Wirtschaftsuniversität Wien

Vienna University of Economics and Business Administration

Working Papers Series:

Growth and Employment in Europe: Sustainability and Competitiveness

Working Paper No. 15

The creative response in economic development: the case of information processing technologies in US manufacturing, 1870-1930

Andreas Reinstaller and Werner Hölzl

June 2001

This working paper series presents research results of the WU-Research Focus:
Growth and Employment in Europe, Sustainability and Competitiveness
The papers are available online under: http://www.wu-wien.ac.at/inst/vw1/gee/workp.html

The creative response in economic development: the case of information processing technologies in US manufacturing, 1870-1930

Authors note: This is a draft and subject to change

by

Andreas Reinstaller
MERIT - Maastricht University
POB 616
NL – 6200MD Maastricht
Tel.: +31 (43) 388 3865
e-mail: a.reinstaller@merit.unimaas.nl

and

Werner Hölzl
Vienna University of Economics and Business Administration (WU)
Augasse 2-6
A-1090, Vienna, Austria
Tel.: +43 (1) 31336-5253
e-mail: whoelzl@isis.wu-wien.ac.at

Abstract

This paper presents a theoretical framework along "Classical" lines in which Schumpeter's concept of "Creative Response" is linked to a theory of induced innovation and the concept of technological regimes. We devote particular attention to the role of indivisibilities between factors of production. On the basis of this framework, we study the adoption of early information technologies, such as typewriters, calculators or Hollerith machines in US manufacturing in the period between 1870 and 1930. We show how the presence of a distinct bias in technical change in US manufacturing led to the opening of a window of opportunity for early information technologies, and how the presence of this bias influenced the technological search and adoption process of firms and how this found its final reflection in the rules and heuristics of the new regime.

Acknowledgements

Comments and discussions concerning an earlier draft of this paper by Robin Cowan, Daniel Eckert, René Kemp, Alessandro Nuvolari, J. Hanns Pichler, Reinhard Pirker, and seminar participants at the Vienna University of Economics and Business Administration are gratefully acknowledged.

Keywords

Technological regimes, systemic innovation, adoption of technologies, path dependence, information technology 1870-1930

JEL

D24, N60, O31, O33, L69

1. Introduction

According to Smith, Ricardo, Marx and later Schumpeter the capitalist economic development is in essence a continual reconfiguration of production and distribution processes. It can take the form of incremental changes or become manifest through radical departures from established practices, which may cause shifts in the technological system or give rise to new techno-economic paradigms (Freeman and Perez (1988): p. 45-47).

If a change in a techno-economic paradigm takes place then a large number of economic subsystems will change as well and a number of new technological regimes (Dosi (1982)) will be established. Most of the heterodox approaches to technical change find it difficult to capture such phenomena adequately, partly because they take an aggregate view, and partly because they lack an explanation for microeconomic incentive structures.

In the Marxian tradition for instance radical change in the capitalist system would be considered to come along with a raise in labour productivity and a fall in the productivity of capital, with the labour displacing Babbage principle dominating any technical advance (see e.g. Hecht (2001)). Even though Marx' work and studies in his tradition (e.g. Braverman (1974)) have provided evidence for this, it may not be the rule, as historical time series suggest (see Duménil and Levy (1995)).

Kaldorian analysts instead would be likely to link the phenomenon to changes in the patterns of capital accumulation and enlist the embodiment hypothesis. Even though this approach is important as it rejects the neo-classical notion of malleable capital, it lacks an elaborate model of how the "clay" character of capital influences investment decisions, especially under conditions of economic strain.

Evolutionary theories have taken a more differentiated view: on a high level of aggregation the transition from one techno-economic paradigm to another is viewed as a substitution process in which a more efficient technology system gradually drives out the established one (examples are Duménil and Lévy (1996) and Silverberg and Lehnert (1993)). On a sectoral level evolutionary work has provided much insight on the dynamics of entry and exit, but has largely failed to provide a satisfactory concept of technological search and adoption (see Malerba and Orsenigo (1995), Metcalfe (1998)). Firms are assumed to merely stumble over a new technology in a stochastic search process, taking place in the neighbourhood of their actual technology.[1] These models are able to capture the path-dependent character of techno-economic development, but they don't tell us why - given a specific institutional and economic environment - one location in the spectrum of techniques is preferred to another, how any change is timed, and once a location is chosen how this choice influences the activities and related heuristics of the technological regimes that are established around that location.

The aim of this paper is to do a humble step in that direction. We believe that for the analysis of changes in the technological system or techno-economic paradigm shifts the influence of prices on unit costs (instead of the other way round) as well as the role of indivisibilities in technologies should not be neglected. By borrowing some of the concepts of the theoretical approaches mentioned before, we attempt to sharpen Schumpeter's concept of creative response (Schumpeter (1947)) and study the technology adoption decisions of firms in a changing environment. For this purpose we have chosen the historical case of the adoption and enforcement of early information technologies in US manufacturing.[2] We build on and complement contributions of Freeman (1989)

---

[1] The diamond metric in Nelson and Winter (1982) or the innovation region in Duménil and Lévy (1996) are examples for this.

[2] By early information technologies we mean all mechanical and electromechanical devices developed for and used to store, handle and process data. The specific technologies studied here comprise typewriters, calculators, file systems, pneumatic tubes etc. We have termed this regime the "First IT Regime" in order to distinguish it from the diffusion of

and David (1991), as well as David and Wright (1999), who in their discussions of the diffusion of electric power generation technology in the late nineteenth century have repeatedly underscored the importance of parallel innovations in the management and administration of firms.

2. Creative response: the choice of technique, its technical bias, and technological regimes

2.1. Choice of technique and technical bias

The adoption of a new technology is the result of an investment decision of a firm. Under competitive conditions a firm will choose a technique that minimises its current and near term cost and allows obtaining a supra-normal profit.[3] The cost structure of any given technique is very likely to depend on specific environmental and institutional factors. They determine its viability and constrain the firm's technology choice directly or indirectly. If the constraints are constant over some period of time, then a systematic bias is likely to emerge in response to the persistency of given factor price relations in the economy. In general the technology should be biased towards the relatively less scarce factors entering production. This is also plausible if it is assumed that through a unit of research investment factor savings of equal proportion can be achieved. Then the return on the research investment in the more expensive factor will be higher (Binswanger and Ruttan (1978): p.25) and constantly higher relative prices of the scarcer inputs will point to the higher cost-saving potential. If the socio-economic environment changes firms will try to adjust their technology accordingly.

It is useful to distinguish between the influence given environmental and institutional conditions exert on the proportions in which factors enter production and their influence on the scale of output. We will first study the effect on proportions. Let us assume - in a Classical fashion - that capital goods are infinitely accumulable as they are produced means of production. Natural resources instead may be available in the quantities needed in the short run, but as they are non-accumulable means to become scarce in the long run.[4] Labour, finally, may be scarce in the short run and become abundant in the long run depending on the type of activities performed and the scale of production. To classical economists changes in labour supply are endogenously determined, as the process of accumulation will lead to an increase in real wages followed by an entry of new labour power.[5] But this assumption is plausible for unskilled labour only. Skilled labour instead needs training and education time. It is not immediately available in the quantities needed. For this reason the entry rate of skilled labour in response to a changing level of the reservation wage is likely to be in-elastic in the short run. Under the given assumptions the observed proportions for some resources and skilled labour should be below average, i.e. a technical bias that saves on resources and skilled labour should be observed.

---

semiconductor devices and related data-processing machinery starting from the middle of the twentieth century, associated with classical studies such as Perez (1985), Dosi (1984), Malerba (1985) or Freeman and Soete (1994).

[3] Although we do not postulate that firms indeed follow such behaviour, it will become clear that the assumptions put forward in this section suffice to describe the development of the First IT Regime. In the exposition we draw on David (1975): chapt. 1, Radner (1975), Binswanger and Ruttan (1978): chapt. 2, Nelson and Winter (1982), Kurz and Salvadori (1997) and Foley and Michl (1999).

[4] We have to distinguish between non-reproducible resources and exhaustible resources. The former do not exhaust, but are of limited size and show diminishing returns as intensity of use increases, while the latter merely "evaporate" due to the entropy law and become increasingly scarce. Economic history shows that even though exhaustible resources are limited and single deposits exhaust, in most cases new deposits are found. It follows that only in a situation where demand is such that there are capacity constraints decreasing returns arise, as also the least profitable deposits have to be exploited (see Kurz and Salvadori (1997); p.359 ff).

[5] Different traditions of thought give different explanations: Technical progress may be thought as setting free enough workers or the real wage may lie over the reservation level of some part of the potential workforce.

It is important to consider at which points in time the quantity constraints on the factors become binding. Skilled labour may plausibly be considered being available in abundance in the long run, as in analogy to unskilled labour it will be produced endogenously to the economic process, but as not being immediately available in the short run. Natural resources instead may in general be available immediately but become scarce as the depletion of their funds reaches its limits. In the short run skilled labour scarcity and resource abundance should produce a bias bending towards a more intense use of capital and resources, while in the long run skilled labour abundance and increasing resource scarcity may eventually reverse this trend. However, we have also to take into account the influence of the scale of production in order to get to a more general statement on the causes of technology adoption.

It is a common conjecture that each technology has an optimum scale of operation. The larger the scale of production, the more stringent will factor scarcities be felt. As the proportions at which factors enter the production process are quasi-fixed for each technique in the short run, a shift in the scale will increase unit costs for any technique operating at or close to its optimum scale. This will induce cost minimising firms to switch to techniques using scarce factors at a lower intensity. From our conclusion before we may deduce that a substitution of skilled labour for capital and resources in all successively adopted technologies will take place, safe that the composition of output and the rate at which shifts occur as well as their sign remain stable over time. This is the situation we find in the historical accounts on the development of the US economy in the nineteenth century (see section 3). If we consider instead the case where the sign of the shifts in output changes frequently and/or the composition of output changes due to an unstable composition of demand, cost-minimising firms will attempt to keep the utilisation rate of capital at the highest possible level, as capital represents fixed costs of production whilst labour is a variable cost component. For this reason they may not have an incentive to build up capacities through an increase of the capital stock, but to use skilled labour more intensely, which in situations of positive output shifts will drive up wages, but allow adjusting quickly to changes in the size and composition of output. This was the situation in the United Kingdom in the nineteenth century (see Habakkuk (1962), and especially Fries (1975)).
From this discussion it becomes clear that the environmental conditions determining the size and the composition of output, will act as a signpost in the search for alternative techniques in the way postulated by Nelson and Winter (1982). They will give rise to technological regimes. It should hence be possible to deduce some general characteristics of the heuristics emerging in these regimes from the general technological bias in the economy in which firms act.

2.2. Technical bias and technological regimes

A starting point for such an analysis is the approach suggested by Saviotti and Metcalfe (1984) who characterise a technological regime through what they have called *process technology* – i.e. the characteristics of the processes used for the production of technologies with certain technical characteristics - as well as through the *product technology* – i.e. the services these technologies provide to the user given certain technical characteristics of the final product.[6] Our analysis here is concerned with the general properties of the product technology vector and its co-evolution with the process technology of any potential technology. Here a few more considerations on the characteristics of a technology are in place.

---

[6] More formally Saviotti and Metcalfe (1984) assume a vector of technical characteristics: $\mathbf{x} \rightarrow \mathbf{t}$, which gives the process technology, with $\mathbf{x}$ being the input vector and $\mathbf{t}$ representing the technological characteristics. The vector of process characteristics in turn spans a Lancasterian service characteristics space: $\mathbf{t} \rightarrow \mathbf{s}$. This projection is called product technology. Assuming a simple linear transformation the latter relationship may be described by a linear system of inequalities $\mathbf{At} \geq \mathbf{s}$, with $\mathbf{A}$ being the transformation matrix. $\geq$ reflects the constraint that a minimum number of technical characteristics must be present in order to give rise to a viable product technology. The discrepancy between product and user technology determines the development pattern of the industry producing the technology as adopters act as selection mechanism of technological designs, see Windrum and Birchenhall (1998).

In the crude state of technological development the production of any commodity may be assumed to be non-separable in its inputs and to enter the production process in virtually fixed proportions. In an expanding economy this would lead inevitably to diminishing returns, as the non-accumulable inputs represent a limit to growth, which has to be compensated. As a consequence cost-minimising firms will search for techniques of production, which use accumulable factors at higher intensities, i.e. they will try to make the production process as independent as possible from non-accumulable or otherwise scarce inputs. Analysing the problem by factor classes one recognises that the production process will always be indivisible from resource use. Fixed capital by itself is produced of matter and due to the entropy law all resources will eventually become scarce. A higher intensity of use of fixed capital may also come along with a more intense use of variable capital, especially when the state of art in technological development is such that the tools applied operate in a rather resource using way. The only way out of this conjectured dilemma is to gradually substitute scarce for less scarce resources, to use more resource saving technologies which can be achieved either through the overall reduction or an increase in the intensity of use of joint products or through the closure of material cycles.[7]

A high degree of separation of the production process from specific types of labour is nevertheless possible. It is achievable through the codification of activities and their transformation into blueprints. The division of labour is a mean to reduce the tacitness of knowledge in the production process and shorten the time needed to produce specific skilled labour types.[8] Knowledge on the workflow of a given production process is codified into specific designs and sequences of activities, which now can be executed jointly. This reduces education time of skilled workers, speeds up production and gives rise to disembodied technical progress. Once the division of labour has progressed so far that the original skills are reduced to single chunks of interrelated information, a complete codification and a subsequent embodiment into specific mechanic movements of machines becomes possible. Roundaboutness of production is so substituted for education time. The degree to which this will happen will depend on the one hand on how economical the embodiment of skills is. The costs of codification may plausibly be considered an increasing function of the complexity of the involved knowledge. On the other hand the viability of an embodiment strategy depends on the recurrence of specific tasks as well. If the latter change continuously, embodiment is not a feasible option. The fundamental characteristic of technologies and the specific technological bias of a socio technical environment influence the character of operational heuristics of the regime, which represent the linkage between the single elements in the input vector of new activities. They shape the service characteristics adopters require from a new technology.

Even though we limit our analysis to the case where skilled labour is comparatively more expensive than capital and a shift in the scale of adopters processes takes place, the analysis could easily be generalised to any constellation of demand composition, scale and technical bias. From what has been said before we should expect the new processes to run at a higher capital intensity, than previous activities. This means that the capital-labour ratio should increase over time towards a technologically optimal configuration. Of course this trend could also be reversed, if capital saving innovations in other activities take place.[9] The technical characteristics of the new technologies should be such as to allow a maximum degree of separability between the factors, or

[7] The qualifications of footnote 4 nevertheless apply.

[8] By tacit knowledge we mean specific process experience and expertise acquired by an operator of a technology through the work with it, by refining and developing some basic operations. This reflects the properties of knowledge, which represents the capacity of an individual to link pieces of information and basic actions in a way that he or she can creatively operate with it. This tacitly acquired knowledge is not codified as it is context dependent and reflects the intellectual history of the operator. The transfer to other individuals thus cannot be immediately.

[9] This is not a contradiction to what has been said, we have just to consider innovations that substitute some capital intense sub-processes in each firm with the production of the substitute taking place in a centralised form. Nevertheless, in the analysis developed so far we would have talked about such a case as a paradigm shift, as the fundamental relationship between input factors has changes.

in other words show a maximum of embodiment. Where this is not possible at all or only to a very limited extent, human-machine interfaces are likely to play a crucial role, as they represent the part of the technology that links labour and capital and therefore the locus where human skills are translated into mechanical operations. In the search for a separable design standards are of uttermost importance, they are a necessary condition for an increase in the division of labour and disembodied technical progress.[10] The specialisation of skills and standardised activities are thus a premise for an increase of productivity. The design of standardised human-machine interfaces that allow for specialisation is essential. In cases where an embodiment was not possible, we should expect the emergence of new professions of skilled workers being specialised in the operation of one particular interface of a machine. By that the time education time and hence the pressure on the factor prices and the labour market should decrease. In the case where full embodiment is possible, the interface is not important and embodied skills become obsolete. This will reduce the skill requirements and thus shift labour inputs from the skilled to the unskilled pool.

3. Changes in the constraints in American technology in the 19th century: the opening of a window of opportunity

3.1. The Bias in American technology and the American System of Manufactures

There is substantial agreement that the cause for the American capital deepening bias are related to three factors: First, the *shortage of skilled labour* provided a strong incentive to embody knowledge into capital and use unskilled labour instead, which was available due to the abundant inflow of immigrants (Habakkuk (1962), Rosenberg (1976), Montgomery (1987)). Second, the relative *abundance of natural resources* in wood, water, carbon and ores allowed a resource and capital intense mode of production (Abramovitz (1989), Wright (1990), Rosenberg (1976)). And third, the *structure and growth of demand* favoured the production of homogeneous goods on large scale, as demand was growing at the pace of the increasing population, which more than tripled in the five decades between 1850 and 1900 (Burn (1931): 306; Abramovitz and David (1995): 17).[11] The relatively low spread in income distribution and the high pace of expansion of demand made the United States a seller's market, where the satisfaction of given needs was more important than the *variety* of given products. The combined effect of these factors explains why foreign observers noticed that American producers tended to "overlook defects [of machines] more than in Europe" and were "satisfied if a machine intended to supersede domestic labour [would] work even imperfectly" (Burn (1931): ibid). The technological development in the US was located at and biased towards the capital intense end of the spectrum of feasible techniques (Ames and Rosenberg (1968), Abramovitz and David (1973), Rosenberg (1976)).

The stability of the factor price relationship determined embodied technical progress (David (1975): p.88) and the specific composition and scale of demand favoured the production of standardised final goods. In reaction to these circumstances a new mode of production emerged in the mechanical industries and spread from there to different sectors of the economy. Firms had started to direct their attention towards the development of a specific production method, which used standardised parts produced by means of specialised machine tools. This lowered the dependence on critically skilled labour, but came at the expense of a more intense use of natural resources (Ames and Rosenberg (1968): p. 831). The American System of Manufactures, as it has been called, emerged in the 1840s (Hounshell (1984), Hoke (1989)). This mode of production was economically viable only when production and assembly were carried out within one plant, as the high capital costs could be offset only trough lower costs in the assembly and product design

[10] In more recent literature on industrial organisation authors are mostly concerned with how inseparabilities and standards between technologies are a result of strategic behaviour.
[11] The population grew from about 23 million in 1850 to 76 million in 1900, reaching 105 million in 1920.

processes. This contributed to increase the minimum efficient scale of operation and firm size (Fries (1975): p.384).
It becomes evident that the American System of Manufactures in the United States is an archetype of a national style of production and technology if it is compared to the British development. In Britain more marked differences in the distribution of income and relative scarcity of natural resources favoured a labour intense but resource saving increase in the division of labour which gave rise to a system of vertically disintegrated but highly flexible shops which could match quickly changing demand patterns (Landes (1969): chap.2, Fries (1975): p.384). It becomes evident here that macroeconomic conditions had an influence on micro-level technology choices.

3.2. The opening of a window of opportunity and the formation of a niche of application for information technologies

3.2.1. Inconsistencies in the American production system and the emergence of large business organisations

The information structure of the manufacturing enterprises in the US in the period of dominance of the American System of Manufactures was rather simple. Firms were single activity units specialising in distinct niches in production. As long as they remained relatively small information was available in an informal way at virtually no cost.
Larger manufacturing firms relied on a decentralised and distributed form of shop-floor control called *inside contracting* (Littler (1982)) where the plant manager contracted internal craftsmen to organise the production of a given number of items in a given period of time for a negotiated price using the manufacturer's factory, tools and materials. The contractor managed his own workforce and organised work. Inside contracting system was an efficient method of indirect control, as it avoided administrative overheads by acting partly "as a substitute for accounting" and distributed the risk of operations (Hopper and Armstrong (1991): 415). The accounting records reflected external market transactions and contained virtually no information about internal operations.

In the period between 1870 and 1900 the competitive pressure intensified due to the development of continuous process technologies and the extension of transportation and communication networks. The increasing urbanisation of the US led to a change the patterns of demand making it more volatile leading to an inconsistency of the production system. Depressions occurred in the 1870s and the early 1890s (Fullerton (1988): p.111). The growth rate of the US economy slowed down from an average value of 6.55 % in the period 1879 to 1888 to 3.35 % in the period of 1889-1889.[12] This development caused also a persistent fall of the profit rate and an economy wide fall of the capital utilisation rate in the years between 1889 and 1898 (Duménil and Levy (1995): p. 354-56). The American System of Manufactures approached a technological and organisational bottleneck.

Business managers realised that the tendency towards mass production of the American System with its capital-intensive and overhead-sensitive mode of production, required a large, steady and predictable demand to assure an adequate return on investment, which could be guaranteed only by a high and constant capacity utilisation. Firms started pursuing market segmentation strategies through new product designs, advertising and geographical diversification. In order to co-ordinate production and distribution, mass producers integrated vertically into distribution. The strategy of firms was to set up networks of agreements, pools and trusts in order to reduce the pressure on profits. As antitrust legislation discouraged these forms of organisation the large enterprise emerged on the scene. The “corporate revolution” gained momentum after the depression in the

[12] See Kendrick (1961): table A-XXII: p. 333-35. Also Total factor productivity calculations show a marked slowdown of total factor productivity in manufacturing in the period between 1889 and 1929 (Kendrick (1961): table D-I: p. 464 and David (1991): table 2 and figure 4, p.323).

1890s, when a massive merger wave merged interdependent enterprises into more and more vertical integrated units with common ownership. The rise in size required new methods of management for the co-ordination on the shop floor and new forms of finance as larger funds had to be collected. Therefore the emergence of the managerial enterprises integrated the two main aspects of keeping the profit rate at a high level. Their emergence went hand in hand with advances in organisation and technology within firms and the rise of finance and the stock market, representing the allocation of capital among industries and firms.
The multifunctional managerial enterprise (or the U-form) emerged, but this required the set up of an administration. The transformation of the enterprise form a purely productive entity towards the modern large enterprise, with its differentiated activities, its hierarchy and a network of complex communication channels and information filters acting "as a substitute for market mechanisms" (Chandler and Daems (1979): p.4) took place gradually.

3.2.2. The opening of a niche of application for information technologies: new business organisations and clerical labour shortage in the late 1870s

As competition was stepped up cost control became important, but with the inside contracting system it was impossible to obtain precise and comparable cost data. The first response to this problem was the Systematic Management movement, which "based its reassertion of control and co-ordination on record keeping and flows of written information up, down, and across the hierarchy" with the aim to "transcend reliance on the individual in favour of dependence on system" and to monitor and evaluate performance (Yates (1989): 10-11). In the late 1870s manufacturers began to introduce labour cost records and to pay wages directly to employees. This allowed to monitor the performance of single workshops, reduce the variance of cost, to redistribute profits from the contractors to the manufacturers and led to the gradual demise of the inside contracting system, as salaried foremen replaced contractors.

The first flow control management systems were pioneered in the late 1870s. Thereby accounting was transformed from a method of record keeping of past performance to a current cost management tool. Reporting methods, cost accounting, production scheduling, incentive plans and other measures, were set up in order to create an unhindered flow of materials and information, to transfer authority from foremen to plant managers and force employees to pay grater attention to the management's goals (Litterer (1963)). Communication became formalised: the centralised staff department communicated downwards imparting the orders of the management, while foremen had to compile reports for the work office. The practical implementation of these systems led to the transfer of many of the foreman's functions and powers to centralised staff departments.

With the refinement and expansion of Systematic Management in the 1900s through the "scientific" principles enounced by Frederick Taylor, the bureaucratic control of the shop floor became even tighter. The division of labour was brought to its extremes. Standard costing became the chief monitoring instrument: "true" standard costs were based "on the engineering redesign and analysis of the labour process" as they are determined by the engineering staff (Johnson and Kaplan (1987), Hopper and Armstrong (1991): p.420). The combination of setting of "scientific and optimal" cost standards and the evaluation of performance with the help of variance reporting made standard costing such an effective instrument of management.

Business hierarchies grew from the top down through vertical integration and the take over of new functions, and from bottom-up as new hierarchical layers were introduced in order to gain control over the shop floor. The problem that arose under this circumstance was to reduce the delay of information flows. To handle this problem new information processing technologies and clerical staff to operate them were needed.

In the 1880s and the early 1890s the problem of labour supply of skilled clerical work was pressing. Clerical work had still the characteristics of a craft and there existed no vocational training institutions for that type of profession (Wooton and Kemmerer (1996): p. 549). The ensuing shortage was overcome by recruiting high school graduated women. Clerical work required English-language skills and a social background that excluded first generation immigrants and working class people. For these women opportunity to work as clerks were very attractive, as many other trades were inaccessible to them. The share of female clerks rose from 2,4% in 1870 to 35,9% in 1910.[13] They provided the material to fill up the typing, computing and book-keeping pools leading to a segregation of the labour market for clerical work along gender lines, where management activities were carried out by men and labour intense and routine operations were done by women (Hartman Strom (1992): p.287; (Davies (1988): p.30). After 1890 the number of private commercial schools increased very rapidly and their graduates contributed together with the increasing mechanisation of the office to relax the pressure on the labour market (Pirker (1962): p.69). The utilisation of the female 'reserve army' brought considerable cost savings as the earnings of female clerks were consistently 25 to 45 percent lower of their male colleagues (Hartman Strom (1992): p.290, Davies (1988): p.32). The average annual earnings of clerks in US manufacturing fell during the two decades between 1899 and 1919.[14]

4. The establishment of the First IT Regime in US manufacturing and the standardisation of office practices

“It was not an accident of fate” (Cortada (1993): p.63) that an office equipment industry was built up at about the time when large, multifunctional enterprises emerged by the early 1880s. Between 1870 and 1890 most information processing devices were invented and innovated (1873: typewriters, 1879: cash registers, 1885: calculators, 1889: Hollerith system, etc.), paralleled by complementary organisational innovations, new forms of distribution networks and marketing tools as well as innovations in the organisation of production. The new technological regime consisted of a number of (electro-) mechanical devices, such as typewriters, calculators, dictating machines, mimeographs, cash registers, timekeeping machines, automatic mailing machines, sorting devices, filing systems, etc. and supported the establishment of new standards of practice in office.[15] We will limit the scope of our analysis to typewriters, calculators, book keeping machines and Hollerith machines.

4.1. The search for new standards of practice and the rise of the office work paradigm

In the new large business administrations information was produced and processed for the first time on industrial scale. The shortage of clerical workers and low potentials for productivity advances made the constraints set by the terse labour market for clerical workers stringent in the 1880s. These circumstances resembled on smaller scale the situation that had led to the development of the American System of Manufactures four decades before. The standardisation of skills could hence be used as an method to relax the wage-pressure on the labour market.

[13] 1880: 4,3%, 1890: 16,9%, 1900: 26,5%, 1910: 35,9%, 1920: 48,4% and 1930: 52%, Sources 1870-1940: total Clerical Workers compiled form J.M. Hooks Woman's Occupations through seven decades US Department of labour 1947 and Historical Statistics, Abstracts of the US Series D57-71 Later: US Bureau of Census Statistical Abstract (1972).
[14] The average annual earnings of clerks in US manufacturing dropped from 1920US$ in 1899 (1929 prices) to 1385US$ in 1919. In the same period the average annual earning of a worker increased from 767,6 US$ to 784,9 US$, (Census (1976), P 1-12).
[15] Brauner and Vogt (1921) provide an almost complete listing of all the office appliances available round 1921.

One of the most interesting characteristics of the American System is that it represented a meta-heuristic or problem solving algorithm for any problem in the production sphere. It gained importance also in the efforts to restructure office work as engineers played an important role in the design of new administrative organisations and related office practices. They tried to cast the logic of the shop-floor into the organisational machinery: in accordance with their experience from the shop floor office machines had to be instrumental in realising a system of standardised activities aiming at the saving of skilled labour and time. The primary objective was to reduce the dependence of administrative processes on skilled clerical labour by increasing the separability of labour and capital good inputs. This process was analogous to the reorganisation efforts on the shop floor, where engineers had pursued the model of a system of modular production based on standardised parts and activities. Accordingly the key requirements of the new office machinery were summarised very concisely by Leffingwell and Robinson (1950): 282-3): "When should office machines be used? To save labour, to save time, to promote accuracy and to relieve monotony."[16]

The build-up of an administrative organisation consisted of two distinct but closely related steps. First, by standardising tasks, data and information channels the division of labour in administrative work was increased. This step was follow by the mechanisation of the activities.
The standardisation of data and tasks proved to be an important precondition for the introduction of office machines, as they could unfold their full productivity potential only if a smooth flow of standardised and indexed information was available. But this was possible only where information was quantitative, standardised or purely numeric. Knowledge intense activities or tasks involving the processing of qualitative data were not amenable to the embodiment strategy. In these fields office machines were applied to support the specialisation of labour in office work. Standardised human-machine interfaces became a crucial adoption criterion, as they were the basic technical element around which the activity and the qualification requirements could be shaped. Where this was not the case, their importance was secondary and hardly if ever any standardisation took place.

This becomes particularly clear for the development of bookkeeping practice. Bookkeeping was sliced into a sequence of distinct and specialised occupations. A change of methods, organisation and processes took place gradually. The first step in that direction was to separate data handling activities from activities of data analysis. The latter were not amenable to standardisation, whilst the first largely were. Thereby the dichotomy of bookkeeping and accounting emerged.[17] Bookkeeping activities in turn were divided into activities of work preparation and activities of data manipulation.

Work preparation tasks, such as the sorting of vouchers and receipts and the search of related ledgers, were executed without mechanical aides, but reached a high degree of specialisation in manpower. Data manipulation activities in turn entailed the codification, processing and evaluation of data and were supported by mechanical equipment (Pirker (1962): p. 81-3). Here adding machines, calculators, bookkeeping and billing machines or even Hollerith systems were adopted. The level of rationalisation and standardisation that was reached in each individual firm was dependent on the type of equipment used, which in turn was determined by the scale at which the information had to be processed.

All this had to be accompanied also be improvements and changes in bookkeeping practice as well as changes in commercial law and taxation. Bound ledger books and registers were replaced by a loose-leaf system of accounts (Wooton and Kemmerer (1996): p.553). Another major improvement was the single-entry system, by which, through the use of carbon paper, all the necessary entries in the different registers could be done in one single step (Pirker (1962): p.80). These changes in turn had to be sanctioned through changes in the legal system that regulated accounting practices.

[16] The citation summarises the headings of the sections in the chapter on office organisation in the reference.
[17] Bookkeeping refers to pure record keeping activities while accounting entails analytical activities.

The evidence presented so far suggests that office machines had to meet three necessary conditions in order to be adopted: they had to complement a function of the administration of a firm, and they had to have a cost minimising effect. The third and most important requirement was that they should allow increasing the independence of operations from scarce clerical labour, i.e. they should be instrumental in increasing the separability of office activities from the scarce input.

4.2. The product technology of office work

[Table 1: Early information technology: innovation characteristics of the most important technologies of the IT Regime, **about here]**

4.2.1. Typewriters and typing: technical characteristics, the viability of the technological choice and new activity profiles

Typewriters were the first technology of the new office work regime. Their domain of application were all activities involving the multiplication and distribution of information on small scale, i.e. in practically all functional fields of organisations producing mail, internal memos and communications, customer-, personnel- and bookkeeping records, contracts, etc. They supported co-ordination functions within the organisation. The information that was processed with them was qualitative and changing continuously, which made an embodiment of any type of skill impossible (Cortada (1993): p.23, Pirker (1962): p.53, Leffingwell and Robinson (1950): p.163).

SEPARABILTIY AND EMBODIMENT

The typewriter as technical artefact was an innovation but strictly speaking it did not represent a productivity increasing technical advance *in itself*. The mechanical construction of the typewriter did not embody any specific clerical knowledge or skills so that its use did not automatically lead to an increase in productivity. The crucial criterion for adoption of the typewriter became its (standardised) human-machine interface. The (quite special) interaction of service requirements and technological characteristics gave birth at first to the QWERTY keyboard, with which its inventors succeeded by way of a trial and error procedure to order the keys in a way that during high speed writing the types would not entangle (Adler (1973), David (1985)). The subsequent development of touch-typing played a crucial role in making the typewriter a viable technology for business administrations, as it contributed to produce a homogeneous labour supply, and to increase productivity. The co-existence of different keyboards with different practices would have lead to a segmentation of the labour market with an inevitably lower elasticity of supply.[18]
In the late 1870s Remington, the first mover in the typewriter industry, started setting up its own typing schools and to furnish trained (female) operators with each machine sold in one package (see Keep (1997): p.406). In 1882 a first textbook on the touch-typing method appeared (Martin (1949): p.479) as a result of the marketing efforts undertaken by Remington to boost the sales of its typewriters.

For adopting firms typewriters represented fixed capital therefore it was an obvious choice to organise their operation in such a way that their rate of utilisation was maximised. This led to the set up of centralised services for typing, (see Leffingwell and Robinson (1950): p. 34) and through that to functional office departments, which pooled standardised activities. The use of one single method proved to be an efficient monitoring tool, as variance measures could be used in order to evaluate the output of each single typist (ibid: p. 539). Typing became a profession and an administrative process on its own right. Typist had a sharply circumscribed activity profile which consisted in taking (shorthand-)notes and writing them on paper with the machine using a particular

[18] This argument was put forward by Gardey (1999).

typing method. Further improvements on the established standards of practice were attained through standardisations of letter styles and formulations, thereby influencing the way business correspondence was done (Leffingwell and Robinson (1950): p.143 ff.).

VIABILITY OF THE TECHNOLOGY AND THE DEVELOPMENT TRAJECTORY

After an initial period of fermentation, where different keyboard designs and typing methods competed for dominance, the QWERTY keyboard imposed itself as the dominant design. The technological closure took place after Underwood had introduced its Model 5 in 1895 that was the first to use a front strike design and the QWERTY keyboard with shift keys. It was superior to competing designs as typing speed could be increased further (see Knie (1991): p.117). By 1900 most of the technical features of the manual typewriter had been introduced. Further improvements regarded complementary technologies such as dictating machines and the electrification of the typewriter. Martin (1949) remarks, that already in the early 1920s the speed potential of the typewriter exceeded the capacity of typists by large. While a keyboard design optimised under an ergonomic perspective could have made typing user-friendlier, less onerous and less error-prone, the speed of typing could have been increased only marginally. The technological trajectory of the typewriter underscores the successful configuration of this design. Indeed, by using the touch typing method a skilled typist was able to type sixty words *on average*, which was twice as much as the speed *world record* for handwriting of thirty words a minute established in 1853 (Yates (1989): p.37). This was a remarkable increase in productivity. Considering that in 1879 Remington sold its Model II for 100US$ (157,3US$ in 1929 prices) a piece (Cortada (1993): p.17) and that by the employment of female typists the salary expenses could be reduced by 400 to 800 US$ a year per employee as compared to a male clerk, the choice of the typewriter reduced cost and increased the speed and the scale at which memos, letter and the like could be produced.

4.2.2. Bookkeeping devices and bookkeeping: technical characteristics, the viability of the technological choice and new activity profiles

As our discussion in section 3.2.1 shows the rise of large administrative organisations in the US manufacturing resulted to a large extent from an attempt to gather and evaluate more quantitative data on the production process with the aim of developing standard cost measures, analyse market development, derive operating ratios and deliver indicators for the management and investors. Bookkeeping and accounting became the most important set of organisational processes. It consisted in activities of gathering, classifying, coding, sorting, calculating, summarising and reporting of information. Positions as a bookkeeper required individuals to have reading and mathematical skills. The capability to perform simple mathematical operations was of foremost importance: rationalisation studies showed that almost 60% of all tasks performed in office work consisted of calculations that consisted to 80% of counting and adding (Pirker (1962): p.66). For information to be a valuable source for managerial decision-making the data had to be processed quickly and without mistakes. It does not take by surprise that adding and calculating machines became the second main pillar of the First IT Regime.[19] Most of these devices were innovated in the late 1880s, but diffused only about ten to fifteen years later on a larger scale.[20]

SEPARABILITY AND EMBODIMENT: CALCULATORS AND BOOKKEEPING MACHINES

Adding and calculating machines were general-purpose tools, as typewriters. They were applicable to a vast range of uses, such as the calculation of daily ledger and cash balances, daily recapitulation, the checking of invoices, freight bills, disbursements and so forth. The mechanical

[19] Adding machines could only perform additions and in rare cases also subtractions, while calculators could perform all the basic arithmetic operations and some more elaborate mathematical operations, like calculating directly percentages.

[20] An explanation for this slow initial diffusion speed may be seen in the fact that bookkeeping practice and related legislation had to change as well.

adding mechanism of these machines embodied the most important skill of a good bookkeeper: quick and reliable adding.
Bookkeeping machines evolved out of other office appliances and entered the market only in the 1920s. In most cases they were tailored to specific uses and were essentially combinations of an adding machine with a typewriter or just normal adding machines with mechanisms allowing special carriage movements. The domain of application was similar to that of adding machines.

On a small scale adding machines and calculators were adopted in order to support accounting clerks in their work. In this field their use favoured a more rational design of the workplace and a more rational work preparation. If the volume of data was large computation pools were set up or alternatively the work was sourced out to specialised firms. The operators of the large accounting and adding machines used there could be introduced to the work very quickly. Typical candidates for these jobs were female grammar school graduates, who were able to learn the use of these machines within a few days (Pirker (1962), p.82). No profession with a specific skill profile appeared, as it had been the case for the typewriter. The reliability and the speed of the computing mechanisms dominated all other considerations, and the human-machine interface played only a secondary role. Comptometer Co. and Burroughs, the two first-movers in the industry, offered full keyboard machines with 81 keys. Dalton and Sundstrand, the two most important followers in the industry used 10-key keyboards. Both designs co-existed up to the 1950s. The two elements determining the lock-in of skill and keyboard in typing were irrelevant for these devices. The interface never obtained the same importance, as the locus of the labour saving potential was embodied. Basic accounting and billing activities became separable from skilled labour inputs.

VIABILITY: CALCULATORS AND BOOKKEEPING MACHINES

The rationalisation effect of calculators and bookkeeping machines consisted in two main features: first, long rows of numbers could be condensed into one single key figure much faster than before. Second, some machines incorporated automatic control devices so that wrong entries were almost impossible. By that the accuracy of these sensible operations improved substantially.
Some optimistic and perhaps overly simplistic studies cited in Pirker (1962), p. 67, found that a well-trained machine operator was able to do the work of three clerks, resulting in savings of in total salary costs of up to 70%. In 1885, in the year of its market introduction, Burroughs offered its machines for 790US$ (1929 prices; Cortada (1993): p.32), the adoption of calculators was a cost saving strategy for large and medium-sized firms
Only for larger firms accounting machines were viable choices. The rental rate ranged from 150 to 500 US$ a month (165-520US$ 1929 prices; Cortada (1993): p.125), summing up to an annual expenditure of 1800 to 6000 US$ a year which amounted to the annual salary of one to three clerks. Taking into account the productivity factors that could be achieved by the application of such machines shown in Table 2 savings were considerable: current account transactions could be carried out ten to twenty times faster as a single clerk could do in purely manual execution.

[Table 2: Data processing capabilities of early accounting machines round 1926**, about here]**

SEPARABILITY AND EMBODIMENT: HOLLERITH MACHINES

Hollerith and Powers machines were very different from the previously listed technologies. They represented a system of electromechanical devices conceived in order to codify and operate on quantitative data on a large scale. They were first developed for public institutions with the purpose to speed up counting and sorting processes, which were prone to mistakes and very laborious. Large business firms discovered the value of these machines soon, as these machines could be used to tabulate sales statistics, sort consumer trend analyses, for payroll and inventory management, etc.[21] A tabulating system consisted of punched cards which were the media on which operating

[21] The first business user was the New York Central Railroad in 1896 using Hollerith gears to process up to four million freight bills a year in order to produce summary reports more frequently. After 1900 large firms in other sectors than

instructions and information were stored, card punch machines, used to transfer the information on the cards, sorting machines and a tabulator used to count the sorted cards. The sorters could be programmed with other punched cards on which a sorting routine was codified. This allowed these machines to be re-programmed and made them very flexible.

This technology was used to process company wide data on a large (industrial) scale. Unlike adding machines, they were not just mechanical supports for a given problem, but were an integral part of a larger information system. This becomes clear if we consider that to sell such devices "a salesmen had not to sell the machine but the organisation" (Pirker (1962): p.79). Salesmen acted as technical advisors as well as organisation designer. Organisational concepts developed for businesses in one particular sector were then used as a blueprint (and sale argument) for other firms in that sector (McPherson (1992)).

The operation of these machines was split into three distinct activities: (i) the codification of sorting and tabulating routines, (ii) the codification of the information to be evaluated and (iii) the evaluation itself, i.e. the actual sorting and tabulating of information. Accounting and organisation specialists carried out the codification of routines. Specific sorting and tabulating processes were stored on punched cards and used when necessary. The programming of routines and routine sequences was an activity that happened only sporadically at the set up of the machine and subsequent organisational changes. The codification and evaluation of information were instead recurrent tasks.

Through their codified programs these machines embodied procedural knowledge on clerical operations on a hitherto unknown extent and almost completely isolated productivity increases in data processing from the skills of the operators of these machines.[22] With the appearance of tabulating machine rooms "for the first time something appears in the office, that can be compared to the working practice on the shop floor" (Pirker (1962): p.95 own translation). The high specialisation and division of labour typical for the shop-floor in the American System found its correspondence in a number of new occupations, that differed mainly in their skill profile: key-punch operators codified and controlled the information; sorters were responsible for the supervision of sorting and tabulating processes; lead-machine operators (also called tabulators) were responsible for the wiring of the control panels and the verification of the machines and programmers finally were responsible for the cybernetic part of the job: programming and designing process flows. The skill requirements increased in ascending order: the skill requirements for key-punch operators and sorters were primary school degrees, tabulators needed to have specific technical skills and held therefore mostly secondary school. The few needed programmers were university graduates in mathematics or engineering and were seen as professional organisers and operated in a middle management environment (see table 1 for a overwiew on skill profiles and training periods).

VIABILITY AND TRAJECTORY: HOLLERITH MACHINES

As Table 2 shows, the volume and the speed of information processed shifted upwards by two to three orders of magnitude. The bottleneck remained the codification of the data. Yet this operation was carried out faster on punch card machines than on any other data-processing machines. In 1896 Hollerith offered his machine for a yearly rental rate of 1000US$ (approx. 1950US$ 1929 prices) and sold a package of hundred cards for one dollar (2 dollars in 1929 prices). A large firm used

---

railroads started using these equipment as well. The first business users were insurance companies, which used the machine for evaluating mortality statistics. Among other large firms were Marshal Field, Eastman Kodak, Scoville Co., National Tube, Pennsylvania Steel, Western Electric (see Cortada (1993): pp. 50 and 54 and Yates (1993)).

[22] Exceptions were keypunches. Their efficient operation relied on the speed with which the codification could take place. In first place this led either to the adoption of the typewriter keyboard (for alphanumerical insertions) or a 10-key keyboard (for purely numerical insertions) with the keys ordered in four rows. Both allowed using touch-typing methods. As the codification of data continued to be the bottleneck in this technology, the use of standardised interfaces was important.

several millions of these cards each year. In the 1930s the rental rate ranged from 3000 to 6000 US$ a year (Cortada (1993): pp.49-50). The enormous productivity possibilities made tabulating gears viable for large firms.

The degree of skill embodiment of most of the technologies finds its reflection also in their technological trajectories. The last column of Table 1 shows that the improvements regarded mostly the data throughput, processing speed, the simultaneous data processing capability and widening of the scope of application of the devices.

4.3. The technological bias and the economic implications of the adoption of the First IT Regime in US manufacturing, 1889-1937

The historical record presented so far suggests that there was a capital deepening bias in the development of the First IT Regime. We put forward the hypothesis, that given the peculiar characteristics of the American technological style, the capital intensity of office work should have been increasing. In support for this conjecture we find, that the per-capita value of capital used for administrative purposes in relation to administrative personnel (C_{office}/L_A) in US manufacturing increased over the years between 1889 and 1937 (table 3). However, this ratio does not tell whether these changes were due to a general tendency in manufacturing to increase the capital stock at any level of employment or whether the ratio increased even though the number of clerks increased. Indeed the capital-labour ratio for manufacturing as a whole (C_{tot}/L_{tot}) and the capital-labour ratio for office work (C_{office}/L_A) do correlate over the whole period (table 4, first row) in a statistically significant way. The degree of mechanisation (C_{office}/L_A) and the degree of "bureaucratisation", (A/P) given by the ratio of clerical to production workers are positively correlated (table 4, third row), supporting the hypothesis that the capital intensity in office work increased in a period of expanding business administrations. But this does not take in account cost related substitution effects, which are at the core of our hypothesis.[23]

[Table 3: Capital-labour relationships in US manufacturing and the First IT Regime and its bias in technical change, 1889-1937**, about here]**

The changing relationship between capital stock and labour is measured best by the ratio of the value of capital stock per man-hour to wages or salaries per man-hour (CMH_{total}/WMH_{total}, $CMH_{office}/WMH_{office}$,). Now the picture turns ambiguous.[24] The data in table 3, row 3 shows that production in overall manufacturing was capital intense, but the ratio declined after 1899 and started levelling out only in the late 1920s. Office work remained labour intense over almost the whole period (table 3, row 4). The value of capital as well as the wage costs fell over the period between 1899 and 1919 corresponding to a general slowdown in total factor productivity, reaching their lower peak between 1909 and 1919. Taken over the whole period the value of office capital employed per man-hour increased steadily. Nevertheless, in the decade between 1919 and 1929 the unit-salaries almost doubled and reached a level that remained constant for the three decades that followed. While all the other factors grew in close relationship to total factor productivity, unit-salaries grew over-proportionately and the increase of the unit value of office capital slowed down. This suggests that the capital intensity in the office increased up to 1929, when the large office machine pools were set up. Up to the late 1920s the degree of mechanisation of office work followed the grand pattern of the American System and changed thereafter. By that time most of the office machine pools had been set up. Nevertheless, office work remained a labour intense because of the remaining knowledge intensity of many clerical and managerial activities, so that the

---

[23] We cannot account for changes in productivity of the single factors as for office work as there is no adequate output measure, nevertheless, the single factors of the coefficients strongly correlate with TFP in manufacturing (Kendrick, 1961: table D-I) over the period 1889 to 1937: CMH_{off} r= 0,65, CMH_{tot} r=0,91, WMH_{off} r= 0,93, WMH_{tot} r=0,97.

[24] For the sake of shortness we will call the capital stock per man-hour unit-capital stock and the wage/salary per man-hour the unit wage/salary.

same degree of mechanisation as on the shop floor could not be reached in office work. The diverging growth pattern between wages and salaries which increased the wage premium on clerical work, suggests that the productivity of clerical work had sharply increased between 1919 and 1929.[25]

In the period between 1889 and 1937 the development of capital intensity in the manufacturing sector as a whole started diverging from that in its administrative units: the unit value of capital in relation to the unit wage declined. This development stands in contrast to the logic of the American System of Manufactures where capital replaces labour. The degree of electrification negatively correlates at high significance levels with the unit capital-labour rate (table 3, row 6). After 1899 a paradigm shift of production had taken place when electric power replaced steam as primary source of energy. The use of electric power drives in industry saved fixed capital (David, 1991: p.334), therefore the real rate of accumulation declined. Capital costs could be lowered through decentralised power units and the possibility to transport energy over long distances brought energy even to the remotest places. Energy intense production methods no longer depended on the presence of a factory owned power generation unit. This shows that even though electrification and bureaucratisation overlapped, the scope of these technology adoptions differed, as electrification was a capital saving technical progress.

[Table 4: Economic effects of the First IT Regime in US manufacturing: correlations.**, about here]**

The question remains, whether the adoption of the First IT Regime indeed helped to lower production costs and to achieve "economies of speed". Table 2 shows that office machines increased the speed of clerical operations. Melman (1951) found that in the period between 1899 and 1947 large firms were able to keep their administrative expenditures per dollar of production expense lower than small businesses despite the rise in the administrative overhead. This seems to have raised also the profitability of production through better co-ordination and organisation of the shop floor. Larger firms benefited more from their use than smaller ones, indicating that scale economies played an important role in the adoption decision of single firms. The correlation analysis in table 4 shows that value added (VA) correlates with the share of clerks in total staff (A/P) and with the share of office machinery and furniture in total capital (C_{office}/C_{total}). These relationships are particularly strong for the sub-period between 1899 and 1919. In that period the changes of these shares (ΔA/P and Δ C_{office}/C_{total}) and the changes in value added (ΔVA) are also correlated, but the effects are ambiguous after 1919. The correlation between the rates of change over the whole period is weakly negative and statistically insignificant different from zero.

5. Summary and conclusion

In this paper we discussed the adoption of early information technologies in US manufacturing between 1870 and 1930. A new technological regime developed, which was part of a larger reconfiguration of the technology system, taking place with the rise of managerial capitalism. It led to the constitution of a new industry and it diffused into almost all sectors of the economy. It shaped the working profile of the emerging white-collar working class and supported the establishment of new professions.

Our study shows that firms started their search for new administrative techniques, the moment a given set of productive activities became inconsistent with the scale of production required. This problem resulted out of previous changes in the production system. The inconsistency of the

[25] Other reasons for this fact could have been either the relative shortage of clerical workers or a higher wage negotiation power. These alternatives do not find historical support. While the first point is not relevant, as the sources indicate that by that time the problem of clerical labour shortage had largely been overcome, the second is of lesser importance, as clerical workers were not unionised (Douglas, 1927: p.573ff).

established office work regime resulted from its incapacity to cope with the flow of information that had to be processed. Firms reacted by trying to identify and isolate the bottlenecks through an increase in the division of labour. Typical bottlenecks were high information throughput activities and the factor increasing the overhead over proportion was scarce clerical labour. The response to the identification of this problem reflects the factor price history and engineering experience in the US: through the application of the heuristic underlying the American System of Manufactures organisational designers tried to overcome the problem by a full-embodiment strategy which allowed to isolate the critical factor, clerical skills, and by that to make clerks themselves exchangeable parts of the system of information production. The extent to which this separation was possible finds its reflection in the subsequent innovations, technological trajectories and emerging path dependencies of the new regime. Finally, we showed that although electrification and the rise of administration overlapped they followed a different logic of technology adoption.

The observed patterns of technological development coincided with our theoretical conjectures. The search capitalist entrepreneurs undertook in the technology space was determined by the constraining factors and a response to the structure of economic incentives. This was not a search in the neighbourhood of the established technique, but one in which the logic of a different technological subsystem was projected into the domain of office work.
In this process indivisibilities played an important role in shaping the actual pattern of technical change. The influence of input prices on unit cost can be best controlled if they can be easily substituted for each other, something that in general is assumed to hold true *a priori* in neo-classical models. But this is never the case. If skilled labour constrains production, then capitalists have a strong incentive to separate their activities from this input through codification and embodiment. But the extent to which this is possible depends much on the complexity of the involved knowledge and hence the costs of codification. We have studied here three cases in which this became apparent: typewriters did not embody any type of skills, as the character of information they were used to process was not standardisable. With adding and accounting machines a high degree of embodiment was reached, but many changes in the field of bookkeeping took the form of disembodied technological advances. Finally, Hollerith machines represented a technological improvement that was almost completely embodied.
The adoption of any of these technologies eventually led to an increase of the elasticity of labour supply for clerical jobs, as workers with a lower skill profile as clerks had before could be employed. Accordingly the skill requirements for office work were to a large extent inversely related to the degree of embodiment.

Our study shows that disembodied advances were a precondition for embodied technical change. It was during the phases of disembodied technical change, that codification of skills and knowledge took place. Once this had been attained the incentive structure was such that firms proceeded to the adoption of skill embodying capital almost surely. What appears to be of interest as well is that the technical advance here studied did not generate a reserve army, but the "creative response" of capitalist firms was such as to generate activities where less skilled workers out of the total potential workforce could be recruited. This suggests that the concept of Marx bias needs some reconsideration, as it starts from the idea that the Babbage principle is applied to *given* activities in order to keep a reserve army of workers and by that wages at the subsistence level. What is nevertheless observed here – in a situation where the laws of techno-economic evolution changed - is an inter-temporal substitution of capital for labour resulting from the attempt to relax constraints on the production process. In the cases studied here the absence of a reserve army for a new set of activities was pushing innovative efforts. The skill requirements of these activities were defined only gradually, as the technology co-evolved with the economic environment.

Table 1: Early information technology: innovation characteristics of the most important technologies of the IT Regime [26]

Technology	User side				Supply side	
	(i)Supported economic function of organisation and (ii) type of processed information	*(i) Source of productivity gains and (ii) effect on established competences, i.e. clerical work before IT Regime*	*New professions*	*Required skills*	*Characteristics of the technical design*	*Incremental improvements / trajectory*
Typewriter	(i) Co-ordination (ii) multiplying codifying of qualitative information	(i) user interface, touch typing and complementary technologies (ii) replacement of copyists	Typist; establishment of typing pools.	Touch-typing (round 60 words a minute), shorthand writing at least 60-75 words a minute (partly replaced by Dictaphones), good language and grammar skills, letter writing ability. High school degree preferred. Training period: approx.250-400 hours	Dominant design: front stroke types, QWERTY keyboard, shift key.	Reduction of typing effort and increase of possible typing speed (electrical typewriters), noise (noiseless typewriters) and size (portable typewriters – but mostly for non-business uses)
Adding and calculating machines	(i) Monitoring (ii) processing of quantitative (accounting) data	(i) Mechanical adding or calculating mechanism, automatic entry controls, user interface (ii) replacement of mathematical skills;	In large enterprises Comptometer or adding machine operators; used in functionalised bookkeeping, sales or billing departments also on sporadic base. Establishment of computation pools.	Machine use. Touch-typing. Training period: few days. Girls round 17 years of age with two years in secondary school.	Large number of application domains – no clear dominant design. Two main principles: adding machines based only on the operation of addition. Calculators that could perform four basic operations. Full keyboards and ten key keyboards.	Size, user interface (ease of touch), electric movements, automatic entry controls, available mathematical operations
Accounting machines	(i) Monitoring and allocation (ii) processing of quantitative accounting data	(i) As for adding machines plus reduction of double entry mistakes through better work preparation (ii) Replacement of book-keepers (mathematical skills, book-keeping skills)	None; used in functionalised bookkeeping departments (i.e. by operators who have to have simple double-entry book-keeping skills but do not need to know balance sheet analysis or budgeting methods) which took also the form of bookkeeping pools.	Machine use. Training period: accounting clerks with double-entry skills two weeks.	Several niche application domains for large scale and back office processing; no clear dominant design. Interface depending on the base machine, i.e. typewriter, calculator or cash register.	Corresponding widely to improvements in adding and calculating machines.
Hollerith – Powers systems	(i) Monitoring and allocation (ii) processing of quantitative (accounting) data	(i) Electric contact principle, codification of information, sorting and tabulating mechnisms (ii) Replacement of mathematical and statistical skills; sorting and indexing tasks.	Card Puncher Sorter Tabulator Programmer; Establishment of card punch units, and machine rooms.	Puncher: in some cases typing skills mostly not; primary school degree. No further skills needed. Training period: 1-4 month Sorter: No special skills, but strong physical constitution required; primary school degree. Training period: round 6 month. Tabulator: secondary school degree and technical skills. Training period: 1,5 to 2 years. Programmer: organisational skills, business skills; preferably university degree in mathematics or a technical discipline. Training period: 4 years.	Dominant design: punched cards as data and as program memory, punch, sort and tabulate process, electric contact principle; interfaces are typewriter – like or typewriter keyboards, 10-key keyboards.	Speed of all parts of the system (e.g. tabulator speed 1900: 415 cards an hour; 1926: up to 4500 cards an hour), size and information content of cards (12 rows 24 columns in 1890, 10 rows 37 columns in 1906, 80 rows 10 columns 1928, 90 column format by Remington Rand in 1930) and related processing capacity (e.g. multiplying punch 1931), improvements of punch process, and further mechanisation of processes (e.g. collator device).

[26] Compiled using information contained in Brauner and Vogt (1921), Meuthen (1926), Leffingwell and Robinson (1950), Pirker (1962), Cortada (1993), Martin (1949).

Table 2: Data processing capabilities of early accounting machines round 1926

Type of machine	Information processing capacity[27], Bit/hour	Current account transactions per hour	Processing speed machine/clerk
Clerk, manual execution	270 (0,03 kbytes)	6	1
Burroughs Adding machine	5400 (0,675 kbytes)	120	20
National Cash register	6300 (0,78 kbytes)	140	23,3
Smith Premier (typewriter combined with a calculator)	2475 (0,31 kbytes)	55	9,166
Elliot Fisher (typewriter combined with a calculator)	2475 (0,31 kbytes)	55	9,166
Ellis (typewriter combined with a calculator)	5400 (0,675 kbytes)	120	20
Underwood accounting machine	2925 (0,37 kbytes)	65	10,83
Hollerith or Powers card punch machine	6750-11250 (0, 84 – 1,4 kbytes)	150-250	25 – 41,6
Hollerith or Powers sorting machine	675000-810000 (84,375 – 101, 250 kbytes)	15000-18000	2500 - 3000
Hollerith or Powers tabulating machine	162000-202500 (20,25 – 25,31 kbytes)	3600-4500	600 – 750

[27] For the calculations we have used information contained in Meuthen (1926). We used the figure of a punched card for a current account transaction (p.43) and the table of single cases that could be performed by the single machines (p.48). On the displayed punched card for such a transaction on 45 columns of 10 digits each the following information was stored: date of the transaction (6 columns), the number and page of the main register (3+3 columns), the type of the transaction (2 columns), the department (2 columns), the main and secondary number of the current account (5+2 columns), debit and credit (8+8 columns) and finally the day and month of the booking (2+2 columns). The information in each of the 45 columns represents 1 bit (on of the ten rows is punched or not punched). It should be noted, that this is only the information content of the card due to the punches and not the information content if the data would be codified by binary numbers, which is likely to be much higher. We calculated hence the implicit information processing capacity and not the effective one. Furthermore we compare the transactions on the basis of how the most advanced technology (Hollerith: punched cards) of the time codified information. This entails that with the purely manual system information was not just written on one single card, but that entailed to fill in fields in several different registers manually, for which a clerk on average needed 10 minutes for one single current account booking operation, Meuthen (1926): 47. Strictly speaking we compare different production functions with the same output.

Table 3: Capital-labour relationships in US manufacturing and the First IT Regime and its bias in technical change, 1889-1937

Year	1899	1889	1904	1909	1914	1919	1929	1937
C_{total}/L_{total} (1929 US$)	3260,98	2171,17	3259,57	3375,85	3871,34	2816,42	6115,11	5586,13
C_{office}/L_A (1929 US$)	17,31	13,04	17,72	20,49	23,68	20,02	49,90	30,60
CMH_{total}/WMH_{total} (1929 US$)	3,34	2,58	n.a.	3,20	n.a.	2,77	2,04	1,96
CMH_{office}/WMH_A (1929 US$)	0,60	0,47	n.a	0,52	n.a	1,14	0,70	0,53

Datasources and definitions see text and data appendix.

Table 4: Economic effects of the First IT Regime in US manufacturing: correlations.

	Total period: 1889-1937	Subperiod
C_{total}/L_{total} with C_{office}/L_A	0.921***	0.852** (1889-1919)
CMH_{total}/WMH_{total} with CMH_{office}/WMH_A	0.034	-0.220 (1889-1919)
C_{office}/L_A with A/P	0.581	0.521 (1889-1919)
CMH_{office}/WMH_A with A/P	0.339	0.743 (1889-1919)
CMH_{total}/WMH_{total} with degree of electrification	-0.789*	-0.967** (1899-1929)
VA to A/P	0.685**	0.975*** (1899-1919)
VA to C_{office}/C_{total}	0.762**	0.858* (1899-1919)
ΔVA to ΔA/P	-0.143 (1904-1937)	0.857* (1904-1921)
ΔVA to $\Delta C_{office}/C_{total}$	-0.204 (1904-1937)	0.883 (1904-1919)

****** statistically significant at the 1% level***
***** statistically significant at the 5% level***
**** statistically significant at the 10% level***

Datasources and definitions see text and appendix.

Data Appendix:

Variable	Meaning	Source
C_{office}	office machinery and furniture in the manufacturing sector	own calculations (see below)
C_{total}	total capital in the manufacturing sector	Census (1976), P123-176, E42
$L_{A,}$	non-production workers, classified as clerical workers in the manufacturing sector	Census (1976), P1-12
L_{tota}:	all employed persons in the manufacturing sector	Census (1976), P1-12
A/P	ratio of non-production to production workers	Census (1976), D233- 681, Kendrick (1961) table A-XI, p.314
WMH_A	salaray per man hour (only clerical personnel)	Census (1976), P1-12, E42, Kendrick (1961) table A-XI, p.314
WMH_{total}	total wage and salary bill per man hour	Census (1976), P1-12, E42, Kendrick (1961) table A-XI, p.314
CMH_A	value of office machinery and furniture per man hour	Census (1976), P1-12, P357-58, E42, Kendrick (1961) table A-XI, p.314
CMH_{total}	total capital per man hour	Census (1976), P123-176, E42, Kendrick (1961) table A-XI, p.314
VA	value added in the manufacturing sector	Census (1976), P1-12, E42
Degree of Electrification	degree of electrification in US manufacturing	David (1991), p.327, table 3 column 1.

Computation of C_{office}:

Series P357, P358 from Census (1976), giving the yearly output of office machinery and furniture were deflated by the wholesalesprice index, E42, to prices of 1929. For each year an export share of 20% for office machinery and 10% for office furniture was assumed following indications in Engler (1970): p.100ff., and Unger (1940): p.57. Due to the specific US tarif history (see Engler (1970)), imports were deliberately set to zero. These data were cumulated assuming a simultaneous exit after ten years. A comparative analysis with linear scraping or progressive scraping methods have shown, that this method tends to overestimate the absolute stock of capital. The growth trends are nevertheless identical. The imputation of the so calculated US capital stock of office furniture and machinery to manufacturing was done by calculating the share of manufacturing in total worked man hours in the national economy given by Kendrick (1961), Table A-XI, p. 314. This coefficient was then multiplied with the share of non-production workers to production workers calculated from series P1-12 in US manufacturing. The resulting coefficient of clerical labour intensity in manufacturing was multiplied with the calculated total capital stock value, thus assuming a fixed coefficient production function for clerical activities. It has to be remarked that regardless of the previous explanations the C_{office} coefficient heavily underestimates the real capital stock used for administrative purposes, as we do not take into account buildings dedicated to these activities, which was rapidly increasing in that period (building of skyscrapers).

6. References

Abramovitz, M. (1989). Resource and output trends in the United States since 1870. *Thinking about Growth*. Abramovitz, M. London, Cambridge University Press**:** 127-147.

Abramovitz, M. and P. A. David (1973). “Reinterpreting Economic Growth: Parables and Realities.” *American Economic Review: AEA Papers and Proceedings* **63**(2): 428-39.

Abramovitz, M. and P. A. David (1995). Convergence and Deferred Catch-up. Productivity Leadership and the Waning of American Exceptionalism. *Growth and Development: The economics of the 21st century*. Landau, R., Taylor, T. and Wright, G. Stanford, Stanford University Press.

Adler, M. H. (1973). *The Writing Machine*. London, George Allen and Unwin.

Ames, E. and N. Rosenberg (1968). “The Enfield Arsenal in Theory and History.” *The Economic Journal* **78**(December): 827-42.

Binswanger, H. P. and V. Ruttan, Eds. (1978). *Induced Innovation: Technology, Institutions and Development.* Baltimore, Johns Hopkins University Press.

Brauner, L. and V. Vogt (1921). *Illustriertes Orga-Handbuch erprobter Bueromaschinen.* Berlin, Organisation Verlagsgesellschaft.

Braverman, H. (1974). *Labor and Monopoly Capital. The Degradation of Work in the Twentieth Century*. New York, Monthly Review Press.

Burn, D. L. (1931). “The Genesis of American Engineering Competition, 1850-1870.” *Economic History: Supplement to the Economic Journal* **3**(January): 292-311.

Census (1976). *Historical Statistics of the United States - Colonial Times to 1970*. Washington, Department of Commerce of the United States of America.

Chandler, A. D. and H. Daems (1979). “Administrative Coordination, Allocation and Monitoring: A Comparative Analysis of the Emergence of Accounting and Oranization in the USA and Europe.” *Accounting, Organizations and Society* **4**(1/2): 3-20.

Cortada, J. W. (1993). *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry they Created, 1865-1956*. Princeton, Princeton University Press.

David, P. A. (1975). *Technical Choice, Innovation and Economic Growth*. Cambridge UK, New York, Cambridge University Press.

David, P. A. (1985). “Clio and the Economics of QWERTY.” *American Economic Review* **75**(May): 332-337.

David, P. A. (1991). Computer and Dynamo: The Modern Productivity Paradox in a Not-Too-Distant Mirror. *Technology and Productivity: The Challenge for Economic Policy.* OECD. Paris, Organization for Economic Co-operation and Development**:** 315-48.

David, P. A. and G. Wright (1999). *Early Twentieth Century Productivity Growth Dynamics: An Inquiry into the Economic History of "Our Ignorance"*. Oxford, University of Oxford**:** 42.

Davies, M. W. (1988). Woman Clerical Workers and the Typewriter: The Writing Machine. *Technology and Women's Voices*. Kramarae, C. London, Routledge and Kegan: 29-40.

Dosi, G. (1982). “Technological Paradigms and Technological Trajectories.” *Research Policy* **11**(2): 147-162.

Dosi, G. (1984). *Technical change and industrial transformation : the theory and an application to the semiconductor industry*. Basingstoke [etc.], Macmillan Press.

Douglas, P. H. (1927). *Real Wages in the United States, 1890-1926*. Boston, Houghton Mifflin.

Duménil, G. and D. Levy (1995). *The Economics of the Profit Rate*. Aldershot, Edward Elgar.

Duménil, G. and D. Lévy (1996). “The Acceleration and Slowdown of Technical Progress in the US since the Civil War.” *Revue Internationale de Systémique* **10**(3): 303-321.

Engler, G. N. (1970). *The Typewriter Industry: The impact of a significant technological innovation*. Los Angeles, University of California.

Foley, D. K. and T. R. Michl (1999). *Growth and Distribution*. Cambridge Mass., London, Harvard University Press.

Freeman, C. (1985). Technical Innovation, Diffusion, and Long Cycles of Economic Development. *The Long-Wave Debate*. Vasko, T. Heidelberg and Berlin, Springer Verlag: 295-309.

Freeman, C. (1989). *The Third Kondratieff Wave: Age of Steel, Electrification and Imperialism*. Maastricht, MERIT University of Maastricht.

Freeman, C. and C. Perez (1988). Structural crises of Adjustment, Business Cycles and Investment Behaviour. *Technical Change and Economic Theory*. Dosi, G., Freeman, C., Nelson, R., Silverberg, G. and Soete, L. London, Pinter: 38-66.

Freeman, C. and L. Soete (1994). *Work for all or mass unemployment?: computerised technical change into the twenty-first century*. London, Pinter.

Fries, R. I. (1975). “British Response to the American System: The case of the Small-Arms Industry after 1850.” *Technology and Culture* **16**(3): 377-403.

Fullerton, R. A. (1988). “How Modern is Modern Marketing? Marketing's Evolution and the Myth of the "Production Era".” *Journal of Marketing* **52**: 108-125.

Gardey, D. (1999). “The Standardization of a Technical Practice: Typing.” *History and Technology* **15**: 313-343.

Habakkuk, H. J. (1962). *American and British Technology in the Nineteenth Century*. Cambridge, Cambridge University Press.

Hartman Strom, S. (1992). *Beyond the Typewriter*. Urbana, Chicago, University of Illinois Press.

Hecht, J. (2001). “Classical labour-displacing technological change: the case of the US insurance industry.” *Cambridge Journal of Economics* **25**(4): 517-37.

Hoke, D. (1989). “Product Design and Cost Considerations: Clock, Watch, and Typewriter Manufacturing in the 19th Century.” *Business and Economic History* **18**: 119-128.

Hopper, T. and P. Armstrong (1991). “Cost Accounting, Controlling Labour and the Rise of Conglomerates.” *Accounting, Organizations and Society* **16**(5/6): 405-438.

Hounshell, D. (1984). *From the American System to Mass Production*. Baltimore, John Hopkins University Press.

Johnson, H. T. and R. S. Kaplan (1987). *Relevance Lost: The Rise and Fall of Management Accounting*. Boston, Harvard Business School Press.

Keep, C. (1997). “The Cultural Work of the Type-Writer Girl.” *Victorian Studies* **40**(3): 101-126.

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

Knie, A. (1991). “Generierung und Härtung Technischen Wissens: Die Entstehung der Mechanischen Schreibmaschine.” *Technikgeschichte* **58**(2): 101-125.

Kurz, H. D. and N. Salvadori (1997). *Theory of Production*, Cambridge University Press, Cambridge, UK.

Landes, D. (1969). *The unbound Prometheus*. Cambridge, Cambridge University Press.

Leffingwell, W. H. and E. M. Robinson (1950). *Textbook of Office Management*. New York, McGraw-Hill Co., 3rd edition.

Litterer, J. A. (1963). “Systematic Management: Design for Organizational Recoupling in American Manufacturing Firms.” *Business History Review* **37**(4): 369-391.

Littler, C. R. (1982). *The Development of the Labour Process in Capitalist Societies: A Comparative Study of the Transformation of Work Organization in Britain, Japan and the USA*. London, Heinemann Educational Books.

Malerba, F. (1985). *The Semiconductor Business - The Economics of Rapid Growth and Decline*. Madison and London, University of Wisconsin Press and Frances Pinter.

Malerba, F. and L. Orsenigo (1995). “Schumpeterian Patterns of Innovation.” *Cambridge Journal of Economics* **19**: 47-65.

Martin, E. (1949). *Die Schreibmaschine und Ihre Entwicklungsgeschichte*. Aachen, Peter Basten.

McPherson, J. (1992). *Computer Engineer, an oral history conducted in 1992 by William Aspray*. New Brunswick, NJ, USA, IEEE History Center, Rutgers University.

Melman, S. (1951). “The Rise of Administrative Overhead in the Manufacturing Industries of the United States.” *Oxford Economic Papers* **3**: 62-112.

Metcalfe, J. S. (1998). *Evolutionary Economics and Creative Destruction*, Routledge, London.

Meuthen, J. (1926). *Die Maschinenarbeit in den deutschen Banken*. Berlin, Julius Springer.

Montgomery, D. (1987). *The Fall of the House of Labour: The workplace, the state, and American labour activism, 1865-1925*. Cambridge, Cambridge University Press.

Nelson, R. and S. Winter (1982). *An Evolutionary Theory of Economic Change*. Boston, Belknap, Harvard University Press.

Perez, C. (1985). "Micro-Electronics, Long Waves and World Structural Change." *World Development* **13**(3): 441-463.

Pirker, T. (1962). *Büro und Maschine*. Basel, Kyklos Verlag.

Radner, R. (1975). "A behavioral model of cost reduction." *Rand Journal of Economics* **6**(1): 196-215.

Rosenberg, N. (1976). Americas rise to Woodworking Leadership. *Perspectives on Technology*. Rosenberg, N. Cambridge, Cambridge University Press.

Rosenberg, N. (1976). Technological Change in the Machine Tool Industry, 1840-1910. *Perspectives on Technology*. Rosenberg, N. London, Cambridge University Press**:** 9-31.

Saviotti, P. and J. S. Metcalfe (1984). "A Theoretical Approach to the Construction of Technological Output Indicators." *Research Policy* **13**: 141-151.

Schumpeter, J. A. (1947). "The Creative Response in Economic History." *The Journal of Economic History* **7**(2): 149-159.

Silverberg, G. and D. Lehnert (1993). "Long Waves and 'Evolutionary Chaos' in a Simple Schumpeterian Model of Embodied Technical Change." *Structural Change and Economic Dynamics* **4**(1): 9-37.

Unger, G. (1940). *Absatzfaktoren und Absatzgestaltung für schreibende und rechnende Büromaschinen*. Leipzig, Handels-Hochschule Leipzig.

Windrum, P. and C. Birchenhall (1998). "Is Product Life Cycle Theory a Special Case? Dominant Design and the Emergence of Market Niches through Coevolutionary Learning." *Structural Change and Economic Dynamics* **9**(1): 109-134.

Wooton, C. W. and B. E. Kemmerer (1996). "The Changing Genderization of Bookkeeping in the United States, 1870-1930." *Business History Review* **70**: 541-586.

Wright, G. (1990). "The Origins of American Industrial Success, 1879-1940." *American Economic Review* **80**(4): 651-668.

Yates, J. (1989). *Control through communication: the rise of system in American Management*. Baltimore, John Hopkins University Press.

Yates, Y. (1993). *From Tabulators to Early Computers in the U.S. Life Insurance Industry: Co-evolution and Continuities*. Cambridge Mass., Sloan School, MIT.