Research Report No. 9
1980

ELECTRONICS, TECHNICAL CHANGE AND TOTAL ECONOMIC PERFORMANCE

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ECONOMIC AND SOCIAL RESEARCH, STOCKHOLM

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ISBN 91-7204-118-8

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I would predict that the standard of life in progressive countries one hundred years hence will be between four and eight times as high as it is to-day.

John Maynard Keynes (1930)

Förvaltningsbolaget Sindex, Stockholm 1980

Foreword

The present study is one of three IUI papers presented to the symposium on Industrial Policies for the 80's arranged by the Spanish Ministry of Industry and Energy in cooperation with the O.E.C.D. in Madrid, May 5-9, 1980. Partial financial support from the O.E.C.D. and from the Swedish Government Committee on Computers and Electronics is gratefully acknowledged.

The paper is a part of a larger study which the Institute is conducting for the Committee. The multidisciplinary character of this study has required quite extensive contacts with staff personnel at companies, especially on the engineering and technical side. Their helpful comments have very much affected the final shape of this paper. The author furthermore acknowledges all the helpful comments and discussions when various parts of this study have been presented to the committee on Computers and Electronics.

Stockholm, in August 1980

Gunnar Eliasson

Contents

1. Introduction

This paper represents an attempt to identify the importance of "electronics" in technical change and economic growth of a national economy. Carlsson (1980) has estimated the magnitudes of technical change at the firm and process levels in various manufacturing trades. In this paper the "residual" in production function analysis, commonly referred to as the technology factor or total factor productivity, has been decomposed further into organizational and other components within the workshop and the firm unity in order to identify where and how electronics affect technical change. In Eliasson (1979) assumptions as to technical change at the firm level and abroad have been varied and the effects on employment and growth at the level of an individual firm, a sector and the national economy have been simulated. This has been done through a micro (firm) to macro model of the Swedish economy constructed at the IUI (Eliasson 1976a, 1978 and 1980)[1]. This two-stage approach allows an indirect assesse-

[1] The above quoted papers will be referred to frequently as above. They are:

Carlsson, B (1980), Technical Change and Productivity in Swedish Industry during the Post-war Period. IUI Research Report No. 8 1980;

Eliasson, G (1979), Technical Change, Employment and Growth. IUI Research Report No. 7 1979.

Eliasson, G (1976a), A Micro Macro Interactive Simulation Model of the Swedish Economy - Preliminary Documentation, Economic Research Reports B15 Federation of Swedish Industries, Dec. 1976;

Eliasson, G (1978) (ed), A Micro to Macro Model of the Swedish Economy, Papers on the Swedish Model from the Symposium on Micro Simulation Methods in Stockholm, Sept. 1977;

Eliasson, G (1980), "Experiments with Fiscal Policy Parameters on a Micro-to-Macro Model of the Swedish Economy", from Haveman & Hollenbeck, Microeconomic Simulation Models for Public Policy Analysis, forthcoming Academic Press 1980.

All other references will be given in full in a footnote.

ment of the "electronics factor" in economic growth. Since empirical evidence is very piecemeal and the electronics factor is typically integrated with many other changes in the factory the analysis will proceed by way of discussion and case illustrations rather than direct measurement.

One important purpose of the simulation experiments was to quantify the magnitude and time dimension of indirect effects of various kinds of technical change through demand feedback or through adjustments of relative prices in an economy.

The analysis in this paper is based on several background IUI studies and on the vast amount of information collected within the Swedish Royal Commission on Computers and Electronics and the grand inquiry into the technical industrial competence of Swedish industry carried out and published in 1979 jointly by the IUI and the Swedish Academy of Engineering Sciencies (IVA).[1]

There will be an attempt at the end to say something about the future. Considering the state of the art, however, the author is of the opinion that enough speculative detail has been presented already, and that we should rather try to place meaningful limits on our ambitions to know about the future.

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[1] The author is a member of the first commission and was a member of one of the four study committees of the second project. The IUI-IVA study was published in Swedish under the title: Carlsson, B, Dahmén, E et al, Teknik och industristruktur - 70-talets ekonomiska kris i historisk belysning. IUI-IVA Stockholm 1979. Also see Carlsson & Waldenström, Technology, Industrial Structure and Economic Growth in Sweden - A 100-year perspective, paper presented to the OECD Symposium on "Industrial Policies for the 80's", Madrid 1980.

2. Electronics - a general purpose technology

The very general applicability of "electronics" makes it difficult to isolate its effects. Electronic devices show up in all stages of industrial and service production and are rapidly penetrating household production and recreation systems. This has led a number of observers to conclude that something entirely new is taking place that will somehow revolutionalize production methods and the life of individuals during a short time span. Electronics and the physics and mathematics behind it have not been generally taught at the elementary school levels among the industrial countries. Therefore there has been an air of mystique around it. Worries on the part of Governments regarding the competitive situation of the national industry on the one hand and the short term adjustment problems (employment, regional, etc) on the other go hand in hand. Does electronics really represent a unique technological change? Is electronics unique in the sense of the steam engine, etc in the industrial revolution? Will it mean more for industrial change than plastics did during the last two or three decades or the steady stream of new materials that is currently flowing out of laboratories for testing and application? Will it mean as much for industrial development as has double entry bookkeeping and rational management techniques?[1] Perhaps Gutenberg's printing press is the appropriate comparison to make when it comes to assessing the economic and social effects of electronics? To some extent an answer has to await a specification on exactly how electronics enters the production process, but the first step will be to delimit what we mean by "electronics".

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[1] Joseph Schumpeter emphasizes the importance of this technique for the efficient management of a large business enterprise in a capitalistic market economy. See his Capitalism, Socialism and Democracy (1943), p 123, in George Allen & Unwin, paperback edition, 1976.

We normally associate the term "electronics" with hardware (computers, microprocessors, chips, etc) capable of processing and memorizing alpha-numerical information at extremely high speed and in very large magnitudes. The technique here is "digital", so we may as well talk about the "digital revolution". This capacity has been increasing at increasing rates and is projected to continue to do so. Rates of change during the last few years have surpassed expectations, and this is part of the cause for alarm. Last year for instance the largest Swedish daily newspaper ran a front page headline implying the possibility of a "skilled worker being replaced by a $3 chip". We should recall, however, that the 1950ies also witnessed an intense discussion on automation, the computer and employment and the 60ies a dramatic wave of expectations related to computer technology.[1] For several reasons the visions all failed to materialize. We are still talking about degrees of change in a "technology" of general applicability that has been known and applied for a fairly long time by now.

Even though handling of numerical information through digital representation is being introduced rapidly in industry it does not necessarily affect economic behavior differently from the introduction of plastics, new energy techniques or rapidly increasing scale economies. There is a lot that can be learned by examining experience as to the economic effects of these technologies.

The digital revolution and the hardware upon which it is based cannot be put to use without a substantial software back up. Lack of software of sufficient quality, primarily skilled manpower, was what frustrated expectations associated with the rate of introduction of the electronic computer during the 60ies. Basic education and experience are perhaps most important, but attitudes in a broad sense are part of the software set up. To over-

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[1] See OECD, Gaps in Technology, Paris 1969 and Simon, H, 1965, The Shape of Automation for People and Management.

look the massive investments in human capital that have to complement the successful introduction of electronics in production, the household, etc can easily mislead both government and industry action. I may venture already here the proposition that without massive investments in appropriate human capital no amount of hardware investment will help. The national authorities should primarily be worried about competitive price pressure from technologically superior competitors abroad. The model simulation runs in Eliasson (1979) indicate that employment effects are substantial when foreign competitors adopt new technologies faster than domestic producers but very small and of short duration when domestic firms take the lead. In the latter case overall growth in the economy is stimulated through demand feed back. These results emphasize the role of the educational level of a country in facilitating understanding and creating positive attitudes to technical change. The very nature of the application of electronics in industry - to which we now turn - makes the importance of the educational level and investments in software more clear.

3. Industrial production techniques - a decomposition

One characteristic of the digital technology or of electronics is that it is potentially everywhere present in its capacity to represent (model) production processes. But production in a modern industrial society is something entirely different from the story told both by the classical theoretical representation of the firm and the general conception of the content of production. The fashioning and assembly of hard, mostly metallic materials through the application of force is no longer the typical and dominant manufacturing activity. A presentation of the modern manufacturing firm should include the following items:

1. The modern industrial good in the hands of the ultimate consumer contains a quite small value added share attributable to mechanical handling of materials (bending, cutting, etc) in factories. A rapidly growing share has been devoted to packaging the product and getting it into the right hands for final use (distribution, advertizing, information, etc). A large and growing share has been devoted to constructing, designing and differentiating the products to suit a spectrum of consumers. For a growing number of products information, support and maintenance systems together with insurance (guarantees) are part of the product definition. This goes all the way from computer systems to ordinary consumer products (cars, cameras, etc). In fact, firms that have not realized this do not generally belong to the successful ones. Internally within the firms a large share of value added is attributable to the moving and storage of the product and its components.

2. As a consequence, large firms in particular are as much marketing and distribution organizations as production plants.

3. A decreasing share of their investments are made up of hardware in buildings, machinery and equipment. Not only our traditional theoretical indoctrination may thus be wrong. Much of the statistics on the production system may also be irrelevant or misleading. The large and growing service component of manufacturing output goes under the wrong labels. The perhaps most important investment categories (R&D, marketing and the building up of human skills capital) may be badly measured or not measured at all.

4. Most firms (even small ones) normally consist of a set of production units or production lines held together by a centralized financial (banking and investment) function.[1]

For some reason the importance of a well balanced asset as well as debt structure in securing a fast and steady flow of activity within the firm has gained practically no attention in the literature which tries to explain production performance of industries.

The economies of scale on the financial side may even be the most important scale factor in determining economic success. To a degree, internal pooling and redistribution of funds within the firm (the banking and portfolio management function) may be more efficient than the credit market, which is often imperfect from Government regulation and subsidies. This may explain part of the success of big business units.

5. Large scale on the production side is a more difficult concept. It is obvious, for instance, that Swedish production units in traditional, not so sophisticated lines of production have been lagging behind foreign competitors in both scale and production efficiency

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[1] See Eliasson, G, Business Economic Planning (Wiley & Sons), 1976.

in recent years (Carlsson, 1980). However, scale is still a relative concept. There are many small firm units in Swedish engineering industries that dominate the world market in their products. They reach the benefits of large scale production to the extent possible within their market segments. Pratten (1976)[1] observed, that while UK firms normally are very much larger than their "corresponding" Swedish firms as financial organizations, Swedish production plants or lines are generally larger or longer than the corresponding UK ones.

The distress of the raw material producers, reported on in Carlsson (1980), may be less due to a failure to invest in the largest and most efficient production plants than to the fact that they are not producing new and more sophisticated products for different markets.

Changing products or product design may in fact be even more important in explaining technical change and commercial success than upgrading production techniques. The two types of technical change (process and product) are often mutually dependent. Carlsson (1980) gives a number of examples of the changes due to new or improved materials in the steel industry (special steel, cemented carbide, etc) and to new handling, storage and distribution techniques for food (frozen food, etc). The fast food Hamburger outlet in fact illustrates the point nicely. New product, production and distribution techniques in combination have captured a niche in the eating market very efficiently.

6. The new technologies, hence, also bring attention to business management as a factor behind growth in total factor productivity - and perhaps an important one.

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[1] Pratten, C F, A Comparison of the Performance of Swedish and UK Companies, Cambridge University Press, 1976.

In Eliasson (1976)[1] four propositions towards a theory of firm behavior were suggested on the basis of an extensive series of interviews with US and European firms. The base proposition or base hypothesis,[2] codifies the middle management planning-budgeting-control sequence which is strongly geared towards running everyday business operations efficiently. Three supplementary hypotheses were contrasted against the base hypothesis. First, efficient base behavior in general created a difficult adjustment process under changing environmental circumstances. Success in such circumstances were characterized by randomness. Second, efficient base behavior means a hardening of the internal financial cohesion of the firm unit. Low profit activities are spotted fast, and discontinued or sold off. Hence a further concentration towards base, non-innovative behavior is normal during difficult periods. Third, while economic life times of existing production equipment is decreasing, the gestation period for new invisible - software - capital (R&D, new product design, skills and experience) is increasing, making business life increasingly risky if not matched by corresponding financial size, capable of extensive advance investment and risk absorption. Carlsson's (1980) measurements demonstrate that technical change at the firm (plant) levels have been fastest in Swedish base industries subjected to strong competitive pressure (environmental change) - the result of efficient base behavior so to speak.

The question asked in Eliasson (1976, op cit, p 244) is whether a large and strong financial unit can administer efficient base behavior on the innovative side, i e reducing the risks associated with investing extensively in innovations. Size reduces internal

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1 Eliasson, G, Business Economic Planning, 1976 (Wiley & Sons), pp 231 ff.

2 The individual firm decision system in the micro-to-macro model that we are going to use (see Eliasson, 1980) operates on the base hypothesis.

flexibility. Much resources on innovative account on the other hand should increase the flow of ideas and new designs. Even though the probability of "finding" a particular innovation within the organization may diminish with size, the possibilities of carrying those ones "found" to their economic fruition should increase. With a lengthening of advance gestation periods for new products business life becomes increasingly precarious for "established" firms in sophisticated, high technology industries. There is no scientific way of weighting these counteracting factors together. The answer is, however, vitally important for the small, advanced and highly specialized industrial nation, and especially so if the policy is such that change be engineered <u>within</u> existing firm organizations, rather than through the disappearance of old units as a result of rapidly expanding, superior competitors, which has been the normal way in a market competitive environment.

4. Technical change - the organization factor

The capacity to represent complex processes in digital form in a computer rather than in the intuitive, analogue fashion in a human brain obviously enters into industrial production in a number of different stages. It can be applied at each production stage or to hold together the entire production process within the firm. The results from a number of studies at the IUI, summarized in Carlsson (1980) and also from several recent inquiries by the Royal Commission on Computers and Electronics point towards the conclusion that technical change is largely a matter of how flows of production are organized. This conclusion is not compatible with the idea of a stable production function that regards production in the entire economy or a sector or even a firm as a gigantic hardware processor. The mysterious "residual" or "technology factor" in production function analysis has been estimated for a number of countries.[1] These studies indicate that a very large part of industrial growth is attributable to technical change, in Sweden about 75% during the entire postwar period. A break down on sectors, however, reveals that as much as 1/3 of this may depend on changes in composition of output at the sectoral level and 1/3 again of changes in the composition of output between firms.[2] This makes roughly half of the residual factor dependent on variations in the composition of output among firms, a true organizational phenomenon that is represented and discussed in the micro-to-macro model in Eliasson (1979). The size of this factor varies with the properties of the national economic system and the efficiency with which it is capable of adjusting to market signals.

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[1] See for instance, Denison, E F, Accounting for United States Economic Growth 1929-1969, the Brookings Institution, Washington DC, 1974; Kendrick, J W, Postwar Productivity Trends in the US 1948-1969, NBER, New York 1973; Nordhaus, W P, The Recent Productivity Slowdown, Brookings Paper on Economic Activity, (3) Nov 1973; Åberg, Y, Produktion och produktivitet i Sverige 1861-1965, IUI, Stockholm 1969.

[2] See for instance essay by Bo Carlsson in the IUI Yearbook 1980 (forthcoming).

A further breakdown of the firm production process yields the same results. A breakdown of production into production lines in a couple of firms attributed half of the residual (technical) factor a reorganization in connection with changing the output mix.[1] A recent case study of a particular workshop in an engineering firm by the Commission on Computers and Electronics indicated that most productivity improvements within the shop were due to changes in production scheduling (that is among other things the ordering of machine tools, and product flows), and much less on individual tool performance. It is interesting to note that machine tools performing the basic functions in engineering workshops of cutting, fashioning, fastening, etc, are still designed and operated in much the same way as in the late 19th century.[2] Even modern factories can still use very old machine tools.[3] It is also well-

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[1] Carlsson, B, Dahmén, E et al, 1979, op cit, pp 122-130.

[2] Kamura, K O and Yamashina, H, Production System Design for Integrated Manufacturing, the Department of Mechanical Engineering, Kyoto University, 1979.

[3] With this in mind it is not so remarkable that Wallander found that as much as 50 percent of production machinery in Swedish engineering industries was more than 25 years old in 1959 and that the average life of machine tools in Swedish industry could be as high as 43 years (see Wallander, J, Verkstadsindustrins maskinkapital. En studie av dess sammansättning och av "maskiners åldrande och död", IUI, Stockholm 1962). Wallander also found that in Sweden as well as France and the US more than 60 percent of machine tools were more than 10 years old towards the end of the 50ies. Surveys for other countries give a similar picture:

Percent of machine tools over 10 years old in early 70ies

Japan	30
West Germany	35
Italy	48
United Kingdom	60
United States	67

Source: Product System Productivity Research. Volume 3: Methodology and Research Needs. Prepared for the National Science Foundation by General Electric Company, Washington DC, 1976 (p. 4-4).

known from the theory of production systems that single machine tools of superior performance have little or no effect on the optimum performance of the entire system if introduced inefficiently into a larger production system. This picture may change with the introduction of new materials, etc which allow new and more efficient processing techniques to be used. Still, a modern workshop as well as a large process industry can be represented in a quite general model form by units that perform different base tasks (cutting, bending etc) at different speeds, guided by more or less automatic procedures. Different scheduling schemes (classes of models) have different properties. At this level we can identify where and how digitally represented automated systems have been applied. Let us illustrate this with the aid of a quite general workshop sequence (model).

5. A workshop model - the benefits of digital representation

The traditional engineering workshop or firm can be decomposed into a sequence of activities. For a fairly uncomplicated product with no loops in the production sequence it looks roughly as in the table below.

(1) Product design
(2) Work scheduling (preparation)

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(3) Parts manufacturing (casting, etc)
(4) Fashioning materials (cutting or forming)
(5) Fastening (welding, glueing, bolting, riveting, etc)
(6) Surface finishing (painting, polishing, etc)
(7) Assembly

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(8) Storage
(9) Distribution

We can observe that until now automated production methods have been introduced mostly in operations where relatively simple tasks are repeated frequently with little variation. This is so, first of all, in parts manufacturing and surface finishing. Here numerical machine tools have been used for many years. They have also been used in fashioning materials. On the fastening and assembly side not so much has been done up till now. Some production sequences on the final assembly line may be automated (a series of specialized welding robots on the car assembly line is a case in point). Automated small parts assembly in telecommunications industry is a quite established technique. Very little has been done in product design except technical calculations. Most advances in automation and electronics application can be found under (2), (8) and (9) in the above listing. It should be noted also that the administrative and office side is not covered by this listing. Many forecasters expect that the 80ies will witness great steps forward in office automation.

Electronic guidance systems are not always necessary for such procedures if they are simple enough. Again it is important to note that something other than electronics can be the leading cost reducing factor in automation. In parts manufacturing the increase in cutting speeds that is often very important usually depends on the introduction of sufficiently tough and durable cutting tools.[1] Durability and costs of tools in turn depend on the lubrication and cooling of the edge. This may be done more efficiently if the operation can be encased and controlled remotely, which requires automation.

Work scheduling of complex engineering production was earlier done manually in a very elaborate and decentralized fashion through a network of operations aided by charts, drawings, pin-tables, etc. The process was a quite stable and repetitive one albeit through a very complex hierarchical network of "standard" operations and checks which can be scientifically represented in a computer model - human interface system. The same goes for product design. Both activities have an intricate interface with the storage and purchase functions of a firm. Since variation and complexity have to do with combinations of stable operations the whole procedure can be digitally represented in a computer. Partial automation of the administration of entire ordering, storage, production and distribution systems began already in the early 60ies. At the shop floor level automated monitoring systems have allowed fundamental reorganization of production flows cutting production time and capital costs (especially inventories) substantially.[2]

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[1] According to SANDVIK experience, for instance, the change from high speed steel to hard core around 1930 reduced cutting time for a certain operation from 26 minutes to 6 minutes. With a new type of cutting edge introduced in the late 70ies, cutting time is down to one minute. See Affärsvärlden Nr 40, 3 oktober 1979 (p 18). Carlsson (1980) in turn reports on new cutting edges and drills as being one of the very important factors behind the fast productivity increases in iron ore mining in the 60ies.

[2] In Nilsson, S, Förändrad tillverkningsorganisation och dess återverkningar på kapitalbindningen, Working Paper No 23, IUI 1980, this ws illustrated in a case study of a factory at ASEA.

It is practically always true that many spectacular improvements in productivity performance can be observed from the introduction of electronics in isolated parts of the production system.

Sophisticated computer aided design (CAD) systems have now been on the market for some time and productivity improvements are startling. These systems are currently being integrated with computer aided manufacturing (CAM) systems, where work scheduling and materials and parts procurement have been achieved but only partial integration with direct manufacturing. Advances are being made at the product definition stage when instant access to drawings, parts inventories and manufacturing capacities and specifications is obtained at the design stage. To the practitioner CAD is still synonymous with graphic applications in the computer and CAM is almost the same as a numerically controlled machine tool. It is easy to imagine the productivity gains associated with a complete integration of the production planning and manufacturing stages, even though the full application of such techniques remains distant in time. This has so far only been obtained in some process industries. In fact, the automated typing-editing-filing and printing system is perhaps the most familiar instance of completely integrated design (by the author) and production (by the printer). Such systems have brought about dramatic work place changes and tumultuous repetitions of 19th century-style sabotage of the new machines in the newspaper world.

However, the traditional engineering factories are far from being automated as yet. Piecewise automation of single operations is being accomplished to an increasing degree and the spot yields in productivity are often very high. The total production sequence is normally under efficient current control through a computerized work scheduling and monitoring system. Robots are now being marketed that can not only perform fairly complex carrying and moving operations but also carry heavy items. But this is very expensive machinery, so the introduction is still slow and restricted to high wage countries or industries. But as they are introduced they allow more compact designs, a more efficient scheduling of the production line (safety and pollution standards can be relaxed for instance), and higher speeds. But this is still only partial achievements. A break down of an entire factory that has been done in an IUI study for the Swedish Royal Commission on Computers and Electronics shows how very high performance figures for some sequences of operations still are fitted into a total production system with quite normal productivity growth.

This can be reformulated in the following way. The spectacular improvements are generally found at a very low micro level (like standard parts production). At the more highly aggregated production line and factory levels, rates of productivity increase take on more normal and modest magnitudes. Estimates are sometimes presented indicating that as much as 50 percent of the factory can be automated, and half of the labor force be made redundant. The normal situation is, however, that it will take 10 years or more to learn how to do it. Such rates of increase in productivity (i e doubling in 10 years) have been characteristic of all Swedish manufacturing industry during the entire post-war period.

The final assembly operations are still mainly carried out manually. The reason is that existing robots cannot yet combine flexibility, variability, reliability and precision to the extent required. Furthermore, the complexity of the assembly operation is not yet known at the engineering design level to the extent necessary for a digital model representation. Work procedures, measures and shapes (models) specified on the drawings often have to be modified at the shop floor when confronted with workshop reality. This is also why a population of skilled workers is needed there.
Probably the assembly line, too, will gradually be automated. High wage costs for skilled workers in combination with a steady accumulation of production knowledge and more sophisticated robots

will be contributing factors. It is often argued that assembly line automation is where the really large labor savings will occur.[1]

Statistical information on the magnitudes involved here is generally lacking. A study on US manufacturing[2] indicates that only about 50% of employment in durable goods industries was directly engaged in physical production in 1969 (activities (3) through (7) in the above table). The rest of the employees were engaged in product design, work preparation, administration and finance, etc.

It was estimated that for 46 industries "with significant assembly content"[3] the average share of direct production labor as defined above engaged in assembly was just above 30%. Slightly more than 20% could be automated, according to rough estimates by experts.[4]

This gives some idea of the automation potential in the future. Other production operations than assembly is where automation has been primarily introduced so far, however, probably not to a large extent by 1969 when the data were collected. Assembly line labor is still a fairly substantial part of total production labor in engineering industries but a quite small part of total labor input.

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1 The productivity gains from robotizing entire assembly lines are normally high although the risks of malfunctions, etc during a long break-in period are also high.

2 Product System Productivity Research, Volume 2: Productivity, Technology and Product System Productivity Research, prepared for the National Science Foundation, Washington, DC, by Charles Stark Draper Laboratory with MIT Center for Policy Alternatives, mimeo, Dec. 1975.

3 Op cit, pp 4-15. Note then that the average assembly content of all manufacturing must be lower.

4 Not based on micro level studies.

Even though automation eventually will cut assembly costs substantially there are clear upper limits to what this can mean to both employment and costs even at the workshop level. Furthermore, it is not necessarily electronics as such that leads the development. In many instances the electronics capacity has been there for years. What keeps development back, besides cost considerations, is insufficient engineering knowledge of the automated machine tools and lack of systematic production experience at the engineering level. The human being that can see, touch and feel and thus guide very delicate finger movements and respond intelligently to erratic behavior on the production line is still very superior to the blind, stiff and not particularly intelligent robot with one hand and two fingers loaded with crude knowledge of the production process. But the robot and other automation devices have got some superior traits if tasks are adopted to their qualifications.

The digitally represented guidance system allows:

(a) high and uninterrupted speed of product flows
(b) maintenance of extreme precision and
(c) stable quality in a
(d) compact environment with
(e) relaxed environmental and safety requirements.

Summarizing so far, we have learned that productivity increases in individual production steps are not representative indexes of productivity growth at the level of a production line or factory. Automation and electronics have entered the engineering workshop at different stages. Some elements of production have been more difficult to automate than other. The first and the fastest steps in automation have taken place in process industries. Simultaneous control of the entire process have reduced bottlenecks, increased total flow speeds and reduced capital requirements. The assembly line constitutes a critical step towards automation in engineering. A number of different production flow organizations have been tried.

In the functional workshop all machine tools of the same kind are clustered in one place. Efficient utilization and flexibility are attained at the cost of higher inventories. Group technology is a combination of the functional workshop and the assembly line. A particular production sequence is concentrated to a particular group of machines. The integrated workshop is a specialized machine sequence for each product.

The different work organizations combine

efficiency in utilization of machine tools
flexibility
higher flow speed and
reduced costs of current capital

in different ways. There are a number of different solutions also within each type of workshop. Thus for instance, it has been argued within the ASEA corporation[1] that machine costs and inventory costs are often of similar magnitude per unit of output. This knowledge can be more efficiently utilized than what is currently the case.

Designing a production system in such a way that excess machinery capacity increases towards the end of the production line can create a higher throughput, and a reduction in inventory, and machine costs along the production line. Redundant machinery

[1] Nicolin, C, "Kapitalanvändningen i industrin", in Herin-Werin, Ekonomisk debatt om ekonomisk politik i Nationalekonomiska Föreningen 100 år, Norstedts, Stockholm 1977.

capacity at one end of the system so to speak reduces total capital requirements.[1] Similarly, a basic principle in workshop design is to have the largest and most expensive machine tools fully loaded. It may be so that the potential in electronics primarily lies in the monitoring and control of entire production systems rather than in helping to carry out particular production operations.

From these examples three conclusions flow;

First, total workshop productivity to a large extent depends on the production flow organization. As it seems this means more than individual tool efficiency. A faulty flow design can easily eliminate the potential usefulness of a new, high performance machine tool.

Second, efficient flow organization and automation fundamentally hinges on access to explicit centralized knowledge of the full production process, some of which currently resides in a decentralized fashion with the skilled craftsmen at the machines.

Third, electronic techniques are gradually improving total factory systems control, beginning with the monitoring of production and inventory flows. The first benefit of this to be materialized is in the form of reductions in capital costs. It is important to observe that increased systems control to a large extent is a capital saving technology[2] and not to look onesidedly at labor saving from automation.

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[1] See Nilsson (1980), op cit.

[2] It will perhaps mean a more capital saving technical progress in the future, in contrast to the past which seems to have been mostly of the labor saving kind. See Bentzel, R, "A Vintage Model of Swedish Economic Growth from 1870 to 1975"; in The Importance of Technology and the Permanence of Structure in Industrial Growth. IUI Conference Reports 1978:2. Bentzel summarizes the empirical results in this respect.

6. The digital revolution - a more theoretical production life

Let us sum up so far. The advantage with electronics is the possibility to model complex production processes precisely in a digital language if they can be described. In principle this has been possible before, but the new hardware development (computers, chips, microprocessors, robots) makes it possible in practice.[1]

The intuitive "analog" skills inherent in traditional production techniques and vested in a not easily accessible form in individual workers and engineers can now be theoretically represented in "production system models". This is an entirely new "intellectual" world for people in the various trades affected - they have to learn a new experience in a very different language, and that in itself is apt to cause resistance.

The educational side does not seem to have been well taken care of. The schooling system is churning out knowledge of the past. On the job training of the new and for the future at best exists at the executive levels. 29 percent of the Swedish labor force in 1979 had had on the job contact with computers or raw output of computers and as much as 27 percent of these, or 7.5 percent of the entire labor force, were regularly working with a computer terminal. This means, that 65 percent of the labor force reported that they had received no education or training

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[1] It is quite instructive here to compare process industries with engineering. Many process industries have a more transparent and more repetitive production system. Automated production systems hence appeared earlier in these industries, and the control and guidance systems were not necessarily based on computers and electronics. The budget process in a large firm is also a very complex production process. It has been difficult and/or impossible to computerize in the sense of an automated factory, not because the computer technology did not exist but because the budget process and accompanying business, etc judgements have not been sufficiently well known. See Eliasson, op cit 1976.

whatsoever on this new technology.[1] If the business world wants to have trouble with its rank and file work force concerning the introduction of new, electronically based techniques, the best thing is not to do anything about their education, much as it seems to be managed today.

However, education is by no means sufficient. To introduce the new techniques of digital representation, rather than man based "analog" skills, a tremendous amount of new and more profound production knowledge has to be made explicit and quantified. I venture the proposition that it is probably much more demanding for a nation to command that knowledge and those skills than to build and to use the hardware itself. The software has to come first. It requires an upgrading of the theoretical and educational base of engineers and workers and of the population at large if the new technology is to be sucessfully accepted and introduced. Systems engineering, for instance, will become an important educational input. The only country in the world with operationally designed systems engineering on the curriculum at technical universities to a more than negligible extent is the US. In Sweden, for instance, there is practically no such training.

The micro processor, in its various and rapidly improving forms no doubt represents dramatic increases in data processing performance. But its application, in decentralized functions within a controlled production system does require technically skilled people. The micro processor won't be supported by the same software facilities as the big main frame computers were and are.

What was true of the larger computers and is even more true of the new hardware: the people competent to use the new technology are the main restriction on its rate of introduction and the main cost items in the computer budget of the user.

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[1] Zetterberg, H, Arbetslivets slutanvändare av databehandlad automation. En informationsskrift från IBM Svenska AB, oktober 1979.

One further conclusion follows. We said earlier that the engineering workshop today performs tasks that are very similar to those in workshops in the middle and late 19th century. The machines are to a large extent of the same universal type albeit faster, more durable, reliable and more compact. The scientific approach to production modelling and organization that the new digital representation offers will probably reveal, as it has already, a number of potential improvements in both production process and product designs. So far, most of the benefits of the new technique come from reorganizing production of roughly the same product. In car manufacturing, for instance, an existing production line may be robotized. However, a frequent experience is that the largest productivity improvements are obtained when the product is redesigned with the new production technique in mind. The new CAD/CAM techniques being introduced just now will offer tremendous opportunities in this respect. The new knowledge of production that is being accumulated, the new scientific techniques of automated production and a gradual shift of industrial output towards new types of more sophisticated products that require very complex prior designs (aeroplanes, computers, chips, etc) may eventually break down the elements of the traditional workshops. The probability for this to happen is enhanced by the rapid appearance of new materials with new qualities that are in turn maybe not most efficiently fashioned by the traditional machines. The automobile hull may be cast or baked in plastics, composite material or aluminium rather than stamped in steel in a sequence of movements. Altogether this may produce such a profound change in the production system of industrialized countries that we may talk about a revolution - but not necessarily an electronics revolution. If we introduce such a host of factors we should be talking about a speeded up rate of general technical change. And more importantly, this won't happen if it is not backed by an equally profound upgrading and change of the scientific skills and attitudes of the population. This has to begin in the educational system. The revolution will take its time. Most people will be prepared and looking forward to it - or it won't happen.

7. Total economic systems effects

When the specialised work automat, the robot, enters the labor market in large numbers at low cost the future may look frightening to many, as it has in the past. There is a fairly voluminous literature to consult - both historic and current. Henry Adams worried already 1862 about the machines taking control of mankind and Johanneson (1968) told the scary story of computers teaming up to produce even more sophisticated computers that eventually made man unnecessary to their survival (like most animals to man already).[1] In the first edition (1817) of his "Principles", David Ricardo illustrated a point by reference to the fully automated machine. Ridicule, however, compelled him to remove this "highly unrealistic example" in later editions.[2] History, however, teaches us that the scary visions of the future painted by contemporary visionaries have all been wrong.

The conclusion we have drawn so far is that it is doubtful that the introduction of electronics means that something very new, far reaching and unique is taking place. Rather we may talk about technical change as being speeded up, although there is little evidence of that yet (see Carlsson, 1980). This relabelling of the problem does not take away a number of probable consequences like a changing work environment, new educational and skill requirements, a different private world and a tremendously upgraded communication or information technology.[3] However, all this is nothing fundamentally new.

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[1] Johanneson, O, The Great Computer, London 1968.

[2] Fabra, P, L'Anticapitalisme. Essai de Réhabilitation de l'économie Politique. Flammarion. Paris 1979.

[3] Recent literature, realizing some of what has been said, already has begun to talk about the "communication" or "information" revolution rather than the "electronics revolution".

Changes of that nature have taken place throughout history and at high speed since the end of World War II. They may not be more dramatic than the impact of the introduction of factory work in the 19th century, the influence of the steam boat on the diet for the inhabitants of the rich nations and the effects of the aeroplane, the television set and the new kitchen technology. Above all, we can learn from the past that the lack of educational capacity to screen and digest unfamiliar, unorganized and difficult information among the public at large will perhaps be the stumbling block for the industrial nations, rocked by the tremendous national mood creating capacity of the new communications technologies.[1] The debate so far is mostly concerned with the possibility of mass unemployment possibility if the new technology is allowed to enter unchecked. The present argument suggests that the competitive situation the national industry will face if it prevents or does not encourage its introduction would be a more suitable cause for concern.

Past experience gives guidance here. Mass unemployment never before came directly out of technical improvements, rather the opposite. Relative technical competence in a broad sense, on the other hand, seems to be strongly associated with the relative material standard of living between countries (see Figure 1).

However, serious unemployment can arise in a specialized economy, if a large basic industry is suddenly caught in a competitive squeeze from abroad, due to technological change. Thus, for instance, new transportation techniques at the end of the 19th century opened up Swedish agriculture to severe foreign competition, making a substantial fraction of agricultural unemployment superfluous. Emigration to the US probably saved us from a persistent and severe unemployment spell at that time.

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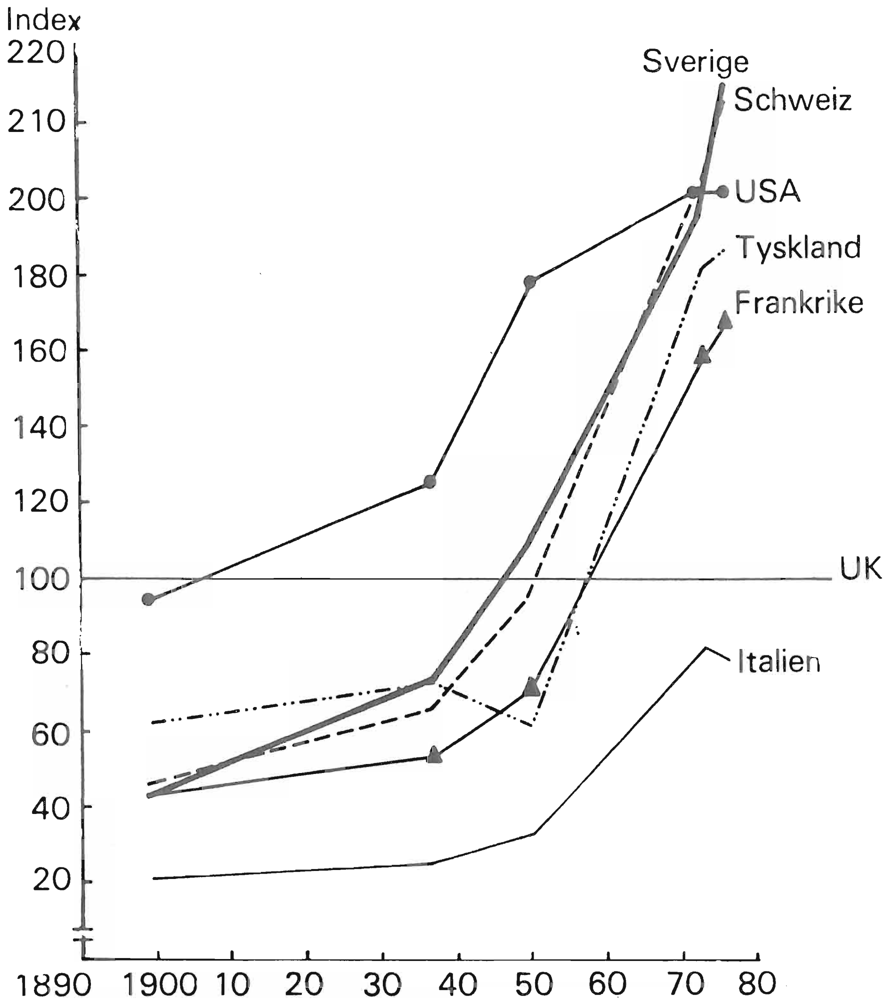
[1] The mysticism, hostility and "secterism" that preceded the referendum on nuclear power in Sweden in March, 1980 is an illustrative case in point. Neither was the outcome insignificant to the future.

Figure 1. GNP per capita in different countries 1890-1975
Index UK = 100



The conclusion on mass employment may, however, look wrong, especially if electronics is presented as something unique and revolutionary with massive implications, illustrated by a some spectacular examples. The following argument can be read frequently:

"Electronics fundamentally affects the production and supply side, and does not to the same extent improve products and boost demand. Hence, the same will be produced with less labor and people will become increasingly unemployed."

The distinction between the supply of the product and the innovation of the product effects is probably wrong or else meaningless. But, even if right, the whole argument is false for a normal, western market based (or roughly so) national economy.

More efficient production in domestic industries generates more profits (and investments) and higher real wages. Hence, increases in capacity and demand go hand in hand even if there may be cyclical aberrations in the process. In a free society every individual has the option to buy more free time by working less or to invest in himself by staying longer in the education system, etc. Supply and demand conditions determine prices on factors and products and these prices in turn balance this choice throughout. It is important not to disregard market price adjustments. Technology improvements (for instance through electronics) in the production system, reduce costs. Firms can maintain or raise profitability and lower prices in foreign markets simultaneously. This in turn means more demand for the same products.

A case from an ongoing IUI study for the Swedish Commission on Computers and Electronics may illustrate this. A particular part was being manufactured by a subcontractor for a large Swedish company. Price competition from abroad was very intense. Without a substantial reduction in unit production costs the whole production line would have had to be shut down. A decision was taken to integrate several numerically controlled (NC) machine tools into one simple transfer machine. It should be noted that the NC machines already were guided and controlled electronically. The transfer system was also based on electronic controls. It could, however, quite well have been a mechanical system. The production time of the part is now down from 30 to 6 minutes. The new investment was quite small. The transfer machine arrangement was conceived, designed and built by the parts manufacturer himself.

This investment not only made it possible to keep producing the part at a satisfactory profit rate. The cost reduction also made it profitable to export the parts to foreign markets. In addition, the transfer machine itself is being sold both in Sweden and abroad. Total employment in both parts <u>and</u> transfer machine production is roughly the same as before the investment. Without the investment the plant would have been closed down. The argument to follow below is, however, that even so, some alternative production most certainly would have absorbed the excess labor created in a fairly short period somewhere else in the same plant, in a different firm, perhaps in a different community provided a reasonably flexible labor market was at hand.

Quite often the Government interferes with the market system to achieve certain ends. It may be preposterous to argue today that the best thing is to leave the problem to the market and everything will be all right in the long run. The dimension of the adjustment process cannot be neglected. We will try here to illustrate and quantify the mechanisms at work by using a market based simulation model of the Swedish economy. It represents a market economy where the Government can interfere in the market system. Above all, the model catches the time dimension of the market process, which is the basic idea. Technical change in the sense of Carlsson's (1980) measurements is explicitly represented at the individual firm level. The structural adjustment process in response to changing relative prices is explicit and endogenous. Even if everything is all right after ten years this may be no solace if there is a 20 percent rate of unemployment during the first 5 years. Even though no effects whatsoever can be seen in the aggregate national statistics, it may not be acceptable if a whole industry disappears in a short time, or if most of the employment disappears even though the firms flourish.

What happens if the Government steps in to prevent the change? Some of these questions are answered and quantified in principle in Eliasson (1980) in simulation runs on the Swedish model. The model is still in a preliminary state when it comes to calibration for purposes of quantification. This has to be kept in mind in what follows. But it is still the only available model where the macro effects and structural change occasioned by technical change at the micro firm production level can be studied systematically.

These are our conclusions about electronics in economic growth.

1. The digital technology is universal. This is the prime problem facing the national economy. It can be potentially applied in all industrial countries with a sufficient educational and skill level if profitability calculations so indicate and in a large number of production activities. To the extent that relative costs are affected, relative prices in world trade will eventually also be affected.

2. A satisfactory assessment of the effects of universal technical change on employment and output hence will have to consider both direct effects, technical change "at home" and indirect effects through foreign competition and prices. Simulation experiments strongly suggest that it is far worse on employment and output to be hit by technical change coming from abroad than to lead the competitive race with technical development of the same magnitude in domestic industries.

3. On the whole, if market price adjustments are not unduly checked employment will be normal in the long run and the adjustment to technical change in both the upward and downward directions will be absorbed by changes in real income. There will be transitory unemployment periods of a few years but no tendencies to cumulative mass unemployment. There are no artificial assumptions in the model that produce these results. Factor prices (like real wages) eventually adjust together with industrial structure so that it pays profit seeking firms to hire labor. The long term unemployment observed then essentially consists of normal turnover in the labor market. The composition of industry and labor will, however, be changed in the process.

4. In fact, interference in the normal market adjustment process (subsidizing failing firms or keeping labor from moving to more remunerative jobs) that prop up artificially high wage and salary levels may be the important explanations behind observed prolonged unemployment situations at the national level.

5. The great risk exposure for a country, hence, arises from being caught unprepared by leading technology advances in other countries and therefore concerns future real income levels.[1] The more sophisticated (or narrowly specialized)[2] the national economy, the greater the exposure, since required structural adjustments will be larger.

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[1] This conclusion is generally in keeping with results from production function analysis, where output today is recalculated at "technology" levels of the past. See section 8.

[2] In a sense, exactly this happened when Swedish raw material industries were caught unprepared by a drastic relative price change of permanent nature after 1975. Cf the simulations with relative price change in foreign markets due to technical change in Eliasson (1979).

6. The risk associated with the absence of domestic hardware production in the electronics sector may be exaggerated (this conclusion flows from the earlier text, not from the model simulations). Systematic production knowledge in combination with sufficient software skills on the engineering and worker sides and the right attitudes come first. Such a human capital endowment takes a long time to create. This may be where the real danger of falling behind lies. This seems to be the assessment of the situation that has matured in Japanese planning circles, perhaps in contrast to prevailing views in some other countries.

8. Technical change and growth quantifications

The traditional way of quantifying effects of technical change on output is by reducing or removing the residual (or technical change factor) in an estimated production function, and recalculating output with the same labor and capital input, i e at a different technology level. This has been done in the above quoted study by the Draper Laboratory and the MIT Center for Policy Alternatives. They find, for instance, (op cit, pp 2-12) that with technology at the 1949 level, US output would have been only 60% of actual output in 1968. This indicates that technology alone has moved GNP 1.4 percentage points each year.

Besides leaving the nature of technical change unspecified, such calculations disregard a number of relevant aspects. For one thing the effects of technical change depend on the volume of new investments that carry the new superior techniques.

Second, the effects also depend on the allocation of investment and hence new techniques on firms and markets. This depends on the economic circumstances at hand when the investment decisions are taken.

Only thirdly does the magnitude of technical change at the firm level impact growth.

For this reason alone different compositions of investment and technical change will mean a different total production potential and a different labor composition.

In addition, the utilization of capacity always influences technical change measurements in aggregate production function analysis. This whole allocation pattern is explicitly recognized in the simulation experiments in Eliasson (1979).

The simulation experiments tell us the following things about technical change in economic growth:

1. Even with the same (identical) technical assumptions at the firm level, different policy and/or market assumptions produce differences in long term (30-80 year) growth rates of the same magnitudes as those observed in Diagram 1. This suggests that a great deal, perhaps as much as half, of the technological competence as measured in the residual technical factor of production resides at the policy level. "Mismanagement" of the market economy can cut as much as one percentage point from the growth rate for a very long period of time. The current practice in many countries of keeping dying firms alive for employment reasons belong to this mismanagement category. In fact, the simulation experiments indicate the importance of a "sophisticated market technology".

2. Good market performance in the micro simulation does not mean immediate adjustments in the production sector to changing market signals in the sense of the classical general equilibrium model. Since changes in relative and absolute prices affect structures, and changes in production structures affect the price structure and so on overly speedy adjustments to an induced change ("shock") may destabilize the whole economic system.[1] There is a trade off between speed of adjustment and long-run efficiency. We know from experience with the model that the less of performance variation between firms in a market in the sense of a Salter curve the more sensitive to such relative price shocks the whole economy.

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[1] See for instance Eliasson, G, "Relative Price Change and Industrial Structure - the Norwegian Case"; in Carlsson-Eliasson-Nadiri (eds), The Importance of Technology and the Permanence of Structure in Industrial Growth, IUI Conference Reports 1978:2.

3. Technical change in terms of the "residual factor of production" at the total industry level has been observed to decrease during the 70ies in most industrial countries. Carlsson (1980) has observed a similar decline at the firm, or production line levels between the periods 1955/65 and 1965/75. He attributes that partly to a slowdown in the growth of demand in the second period relative to the first. This led to a reduction in investment spending. At the same time, he observes that scale economies have continued to increase and have now reached far beyond the domestic Swedish market in many cases. In combination with increased international competition, this has also tended to reduce investment. New investment is the factor that brings in new technology.

4. This does not exclude the possibility that pure technical change has not at all been reduced to the same extent as aggregate productivity measurements suggest. Whether it is still growing as fast as before or at even higher rates cannot be concluded from existing measurements. Carlsson observes that his measurements are concentrated to technologies in not particularly expanding and innovative markets. To some extent this reflects the importance of raw materials production in Swedish industry.

5. On the whole, Carlsson's estimates suggest that labor productivity at the production line or factory levels in some frontier technologies have been increased by 2.5 percent for all Swedish industry for the period 1955/75.[1] Additional evidence suggests that this estimate should be qualified by at least $\pm\frac{1}{2}$ percent interval. This is, however, pure technical change at the factory level, although our analysis suggests that most of technical change below that level also originates from structural change or reorganiza-

[1] In principle this represents internationally available technologies - an international technical frontier so to speak. The above estimates however, have been weighed together by the output composition of Swedish industry. See Carlsson (1980).

tion of production flows. We know that this rate of change corresponds to an increase of total factor productivity (the residual factor) as measured in traditional production function analysis by 4.5 percent per annum 1955/65 and 3.5 percent 1965/75.[1]

This in turn corresponds to 76 percent and 94 percent of total change in output respectively. These results are generally compatible with the simulation experiments in Eliasson (1979) although the micro-to-macro interpretations give them a very different meaning. By increasing the rate of general technical change at the factory level by one percentage point per annum (DMTEC in Diagram 1 in Eliasson (1979) or the measures in Table 1 in Carlsson (1980), i e from 2.5 to 3.5 percent for the period 1965/75), and allowing the simulation to run for 30 years the long run output level is raised some extra 18 percent[2] or about 0.6 percent extra per annum. The 2.5 percent frontiers technical change at the factory level then would explain roughly 1.5 percentage points output growth per year or ca 40 percent of the residual technical factor. The rest or about 60 percent of total factor productivity growth depends of changing in the composition of output between firms. This result in turn compares well with an alternative estimate of 50 percent made with other statistical methods on different data.[3]

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[1] See Carlsson-Dahmén et al (1979), op cit.

[2] Not capacity to produce which is much higher but quite meaningless in a 30 year perspective. The added maximum capacity to produce of individual firms is not physically feasible for labor and other reasons, and even lower levels are not economically feasible except in particular relative price structures. This is the advantage of the micro market interpretation. To make the estimates compatible with the above mentioned production function estimates for all industry actual production trends should be used.

[3] See Carlsson, B, Content and Importance of Technical Change in Economic Growth, IUI Yearbook 1979/80 (forthcoming).

6. Technical change is defined at the plant level (one whole production process). Simulations indicate that one universal step change in productivity in new investments to a new "steady state" generates a 20 to 25 year business cycle. So far as we can judge from our knowledge of the model properties long waves (10 to 20 years) of innovations manifested in the form of an average DMTEC wave and a random distribution of individual DMTEC measures across firms each point in time would create very stable output fluctuations of the 50 year Kondratiev type, discussed in Carlsson (1980)[1] If a strong business cycle downswing occurs on the backside of such a cycle, simulation experience suggest that it is very difficult to counter the effects with contracyclical measures.

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[1] Unfortunately such simulations are very expensive to run, so we have had to abstain for the time being.

9. The future - more or less technical change

The conclusion of this paper is that forecasts of technical change and of its effects on employment and growth that do not properly account for the market adjustment process should be regarded with great suspicion. Economics enter in a fundamental way. The hardware that dominates both popular and scientific literature on the matter is very much reined in by the economic factors. By identifying the location and role of "electronics" in the production process it has not been possible to confer upon it the characteristics of uniqueness. However, its universal applicability suggests a potential increase in the rate of technical change if electronic techniques are combined with other elements of technical change (new materials, etc). Even so, it is doubtful whether such an increased rate of pure technical change has as yet taken place, other than in some sporadic but spectacular examples.

Large steps in scale economies and new and superior materials have been introduced when cost considerations have made this imperative. The same thing is likely to happen in the case of "electronics". Spectacular improvements are reported at very low micro levels in the production workshops. Since improvements are normally introduced gradually there is no reason to expect dramatic jumps at the aggregate firm, sector or industry levels from electronics or any other kind of technology.

If ever realized, even the fully automated factory discussed so intensely will be a collection of both hardware improvements and bits and pieces of production experience accumulated as individual production sequences have been automated. This stretches the technical change over a long period.

Finally, "electronics" more than perhaps other innovations consist of a symbiosis of hardware and production knowledge. The educational knowledge and skill capital will be the lagging factor.

The printing technique is perhaps the best analogy to use. It has been with us since the middle of the 15th century. It has affected our private and professional lives profoundly since then and to our great benefit. Its application is universal but its permeation of society has been quite slow. In the beginning its frequent use was prevented for lack of paper to print on. The main factor that slowed down its efficient introduction and general use was, however, the high rate of illiteracy. Education and the general acquisition of reading skills (human capital) made the technique of printing the useful tool of advanced industrial nations that it is today. A similar, educational process is needed before we will see the same profound effects of the "digital revolution".

Suppose we succeed in accomodating the new universal technique into the Swedish economy in a smooth and fast way through an efficient educational program. Suppose technical change at the plant level occasioned by this turns the long Kondratiev cycle upwards again some time in the late 80ies. This is quite possible in terms of our analysis. But the resulting economic upturn would be as much the result of greatly enhanced engineering knowledge, and perhaps new attitudes, as of electronic applications.