? Evidence from Comparative Electrification

Was the experience of delayed and then accelerated TFP growth, associated with electrification, uniquely an American phenomenon, or do we find similar patterns elsewhere?[4] A truly global analysis would be a vast project, but an appropriate place to begin is with the United Kingdom, where we can draw upon the work of Charles Feinstein with various co-authors. Of course, there were so many contrasts in economic conditions between these two countries during the period of interest, that there is no assurance that any simple comparisons would be at all meaningful. As a self-sufficient continental power, the U.S. escaped damage during World War I and was largely insulated from the travails of the international economy during the 1920s; Britain, on the other hand, was uniquely afflicted during that decade by the loss of traditional markets for manufactured goods and the overvaluation of the pound.

In view of those differences, it comes as something of a surprise to find a remarkable number of qualitatively similar patterns in the British productivity data. These emerge when the record of the for the period 1924-1937, is contrasted with that for the pre-war era. Matthews, Feinstein, and Odling-Smee (1982) report that TFP for the economy as a whole rose at 0.70 percent per year during 1924-1937, compared to 0.45 percent per year for 1873-1913, the acceleration being led by manufacturing, where TFP growth jumped from 0.6 percent to 1.9 percent per year (p. 229). A particularly striking feature of this surge was that the capital-output ratio in manufacturing declined at the rate of 2.4 percent per annum during 1924-37, reversing the trend of the entire period stretching from 1856 to 1913 (p. 378). Not only did the productivity of manufacturing capital increase for the sector as a whole, but the authors go on to note:

> It is remarkable that a fall in the capital-output ratio between 1924 and 1937 is found in every manufacturing group without exception, including rapidly growing industries such as vehicles and electrical engineering, where a legacy of old excess capacity can hardly have been important (p. 384).[5]

---

[3] See, particularly, the essays by Helpman and Trajtenberg, and by Aghion and Howitt, in Helpman (1998).

[4] Special thanks are due at this point to Angus Maddison and R.C.O. Matthews for their privately communicated comments on David and Wright (1999), in which both suggested that we take notice of the experiences of industrial nations other than the US.

[5] The capital stock data underlying these results may be traced back to Charles Feinstein's first published book, Feinstein (1965).

Inspection of cross-section relationships within manufacturing suggests that, as in the U.S., there was a positive correlation between the growth of capital productivity and of labor productivity during this period (p. 240).

When we turn to the text of Matthews, Feinstein and Olding-Smee (MFO, 1982) for an explanation of these patterns, we find that at the top of the list is electrification, 'a change that extended over the whole range of manufacturing....a development that was accompanied by an increase in the proportion of electricity purchased as opposed to generated within the firm' (p. 385). The authors note that

> apart from this straightforward capital-saving effect (as far as manufacturing was concerned), it is likely that a capital-saving effect also resulted because electrification permitted the more flexible and efficient use of any given horsepower. One of these consequences was the extension of the use of (relatively cheap) machine tools (ibid.).

More recently, Feinstein, Temin and Toniolo (FTT, 1997) identify electrification as one of the key forces behind the movement known in Europe as 'rationalization' of industry, entailing 'closer control over the pace and continuity of effort by the labour force' (p. 80). This latter formulation resonates with the observations of David and Wright (1999), concerning the confluence during the 1920s of technological developments and the diffusion of new managerial practices.

What does this remarkable parallelism imply for our thinking about general purpose technologies? First, it is encouraging confirmation that factory electrification was indeed a GPT, with pervasive effects across virtually all manufacturing industries. Because central-source power generation required large fixed-capital investments, which in turn opened opportunities for capital-saving conversions across a wide range of industries, we should expect to see many common features in the experience, even in countries that differed in many other respects. Secondly, however, once underway, the diffusion of electricity as a primary power source in manufacturing establishments seems to have proceeded more rapidly in the UK than in the US during the post WWI era. The electricity supply industry Britain had started down a very different and more decentralized course during the period 1880-1914, and the development of large central generating plants serving regional networks was a comparatively late phenomenon, initially confined to the Northeast.[6] The Central Electricity Board was established by Parliament only in 1926, but progress thereafter was rapid, with the bulk of the national power grid being constructed between 1929 and 1933 (FTT 1997, p. 181).

Consistent with this lag behind the US in the widespread availability of cheap purchased electric power for its industrial districts, in Britain the growth of TFP in manufacturing was slower during the 1924-1929 interval than it was over the course of the following cyclically comparable period, 1929-1937 (See MFO 1982, p. 610). Furthermore, it appears that by the end of the 1930's the extent of diffusion of electric power in British manufacturing as a whole essentially matched that in the US (ibid, p. 385, note 5). We interpret this rapid catchup as an aspect of the experience of a 'follower' country, which can adopt a well-developed technology from abroad relatively quickly, without having to retrace

[6] See Hughes (1983) for comparisons between Britain, Germany and the U.S., which highlights the early lead of the latter in developing extensive regional universal electrical supply networks based upon 3-phase A.C. current, particularly in the Midwest. On the continuing entry during 1900-13 of many small DC-based electrical supply companies in Britain to which the North East regional network built by Mertz was the exception see Hannah (1979), esp. p. 38.

all the steps and mis-steps of the social learning trajectory that had occurred in the country that pioneered the application of the technology in question.

Thus a second point brought out by this comparative approach to the subject is that the pace of GPT diffusion may be very different in leader and follower nations, a consideration that GPT theorists have thus far largely overlooked.[7] This observation, of course, can be read as lying squarely within the tradition of historical analysis springing from Thorstein Veblen's (1915) remarks on 'the penalties of taking the lead', and made familiar in the literature of development economics by Alexander Gerschenkron's (1962) more elaborate formulation of 'the advantages of economic backwardness'.[8] On the other hand, it does not follow that the faster diffusion of a GPT automatically translates into a higher average rate of growth of labor productivity or total factor productivity. Even during the interval 1929-1937, the trend growth rate of manufacturing TFP in Britain remained far below the spectacular pace of advance (averaging more than 5 percentage points per annum) that was recorded for the sector in the US during the 1920's.[9] A proximate explanation of this quantitative divergence may be found in the much faster growth rate of average manhour productivity that established itself in the US following World War I, and this directs our notice to another, underlying aspect of difference between the two industrial economies' experiences.

Where the records of the US and Britain diverged most sharply was in the labor market. The upward jump in the real hourly wage between 1913 and 1924 was in fact common to both countries, and indeed to many other countries at that time, being occasioned in a proximate sense by inflation of 1915-20 and the subsequent deflation of 1920-21, i.e., by global economic forces. In Britain, however, the increase in labor costs was accentuated by the one-time national reduction in hours of work, enacted in 1919, a development that had no counterpart in the U.S. prior to the 1930s. But whereas in the U.S., this wage increase appears to have precipitated a spectacular burst of growth in labor productivity at better than 5 percent per year, in Britain the acceleration was far less robust, amounting to a rise of less than 2 percentage points in the annual growth rate. Thus, during the decade of the 1920s, the

---

[7] We hasten to add that the U.S. was by no means an across-the-board technological leader relative to the U.K. in the 1920s, especially if that concept is defined in terms of scientific and engineering sophistication. But in the specific historical case of large-scale electric power generation and delivery, the U.S. was undeniably the pioneer nation

[8] This point may be further illustrated by reference to the historical record of factory electrification in Japan. Minami (1987) points out that in comparison with the US, and *a fortiori* with Britain, the Japanese 'age of steam power' was very much 'compressed' -- or, we might say, 'abridged' by the precocious rise of the fraction of primary horsepower capacity in manufacturing industries that was electrified. The electric power diffusion measures for individual industries, like that for the whole manufacturing sector in Japan closely parallel those for the US from the mid-1920s onwards. Further examination of this and other cross-national comparisons, however, cannot be pursued here.

[9] Nor was the acceleration of the British TFP growth rate for manufacturing (between the pre-1914 and 1924-1937 periods) as marked, in either absolute or relative terms, as that which has been estimated for the US. The TFP calculations for US. manufacturing without allowance for purchased energy inputs are perhaps those most directly comparable with the estimates for Britain by MFO (1982) , which were cited in the text above; for the 1889-1909 interval the average annual growth rate of 0.7 percentage points corresponds closely to the 0.6 percentage point pre-1914 trend rate in Britain. The same productivity growth series for the US shows a rise to 5.3 percentage point per annum during 1919-1929, before falling back to the 2 percentage point per annum level during 1929-1937 (see David 1991: Table 2, Cols. 4, 7). A comparison of the US multifactor productivity growth rates in the manufacturing sector (making adjusted for inputs of purchased energy) finds a still bigger jump of approximately 5.1 percentage points per annum between the decades 1909-1919 and 1919-1929.

U.S. increased its already large labor productivity lead vis-a-vis Britain and Germany (Broadberry 1993).

Undoubtedly there are many reasons for this contrast in the quantitative impact of a common GPT, even where the qualitative effects were similar. As previously noted, U.S. manufacturing firms had long experience with adapting to high-wage conditions, and were able to accelerate a restructuring of labor relations that was already underway in many industries. But one specific additional feature that suggests itself is the match between the technologies advanced by electrification and the institutions of education and worker training in the country. Evidence recently developed by Goldin and Katz (1998) indicates that the new manufacturing technologies were well-adapted to the attributes of the high school graduates emerging from educational reforms in the U.S. in the decades just prior to the 1920s. Our examination of this question (in David and Wright, 1999: section 4), has suggested that this was not because the American secondary school systems of the day were supplying industry with a workforce whose members had received specific cognitive information and particular skills required by the new, electrified manufacturing technologies. Rather, the new factory regime increasingly called for workers who were literate and numerate enough to be readily 'instructable' on the shop and factory floor; employers in the technologically more sophisticated industries sought workers who could accustom themselves to a succession of work routines, and who would be reliable in the execution of mechanically assisted tasks where consistency of performance had become more important in the context of integrated, high-throughput systems of production. High school attendance and high school completion appear to have constituted signals of these attributes and of the motivation to respond to experience-based wages and job promotion incentives that were designed to stabilize and upgrade the quality of the workforce employed by the leading manufacturing firms in this era.

In contrast, the same decade has been identified as one of missed opportunity for the British educational system, as the older apprenticeship institutions were in decline, yet were not replaced by new forms of technical and continuation schooling (Sanderson 1988, Broadberry and Wagner 1996). Thus a third implication of this comparison is that the impact of any particular GPT diffusion may be strongly conditioned by circumstances affecting the supply of complementary productive inputs. To the extent that GPT's have a capability for widespread applications across many branches of the economy concurrently, and, if they successfully percolate and are able to take hold in that fashion, are likely to give rise to synergetic interactions and positive feedbacks, the availability of correspondingly generic complementary inputs is likely to constitute a critical constraint not only upon the extent of the GPT's diffusion but upon the impact this has upon productivity. The case at hand thus suggests that a critical factor in differential productivity performance may have been the management competencies rooted in the antecedent industrial experience, and the continuing disposition of institutional and public policy as it affected the provision of access to 'educational attainment' signals of general worker quality (as distinguished from traditional craft apprenticeship) sought by employers in establishment that were becoming committed to factory electrification.[10]

[10] This dynamic process is one in which there are positive feedback externalities of the kind found more generally at work in market-driven, *de facto* 'standards-setting'. Abramovitz and David (1996) discuss some aspects of the reciprocal historical relationships between the emergence of educational-attainment based hiring standards in US labor markets and the formation of perceptions of material advantage associated with extended schooling, and the growth of popular support for the movement towards public provision of mass secondary education -- even at the appreciable costs to many families of foregoing earnings from their children's labor.

4. Dynamos and Computers: Uses of History and Historical Analogy

By drawing an explicit analogy between 'the dynamo and the computer', David (1991) sought to use the U.S. historical experience to give a measure of concreteness to the general observation that an extended phase of transition may be required to fully accommodate and hence elaborate a technological and organizational regime built around a general purpose digital computing engine. This 'regime transition hypothesis' has suggested itself as a possible resolution of the so-called 'productivity paradox', wherein new computer and information technologies (now commonly designated as ICT) have been rapidly and visibly diffusing through the economy at the same time that the growth rate of TFP has fallen to historic lows, in the US particularly. An understanding of the way in which the transmission of power in the form of electricity came to revolutionize industrial production processes tells us that far more was involved than the simple substitution of a new form of productive input for an older alternative. The pace of the transformation must be seen to be governed, in both the past and current regime transitions, by the ease or difficulty of altering many other technologically and organizationally related features of the production systems involved.

Recent estimates of the growth of computer stocks and the flow of services therefrom are consistent with the view that when the 'productivity paradox' began to attract attention, the US economy could be said to have still been in the early phase of the deployment of ICT. Figures developed by Dale Jorgenson and Kevin Stiroh (1995) reveal that in 1979, when computers had not yet evolved so far beyond their limited role in information processing machinery, computer equipment and the larger category of office, accounting and computing machinery (OCAM) were providing only 0.56 percent and 1.5 percent, respectively, of the total flow of real services from the (non-residential) producer durable equipment stock. But these measures rose at 4.9 percent in 1985, and had ballooned to 13.8 percent by 1990, and 18.4 percent two years after that. Thus, the extent of 'computerization' that had been achieved in the whole economy by the late 1980s was roughly comparable with the degree to which the American manufacturing sector had become electrified at the beginning of the twentieth century. When the historical comparison is narrowed more appropriately to the diffusion of secondary motors, a proxy for the spread of the unit drive, the growth rate for 1899-1914 is almost precisely the same as that for the ratio of computer equipment services to all producers' durable equipment services in the US.[11]

While there seems to be considerable heuristic value in this historical analogy, a cautious, even skeptical attitude is warranted regarding the predictions for the future that some commentators have sought to extract from the quantitative resemblance between the two transition experiences. For one thing, statistical coincidences in economic performance are more likely than not to be mere matters of coincidence, rather than indications that the underlying causal mechanisms are really one and the same. One can use the historical evidence quite legitimately when suggesting that it is still too early to be disappointed that the computer revolution has not unleashed a sustained surge of readily discernible productivity growth throughout the economy. But that is not the same thing as predicting that the continuing relative growth of computerized equipment must eventually cause a surge of productivity growth to materialize, nor does it say anything whatsoever about the future pace of the digital computer's diffusion. Least of all does it tell us that the detailed shape of the diffusion path that lies ahead will mirror the curve traced out by the electric dynamo during the early decades of the twentieth century. One cannot simply infer the detailed future shape of the diffusion

[11] David (1999) provides this and other quantitative indicators, including comparisons of the decline in the real price of computer services with that of purchased electricity and electrical machinery (of a constant kind).

path in the case of the ICT revolution from the experience of previous analogous episodes, because the very nature of the underlying process renders that path contingent upon events flowing from private actions and public policy decisions, as well as upon the expectations that are thereby engendered all of which still lie before us in time.

Eschewing blind faith in historical repetition, we nonetheless can draw insights from the record of analogous past experiences that help us to understand the so-called 'productivity paradox' by indicating relevant margins and constraints governing the linkage between new information technologies and the improvement of measured productivity. Here, we believe, there is a case to be made for viewing the path taken up the present as one among a number of available alternatives – a path whose selection, viewed in retrospect, was responsive to considerations that led away from a tight coupling between new technological artefacts and the task productivity of the individuals and work groups to whom those tools were offered.[12]

The widespread diffusion of the stored program digital computer is intimately related to the popularization of the personal computer as a 'general purpose' technology for information processing and the incremental transformation of this 'information appliance' into the dominant technology of information processing. For the personal computer, as for its parent the mainframe, and its cousin the minicomputer, adaptation and specialization has been required to apply a general purpose information processing machine to *particular* purposes or tasks. It is something of an historical irony that the core elements of the adaptation problems attending this GPT's diffusion into widespread business application may be seen to derive from the historical selection of trajectory of innovation that emphasized the 'general purpose' character of the paradigmatic hardware and software components.

The origins of the personal computer required the invention of the microprocessor which was a technical solution to the problem of creating a more 'general purpose' integrated circuit to serve a specific purpose, a more flexible portable calculator – a foundational application that ultimately provided uneconomic due to the lower relative costs of more specialized integrated circuits. During the 1970s it was recognized that the microprocessor provided a general solution to the problem of the electronic system designer confronted by an ever growing array of application demands. During the same period, efforts to down-scale mainframe computers to allow their use for specialized control and computation applications supported the birth of the minicomputer industry. These two developments provided the key trajectories for the birth of the personal computer. As microprocessors became cheaper and more sophisticated and applications for dedicated information processing continued to expand, a variety of task-specific computers came into existence.

One of the largest markets for such task specific computers created during the 1970s was that for dedicated word-processing systems, which appeared as an incremental step in office automation, aimed the task of producing documents repetitive in content or format such as contracts, purchase orders, legal briefs, and insurance forms, that could be quickly modified and customized based upon stored formats and texts. They became attractive and were often adopted where the production of forms and texts generated full time work for more than a single employee. But the inability of the vendors of the pioneer dedicated word-processing hardware to furnish their customers with new software – for they had adopted a strategy of providing only proprietary software – led to both a perceived and actual absence of flexibility; the technology was not responsive to the proliferating user needs arising from the growing number of product installations.

[12] The following draws upon a more detailed treatment of the productivity implications of the general purpose formulation computer technology that has characterized the personal computer revolution, provided by David and Steinmueller (1999: Section 7).

The displacement of dedicated word processors by personal computers thus came relatively rapidly in the mid-1980s, driven by the apparent superiority of the latter in a number of the relevant dimensions of comparison. The personal computer was quickly perceived to be more ‘flexible’ and more likely to be ‘upgrade-able’ as new generations of software were offered. Moreover, personal computers could use many of the same peripherals, such as printers: because the widespread adoption of the new technology raised the demand for compatible printers, the dedicated word processors found themselves unprotected by any persisting special advantages in printing technology.

The dedicated word processor’s demise was re-enacted in numerous markets where dedicated ‘task-specific’ data processing systems had begun to develop.[13] The ‘general purpose’ software produced for these platforms not only discouraged task-specific software, it also created a new collection of tasks and outputs specifically driven by the new capabilities such as ‘desk top publishing’ (typeset quality documents), ‘presentation graphics’ (graphic artist quality illustrations for speeches and reports), and ‘advanced word processing’ (the incorporation of graphics and tables into reports). All of these changes improved the ‘look and feel’ of information communication, its quality and style, the capability for an individual to express ideas, and the quantity of such communications. But singly and severally they made very little progress in changing the structure of work organization or the collective productivity of the work groups employing these techniques. The disappearance of task-based computing in favour of general purpose personal computers and general purpose (or multi-purpose) packaged software was thus largely completed during the 1980s.[14]

The early evolution of the personal computer can therefore be seen as having laid waste to the development of an entire family of technically-feasible information processing systems focused on the improvement of ‘task-productivity’ in applications ranging from word processing to manufacturing operations control. In many cases, it also precluded effective development of collective ‘work group’ processes whose synergies would support multifactor productivity improvement. Instead of ‘breaking free’ from the mainframe, these general purpose engines often wound up ‘slaved’ to the mainframe, using a small fraction of their capabilities to emulate the operations of their less expensive (and less intelligent) cousins, the ‘intelligent’ display terminals. Information systems departments confronted a growing array of demands for access to databases and reporting systems that had been expensively and laboriously constructed so that managers might construct reports more to their liking and more effective to their purposes, using their new spreadsheet tools.

By 1990, then, the personal computer revolution, like other revolutions, had left carnage behind while seizing control of the future of information processing. The revolutionaries had kept their promise that the personal computer would match the computing performance of the mainframes of yesteryear. What was not achieved, and could not be achieved, by this revolution was a wholesale reconstruction of the information processing activities of organizations. Rather than contributing to the rethinking of organizational routines, the spread of partially networked personal computers supported the development of

[13] See the discussion in Steinmueller (1996).

[14] In the medium and large enterprises of 1990, what remained was a deep chasm between the ‘mission critical’ application embedded in mainframe computers and the growing proliferation of personal computers. The primary bridge between these application environments was the widespread use of the IBM 3270, the DEC VT-100 and other standards for ‘intelligent’ data display terminals, the basis for interactive data display and entry to mainframe and minicomputer systems. From their introduction, personal computer had software enabling the emulation of these terminals, providing further justification for their adoption.

new database and data entry tasks, new analytical and reporting tasks, and new demands for 'user support' to make the general purpose technology deliver its potential.

This is not to claim that the process should be regarded as socially sub-optimal, or mistaken from private business perspective. A basis for such judgements, one way or the other, does not exist, as yet. It appears that what was easiest in an organizational sense tended to be the most attractive thing to undertake first. The local activities within the organization that were identified as candidates for personal computer applications often could and did improve the flexibility and variety of services offered internally within the company, and externally to customers that would, through the intermediation of personnel with appropriate information system access, receive an array of service quality improvements. Arguably, many of these improvements are part of the productivity measurement problem as they are simply not captured in the real output statistics, even though they might enhance the revenue generating capacity of the firms in which they are deployed. The availability of 24-hour telephone reservation desks for airlines, or the construction of worldwide networks for securing hotel, rental automobile, or entertainment reservations, represent welfare improvements for the customer that do not appear in the measured real GDP originating in those sectors, nor in the real value expenditures on final goods and services.

5. Historical Reflections on 'General Purposeness' and the Future of the ICT Revolution

The historical trajectory of computer technology development now appears to be about to undergo a profound and portentous change of direction. At least three new dimensions are emerging strongly enough in commercial applications to deserve brief notice. None of these developments are likely to displace the use of personal computers in the production and distribution of information that must be highly customized, or that arises from the *ad hoc* inquiries similar to the research processes for which the general purpose computer was originally invented. What they do promise is greater and more systematic efforts to integrate information collection, distribution and processing efforts. In attempting to take advantage of these opportunities, enterprises and other institutions are forced to re-examine workflow and develop new methods for information system design.

First, a growing range of information technologies have become available that are purpose-built and task-specific. Devices such as supermarket scanners were applied to a wide range of inventory and item tracking tasks and related 'data logging' devices were to be found in the hands of maintenance, restaurant, and factory workers. The environmental niches in which these devices were able to achieve a foothold are ones where the mass produced personal computer was neither appropriate nor robust. These more 'task specialized' devices have become sufficiently ubiquitous to provide the infrastructure for task-oriented data acquisition and display systems, in which up to date and precise overviews of the material flows through manufacturing and service delivery processes.

Secondly, the capabilities of advanced personal computers as 'network servers' has become sufficiently well developed that it is possible for companies to eliminate the chasm between the personal computer and mainframe environment by developing the intermediate solution of client-server data processing systems. This development is still very much in progress and reflects the more complete utilization of the local area networks devised for information and resource sharing during the personal computer era. In this new networked environment, the re-configuration of work organization becomes a central issue, strategic and practical issues surrounding the ownership and maintenance of critical company data resources must be resolves, and these often are compelling enough to force re-design of the organizational structure.

Thirdly, the development of Internet technology has opened the door to an entirely new class of organization-wide data processing applications as well as enormously enhanced the potential for collective and cooperative forms of work organization. Applications and their maintenance can be controlled by the technical support team who would previously have been responsible for the company's centralized data resources. The common standards defining Internet technology have the fortuitous feature that virtually all personal computers can be similarly configured, facilitating not only intra-company network but also *inter*-company networking.

The 'general purpose' trajectory followed by the spectacular development of personal computer technology has greatly reduced the price-performance ratio of the hardware, without effecting commensurate savings in the resource costs of carrying out many specific, computerized tasks. Some part of the limited resource savings clearly has been transitional, as personal computers were added to existing mainframe capacity, rather than substituted for it, and, indeed, were under-utilized by being allocated the role of intelligent terminals. This aspect of the story bears some strikingly similarities with the early progress of factory electrification, wherein the use of the group drive system supplemented without replacing the distribution of power within factors by means of shafts and belting; this added capital to an already highly-capital-using industrial power technology, without instigating any reorganization of factory layout and routines for materials handling. It was not, however, until the dynamo could be effectively integrated into individual tools under the unit drive system that the major capital-saving contributions to multi-factor productivity growth from thorough-going factory redesign could be realized. A similar structural change, based on digital information technologies embedded in hand held devices – or other robust and specialized tools that are carried on belts, sown into garments, or worn as head-gear – that are linked through sophisticated networks to produce complex and interactive systems, may be a promising trajectory of ICT development that will impinge directly upon specific (and hence more readily measurable) task performance.

Other portents for the future may be seen in the expansion of inter-organizational computing for the mass of transactions involving purchase ordering, invoicing, shipment tracking, and payments, all of which continue at present to absorb much specialist white-collar labor time. Such service occupations might be viewed as the modern day counterparts of the ubiquitous materials-handling tasks in the manufacturing sector that became the target of mechanization innovations during the 1920s. A continuation of the presently still-limited growth of 'tele-working'. In the US about one fifth of the workforce time in large service sector firms is now provided via data communications networks with employees homes – would eventually yield significant capital-savings in the reduced requirement for commercial office space and transport infrastructure facilities. Major organizational reconfigurations of this kind, which lend themselves to applications across a wide array of specific branches of the economy, seem the most promising prospects for the realization of the potentialities of the information technology revolution in a sustained, 'yeast-like' surge of productivity growth.

References

Abramovitz, M. and P.A. David (1996). 'The Rise of Intangible Investment: the U.S. Economy's Growth Path in the Twentieth Century', in *Employment and Growth in the Knowledge-Based Economy*, eds., D. Foray and B.-A. Lundvall, (OECD Documents). Paris: OECD.

Bresnahan, T., and M. Trajtenberg (1995). 'General Purpose Technologies: Engines of Growth', *Journal of Econometrics* 65: 83-108.

Broadberry, S. (1993). 'Manufacturing and the Convergence Hypothesis', *Journal of Economic History* 53:772-95.

Broadberry, S., and K. Wagner (1996). 'Human Capital and Productivity in Manufacturing during the Twentieth Century', in *Quantitative Aspects of Post-War European Economic Growth,* edited by B. van Ark and N.F.R. Crafts. Cambridge: Cambridge University Press.

David, P.A. (1991). 'Computer and Dynamo: The Modern Productivity Paradox in a Not-too-distant Mirror', in *Technology and Productivity*. Paris: OECD.

David, P. A. (1999). 'Digital Technology and the Productivity Paradox: After Ten Years, What Has Been Learned and What Do We Need to Know?' Prepared for the White House Conference on Understanding the Digital Economy, Washington, D.C., May 25-26, 1999.

David, P. A. and W. E. Steinmueller (1999). 'Understanding the Puzzles and Payoffs of the IT Revolution: The 'Productivity Paradox' after Ten Years', Ch. 1 of *Productivity and the Information Technology Revolution*, P. A. David and W. E. Steinmueller, eds., Harwood Academic Publishers, forthcoming in 1999.

David, P.A., and G. Wright (1999). 'Early Twentieth Century Growth Dynamics: An Inquiry into the Economic History of Our Ignorance', Stanford: SIEPR Discussion Paper No. 98-3. Prepared for presentation at the Economic History Society Annual Conference, held in St. Catherine's College, Oxford, 26-28 March, 1999.

Devine, W. Jr. (1983). 'From Shafts to Wires', *Journal of Economic History* 43: 347-372.

DuBoff, R. (1979). *Electric Power in American Manufacturing 1889-1958*. New York: Arno.

Feinstein, C.H. (1965). *Domestic Capital Formation in the United Kingdom 1920-1938*. Cambridge, England: Cambridge University Press.

Feinstein, C.H., Peter Temin and Gianni Toniolo (1997). *The European Economy Between the Wars.* Oxford: Oxford University Press.

Gerschenkron, A. (1969). *Economic Backwardness in Historical Perspective*. Cambridge, Mass: Harvard University Press.

Goldin, C., and L. Katz (1998). 'The Origins of Technology-Skill Complementarity', *Quarterly Journal of Economics* 113: 693-732.

Harberger, A. (1998). 'A Vision of the Growth Process', *American Economic Review* 88: 1-32.

Helpman, E., editor (1998). *General Purpose Technologies and Economic Growth*. Cambridge, MA: The MIT Press.

Hannah, L. (1979). *Electricity Before Nationalisation*. London: Macmillan.

Hounshell, D. (1984). *From the American System to Mass Production*. Baltimore: JHU Press.

Hughes, T.P. (1983). *Networks of Power: Electrification in Western Society, 1880-1930*. Baltimore: JHU Press.

Jerome, H. (1934). *Mechanization in Industry*. New York: National Bureau of Economic Research.

Jorgenson, D., and K. Stiroh (1995). 'Computer Investment, Capital and Productivity in the US', *Economics of Innovation and New Technology*, 4 (3-4).

Kendrick, J. (1961). *Productivity Trends in the United States*. Princeton: Princeton Univ. Press.

Matthews, R.C.O., C.H. Feinstein, and J.C. Odling-Smee (1982). *British Economic Growth 1856-1873*. Stanford, CA: Stanford University Press.

Minami, R. (1987). Power Revolution in the Industrialization of Japan, 1885-1940. Tokyo: Kinokuniya Co.

Sanderson, M. (1988). 'Education and Economic Decline, 1890s-1980s', *Oxford Review of Economic Policy* 4: 38-50. Reprinted with postscript in C.H. Feinstein (ed.), *The Economic Development of the United Kingdom since 1870*. Cheltenham, UK: Edward Elgar.

Schurr, S.H., et al (1990). *Electricity in the American Economy*. New York: Greenwood Press.

Steinmueller, W. E. (1996). 'The U.S. Software Industry: An Analysis and Interpretative History', in D. C. Mowery, ed., *The International Computer Software Industry*. Oxford: Oxford University Press, pp. 15-52.

Veblen, T. (1915). *Imperial Germany and the Industrial Revolution*. New York: MacMillan.

UNIVERSITY OF OXFORD

Discussion Papers in Economic and Social History

1 Hans-Joachim Voth and Tim Leunig, *Did Smallpox Reduce Height? Stature and the Standard of Living in London, 1770-1873* (Nov. 1995)

2 Liam Brunt, *Turning Water into Wine - New Methods of Calculating Farm Output and New Insights into Rising Crop Yields during the Agricultural Revolution* (Dec. 1995)

3 Avner Offer, *Between the Gift and the Market: the Economy of Regard* (Jan. 1996)

4 Philip Grover, *The Stroudwater Canal Company and its Role in the Mechanisation of the Gloucestershire Woollen Industry, 1779-1840* (March 1996)

5 Paul A. David, *Real Income and Economic Welfare Growth in the Early Republic or, Another Try at Getting the American Story Straight* (March 1996)

6 Hans-Joachim Voth, *How Long was the Working Day in London in the 1750s? Evidence from the Courtroom* (April 1996)

7 James Foreman-Peck, *'Technological Lock-in' and the Power Source for the Motor Car* (May 1996)

8 Hans-Joachim Voth, *Labour Supply Decisions and Consumer Durables During the Industrial Revolution* (June 1996)

9 Charles Feinstein, *Conjectures and Contrivances: Economic Growth and the Standard of Living in Britain During the Industrial Revolution* (July 1996)

10 Wayne Graham, *The Randlord's Bubble: South African Gold Mines and Stock Market Manipulation* (August 1996)

11 Avner Offer, *The American Automobile Frenzy of the 1950s* (Dec. 1996)

12 David M. Engstrom, *The Economic Determinants of Ethnic Segregation in Post-War Britain* (Jan. 1997)

13 Norbert Paddags, *The German Railways - The Economic and Political Feasibility of Fiscal Reforms During the Inflation of the Early 1920s* (Feb. 1997)

14 Cristiano A. Ristuccia, *1935 Sanctions against Italy: Would Coal and Crude Oil have made a Difference*? (March 1997)

15 Tom Nicholas, *Businessmen and Land Purchase in Late Nineteenth Century England* (April 1997)

16 Ed Butchart, *Unemployment and Non-Employment in Interwar Britain* (May 1997)

17 Ilana Krausman Ben-Amos, *Human Bonding: Parents and their Offspring in Early Modern England* (June 1997)

18 Dan H. Andersen and Hans-Joachim Voth, *The Grapes of War: Neutrality and Mediterranean Shipping under the Danish Flag, 1750-1802* (Sept. 1997)

19 Liam Brunt, *Nature or Nurture? Explaining English Wheat Yields in the Agricultural Revolution* (Oct. 1997)

20 Paul A. David, *Path Dependence and the Quest for Historical Economics: One More Chorus of the Ballad of QWERTY* (Nov. 1997)

21 Hans-Joachim Voth, *Time and Work in Eighteenth-Century London* (Dec. 1997)

22 Tim Leunig, *New Answers to Old Questions: Transport Costs and The Slow Adoption of Ring Spinning in Lancashire* (Feb. 1998)

23 Title reserved

24 Federico Varese and Meir Yaish, *Altruism: The Importance of Being Asked. The Rescue of Jews in Nazi Europe* (May 1998)

25 Avner Offer, *Epidemics of Abundance: Overeating and Slimming in the USA and Britain since the 1950s* (Nov. 1998)

26 David Stead, *An Arduous and Unprofitable Undertaking: The Enclosure of Stanton Harcourt, Oxfordshire* (Nov. 1998)

27 Oliver Grant, *The Diffusion of the Herringbone Parlour: A Case Study in the History of Agricultural Technology* (Dec. 1998)

28 Antonia Taddei, *London Clubs in the Late Nineteenth Century* (April 1999)

29 Liam Brunt, *Estimating English Wheat Production in the Industrial Revolution* (June 1999)

30 Matthew Braham, *Volunteers for Development: A Test of the Post-Materialism Hypothesis in Britain, c. 1965-1987* (June 1999)

31 Paul A. David and Gavin Wright, *General Purpose Technologies and Surges in Productivity: Historical Reflections on the Future of the ICT Revolution* (Aug. 1999)

University of Oxford

Discussion Papers in Economic and Social History

are edited by:

papers may be obtained by writing to
Avner Offer, Nuffield College, Oxford, OX1 1NF email:avner.offer@nuffield.ox.ac.uk