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# EMPLOYMENT AND TECHNICAL CHANGE[1]

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## RESUME

### CHANGEMENT TECHNIQUE ET EMPLOI

Cette revue de littérature sur le thème du changement technique et de l'emploi part d'une mise en perspective historique des débats, soulignant le contraste entre le credo moderniste qui suivit les années de croissance forte et les inquiétudes que fait naitre le changement technique en période de stagnation. Trois catégories d'approches contemporaines sont présentées: les approches néo-solowiennes qui, à partir des travaux précurseurs de Solow, développent une nouvelle théorie de la croissance, les approches néo-keynésiennes qui réalisent des travaux d'estimation et de prospective en s'appuyant sur de grands modèles multisectoriels et enfin les approches dites structuralistes d'inspiration schumpétérienne qui identifient plus directement la dynamique des innovations. Les complémentarités que fait apparaitre cette revue de littérature invitent à combiner ces diverses approches pour mieux répondre aux nombreuses questions qui restent ouvertes.



Mots clés : changement technique, emploi, histoire de la pensée



## ABSTRACT

### TECHNOLOGICAL CHANGE AND EMPLOYMENT

This survey on technological change and employment starts with an historical perspective which underlines the contrast between the credo following the years of rapid economic growth and the concerns over the effects of technological change in the present period of slow economic growth. Three types of approaches are presented: the solowian ones which develop a New Growth Theory, starting from Solow's seminal early works, the neo-keynesian ones which rely on large multisectoral models to estimate past and future effects of technological change and the neo-schumpeterian ones which are more directly oriented towards the nature and dynamics of innovations. The complementarities displayed in this survey suggest that combinations of these various perspectives would help to answer some of the pending questions on this issue of technological change and employment.



Key words : technological change, employment and history of thought.

JEL Classification : 03, 033, 04, J23

## CONTENTS

## SECTION I - TECHNICAL CHANGE AND EMPLOYMENT: A RETROSPECTIVE OF THE DEBATES AND ISSUES.

The relationship between technological change and employment, a most debated issue since the beginning of the industrial era, remains both controversial and highly topical. For several reasons it is useful to start the discussion on this issue by reviewing a long history of debate:

- first, past questions and theories are, in this case, still relevant;
- second, employment issues are specific and need to be treated separately from the general questions pertaining to the economics of technological change;
- third, general approaches cannot treat all the complexities of this issue;
- fourth, the advanced economies may currently be experiencing a change of technological paradigm which can only be appreciated by taking an historical perspective.

Section I of this chapter is thus devoted to the history of the debate. Section II then surveys the more contemporary issues in the analysis of technological change and employment. Section III provides conclusions and suggestions on future research.

In this chapter we distinguish four time periods: a pre-industrial one where techniques and users have a complementary relationship; an industrialization phase where substitution of machines for labour across all sectors becomes a key issue; a third phase of rapid economic growth following the Second World War where fully fledged technological progress helps to overcome labour shortages and to generate higher productivity; and a fourth contemporary phase, where the new technological system may be used in different ways according to some endogeneous processes with marked uncertainties. In this chapter these historical phases of economic development are presented along with the successive emergence of different schools of economic thought.

### 1 The pre-industrial phase

As observed by Landes (1969), the notion of technical progress postdates the industrial revolution. In effect the development of industrial activities was accompanied by cumulative and interdependent changes in techniques, whereas prior to the mid-eighteenth century techniques seemed tied to groups or social organizations. In this early period users were the creators, or close to the creators, those who had codified the techniques. The best example is the organization of corporations in the Middle Ages. In crude terms, technology is seen as the domain of practical man, passing on his technical knowledge, most often orally, to other members of his group. For this "homo faber" technology is rather disconnected from science. The techniques of identical trades may even differ from one place to another. There may be drastic changes, transforming a whole corporation, but the implementation of a new technique keeps a local character. Spillovers remain relatively limited outside the social group linked to a given technique. However this broad complementarity between men and techniques is only a loose characterization, for it is applied to a large set of various situations from medieval crafts and classical techniques of water distribution, to mills of all kinds, weaponry, or even to the Renaissance arts of architecture! While science and technology were not always that far apart (as for instance in the development of optical instruments), and indeed there was during the Renaissance some perception of the overall power of technical change (as expressed in Da Vinci's vision of the future), it is still true that in pre-industrial times each technique seemed to have a direct relation of its own with its users. Rules of use were rather strictly codified. No links were established between techniques, no common potential for change was widely perceived. Such segmentation and codification may be considered as a dominant, distinctive feature of the complementary relation between men and techniques prior to the industrial revolution. Social groups could be endangered and eventually disappear if the technique they were associated with was superseded by another. However there was no clear understanding that such events could affect other parts of society once the new technique met the needs of that society[3].

## 2 From early industrialization to the nineteen thirties.

By contrast, the process of industrialisation made it clear that the spread of machinery had impacted on the whole of society. The notion of technical change came out of the recognition that changes in techniques could be cumulative and affect a wide range of activities. It is useful to distinguish three sub-periods within the long span of time starting with the early phase of industrialization and ending with the economic depression of the 1930's and the Second World War.

[3] The mercantilists showed some concern for the threat to qualified labour from the diffusion of machinery and consequently tried in some crafts to limit the substitution of capital for labour.

In the first sub-period, which corresponds to a phase of industrialisation roughly up to the second half of the nineteenth century, it slowly appeared that technical change, by means of increased mechanization, could simultaneously reduce employment in some activities and lead to an increase in employment in other activites. Men and techniques were still seen as locally complementary, but the replacement of some techniques of production by mechanized methods became a general phenomenon. Adam Smith gave a particularily dynamic view of the process of labour division linked to this introduction of machines, insisting on the opportunity given by the continuous improvement of machinery in times of market expansion. Still, the overall subtitution of capital for labour, linked with mechanization, raised for the first time the question of the impact of technology on employment. The social context in which this was taking place was also dramatic.

In the early phase of industrialisation, peasants had been led out of agricultural activities into factory work. Once a large share of the labour force became directly dependent upon industrial jobs, technical change (i.e. the spread of new, more efficient machinery requiring less manpower) appeared as a real threat. In the midst of the Luddite riots fierce debates on this issue of unbalanced technical change took place at the beginning of the nineteenth century in the U.K. Classical economists (John Stuart Mill, John Barton) developed a theory of compensation according to which the jobs displaced in a given activity would be replaced, first through an enlarged production of machinery itself, and second by means of rises in the levels of demand brought by the reduction in prices allowed by the introduction of the new techniques. Most of the classical economists maintained that compensation was effective, bringing new jobs in sufficient numbers and within a reasonable span of time. No good reason was given for this belief. Ad hoc arguments were often given to explain how the substitution of capital for labour in one place was matched by an expansion in another place. Some confusion did exist between the issues raised by the invention of new machines and the issues raised by the spread of machinery (mechanization). An illustration of such misunderstanding was given in most contemporary interpretations of Ricardo's famous chapter "On machinery", added to the third edition of his "Principles" in 1821, where his statement "machinery and labour are in constant competition" refers to mechanization (see Hicks 1969, Heertje 1973) more than to technological change per se. Incidently, the difference would only be made clear a century later with Schumpeter's distinction between innovation (the surge of new machines) and diffusion (the spreading use of machines to be substituted for old techniques). Still, at the time the distinction was not so necessary, the important issue being the diffusion of new techniques of production using more machinery (i.e what we would now call mechanization), made available by the development of the machine tool industry[4]. This perspective is also consistent with the previous comprehensive perception of techniques, the real social innovation being the mechanization of a whole range of production techniques.

The big issue is then whether the new trend towards substitution of capital for labour will produce a change in the pre-existing ratio between labour and capital. A majority of classical economists give a positive answer (Smith, Malthus or Say), although for different reasons and with little reference to the statistical facts. Others, like Ricardo in the famous chapter mentioned above, taking into account the bitterness and magnitude of the struggles against mechanization, acknowledge that full compensation of job losses is by no means certain[5]. Marx stresses that the compensation thesis underestimates the waste and misfortune created by the fact that new jobs are unlikely to benefit the displaced workers directly, being located elsewhere or with a lag in time and requiring different qualifications (raising therefore the issue of structural unemployment). Overall this sub-period, when the classical economists developed their arguments, was marked by distressed conditions for the working class and a spreading use of machinery powered by steam engines.

By contrast the second sub-period, starting with the last third of the nineteenth century, witnessed some improvement of working conditions and wages, while productive capital experienced the mature phase of steam power, quickly followed, at the turn of the century, by the rise of electric power[6]. This period coincides with the development of the marginalist school of economic thought of Walras, Jevons and Menger, who followed up this

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[4] This development, made possible by the mastery of the steam engine, has still to be contrasted with the transformations brought to the machine industry by the surge of new machines (as product innovations) which corresponds to the effects of technical change stricto sensu.

[5] i.e."the opinion entertained by the labouring class, that the employment of machinery is frequently detrimental to their interests, is not founded on prejudice and error, but is conformable to the correct principles of political economy."

[6] Devine (1983) provides interesting figures to illustrate this transition: the shares of mechanical power drives in U.K. industry in 1870 were 52% steam, 48% water, in 1900, 81% steam, 13% electricity and 7% water, and finally by 1930 78% for electricity, 16% steam and 1% water.

debate on capital/labour substitution, but starting from the premise that market mechanisms tend to adjust any capital/labour substitution to the advantage of both workers and capitalists. Meanwhile a major shift in approach was accomplished. Compensation is no longer addressed in terms of employment but is, ex ante, addressed in utilitarian terms: the best combination of capital and labour will occur which corresponds to the case where both labour and capital obtain the greatest marginal returns in terms respectively of utility and profit[7]. In this static approach of the neo-classical economists, technical change disappears together with the shocks that it gives rise to. Instead a smooth process of change, but one which does not change the basic capacity of capital and labour to adjust in accordance with their relative scarcity, is introduced and will be expressed in the production function. The idea that capital and labour are substitutes starts to be applied at the level of the representative firm[8]. This new theoretical framework rules out from the start the possiblity of technological unemployment, once market adjustments are properly allowed for.

According to Gourvitch's survey (1940), the problem of technological unemployment only reappeared in the economic literature in the 1920's, in the aftermath of the First World War, i.e. at the beginning of our third sub-period. In the interwar period the numerous ups and downs of the labour market, culminating with the mass unemployment of the early thirties, stimulated a resumption of the debate. Clarification of the diverging views of classical and neo-classical economists, regarding the substitution between labour and capital came as early as the twenties. A good example of such clarification is given by the contribution of Neisser (1932), a member of the Kiel school, which was much interested in the twenties in the issue of capital/labour substitution. The point is made that in a world where the capital stock and the labour force are fixed, adjustment to full employment via changes in wages can only occur within a limited range. If it takes time to built up new capital stock, anything can happen in the mean time from persisting unemployment to improvements in technology, boosted by capital accumulation. Another example of such

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[7] Keynes based his own use of the label neo-classical (still uncommon in 1936) precisely on this shift from a concern for employment to a concern for workers' utility.

[8] The way in which technological change in the form of a shift from steam power to electric power seems to allow for further mechanization gives some support to this view of local substitution between labour and capital.

clarifying developments is the contribution of Lederer (1931), which attributed the severe unemployment of the early 30's to excessively labour-saving technological change[9].

The economic depression of the thirties brought back to the forefront the question of involontary unemployment. The early stage of the Keynesian revolution made it clear that "underemployment equilibria" exist[10], but this theorization remained marginal until after the Second World War.

This sub-period remains transitional as regards both the evolution of techniques and economic thought. Industrial machinery was mainly driven by electrical power at the time, and the main technical issues centered around organizational aspects as raised by the concentration of capital and the implementation of Taylorian methods of scientific work organisation. Many inventions took place in the thirties which would not be exploited until the post-war era. Meanwhile major theoretical economic developments were made by Keynes and Schumpeter, but these did not directly address the whole issue of technological change and employment[11].

The real change of perspective in this debate on the substitution of capital for labour came about in the post-Second World War period, when the bitter experiences of the thirties and forties had made it clear where disequilibrium on unsteady labour markets could lead to.

## 3 Technological change as a factor of growth in the post-war period

This change in perspective was first brought about by a widespread post-war committment to upgrade the capital/labour relationship and to develop welfare institutions. This drive towards "Modern Capitalism"[12] was fueled by exceptional economic conditions.

[9] The work of Lederer in many ways paralleled that of Schumpeter, as pointed out in the survey by Freeman and Soete (1985); however Lederer seems to depart more clearly from the neoclassical equilibrium theory than Schumpeter by allowing for sustained, and not only cyclical, technological unemployment.

[10] But with little reference to technological unemployment per se, although with clear insights on the role of investment behaviour, leaving it to Schumpeter to stress the attraction of entrepreneurs for new processes.

[11] Keynes focuses on employment and gives very little room in his analysis to technological change per se. Schumpeter on the contrary stresses the nature and importance of technological change but remains rather vague on the determinants of employment.

[12] to recall Shonfield's (1965) early assessment of the changes which took place in that period in the overall organization of capitalist economies.

The potential for catching-up on innovations (making use of all the inventions made in the 30's and 40's), and the impetus given by reconstruction, led rapidly to full employment in the 1950's. At the turn of the 1960's the major issue was labour shortages rather than technological unemployment (see Maddison 1964, Kindleberger 1967). The main questions therefore centered on the capacity of technological change to improve the use of limited human and natural ressources. In fact the developed economies experienced in the 60's some of their highest productivity growth rates for more than a century (see Maddison 1982).

The growth model developed by Solow (1957)[13] plays a central role in the type of questions and theoretical frameworks developed in this period. As full employment is achieved, questions tend to bear on the capacity of an economy to increase its pace of economic growth for a given level of inputs. The size of the "residual", i.e of the share of the growth rate which does not directly follow from the quantities of factors used up in the production process, has to be explained. Answers have been rather empirical: the residual encompasses the effects of all production factors unaccounted for as well as some external windfall. At any stage the residual is therefore a measure of technical change, in gross terms, which can be netted by identifying all the contributing factors. The works of Denison (1967, 1979) illustrate the wide range of contributions that can be called upon, if any spending (even by the State) can be considered a contributive factor. Alternative approaches require a more explicit definition of the basic nature of technological change and of its determinants (as will be shown with the developments of the last, contemporary, phase).

For our purposes it is interesting to note that the structure of employment by sex, levels of education and training has been considered as contributing "factors" in these growth accounting exercices (see Denison 1967, 1979). Indeed during this period the impact of labour qualification on the capacity to make the best of the technological potential was one of the main issues regarding technological change and employment. Aside from Denison's works mentioned above, such concern for the effect of the structure of employment on the productive capacity of the economy can also be seen in the Hecksher-Ohlin-Samuelson (HOS)

[13] with its successive elaborations, starting from a Cobb Douglas production function and an exogeneous trend in technological change and moving towards more elaborate formulations, where technological change is partly endogenised (the vintage production function of Solow) or accounted via various types of elasticities (CES and translog production function).

approach to international trade, where factor ressources are supposed to account for the pattern of trade specialization [14].

In contrast it has also been argued that during the period of sustained economic growth technological change induced some deskilling of the labour force. The previous period had raised questions around the implementation of Taylorian modes of work organization. The economic growth of the post-war period, together with the shift (mentioned above) in the capital/labour relationship, helped to extend and to realize the full potential of what have been called "Fordist growth regimes" in most of the developed economies during the golden age of capitalism (see Boyer 1988, Marglin and Schor 1990). The relative deskilling that this extension of Taylorian organizations in industry could represent could thus be seen as part of a trade-off where real wage increases, along with increased welfare and protection, compensated for a relative loss of autonomy and local creativity of the rank and file workers[15]. Thus even within non-orthodox economics, the issue of deskilling remained widely debated and influenced by the type of post-war "Keynesian" trade-off prevailing in the labour market of the country of reference.

To assess the full extent to which each thesis is relevant one needs a thorough understanding of what technological change really is. The neo-classical synthesis, which played a dominant role in the analysis of economic growth after Solow's work, treated technological change as a continuous exogenous flow, unrelated to the pace of economic growth, and therefore did not provide much understanding[16]. Its extension to account for embodied technological change using vintage production functions, or developing more sophisticated production functions from C.E.S. to translogs and others, still fell short of the findings of the economics of technical change which followed from Schumpeter's views (Schumpeter 1912, 1946) or from contemporary works on diffusion (as in Griliches 1957 or

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[14] To take into account the qualification of the labour force is a necessary condition for the H-O-S approach to overcome such paradoxes as raised by Leontief (1953, 1956), who noticed that the trade pattern of the US economy had a stronger labour content than predicted.

[15] On this deskilling see Braverman (1974); for the disciplinary issue linked with organizational change see Marglin's (1974) critique of Adam Smith's analysis of the changes in the division of labour and the long term analysis of the US capital/labour relationship in Bowles, Gordon, Weisskopf (1985).

[16] The Cambridge U.K. criticism partly bore on this view of an homothetical growth of the capital stock (see Robinson 1965, Harcourt 1969). The attempt by Kaldor (1957) failed to provide a real alternative.

Mansfield 1961). Basically, in these times of rather steady growth and full employment the need for a more realistic view of technological change was not that pressing.

The economic crisis of the 70's, as shown in the break down of the productivity trends of the 50's and 60's, radically changed the scene. With the rapid increase in unemployment levels two transformations of the economic environment became apparent, both with far reaching consequences: first, economies around the world had become much more interdependent and the above treatment of technological change as manna from heaven was too orientated towards a closed economy; second, technological changes themselves seemed to be leading more to the emergence of a new system of techniques centered around information technologies, than to an ongoing flow of undifferentiated changes. The scene, set for the 80's and 90's, thus somehow regained some of the traits of the early classical period: the suddenness of technical changes, the displacement of workers, and mass unemployment in the context of a reshuffling of the world economic order.

## 4 Endogeneous technical change in a transition phase.

The thesis that a new technological system started to diffuse in the 1970's has been based on the pervasiveness of technological changes related to information technologies that take advantage of the miniaturisation of micro-processors. A significant figure is the sixty per cent annual growth rate since 1959 in the number of bits per integrated circuit (which is equivalent to multiplying the density by 100 every ten years).

The co-existence of a marked diffusion of a new technological system with slower productivity growth appeared to be paradoxical (sometimes called the Solow paradox, to echo Solow's own astonishment that computers should be found everywhere except in statistics of productivity). The fact that this technological diffusion, slow growth of the economy and persistent unemployment[17] existed together led some to raise again the issue of technological unemployment.

New approaches to this issue led economic theories to stress the importance of technological change per se as a behavioural process at least partly endogenous to the growth process. The uncertainty induced by the evolution of such complex interdependent systems

[17] In EC countries that had enjoyed near full employment until the mid seventies, the rate of unemployment had reached 6% by the end of the seventies, shifting to an unemployment rate of 9% in the late 80's when price inflation had been curbed and effects of the oil crisis could no longer be invoked.

as modern open economies was also widely acknowledged. Many theoretical developments have been presented to account for the interaction between invention, innovation and diffusion on the one hand, and investment, work organization, productivity growth and distribution on the other.

We shall review these developments, or more precisely how they relate employment to technological change, in the following section. For the moment let us stress, and thus close this overview of the historical debate, that the past decade, following the breakdown of economic growth in the seventies, has been marked by a revival of Schumpeterian ideas on technological change and long term economic growth.

In the first place the slowdown in the 70's occurred roughly in line with the downswing of the fourth Kondratiev long wave. Although one should not have too mechanical a view of the dating of these long cycles[18], in a Schumpeterian perspective information technology may well be considered as the new technological system which will boost the upswing of the fifth wave. This gives some insight as to the time duration of diffusion of the new system.

The main sign of the Schumpeterian revival stems from the widespread belief that technological change is largely endogenous and follows from the different strategy of agents as regards innovation and diffusion. In open economies the capacity to take advantage of the potential of a new technological system has also been reckoned to be the key element in

[18] A rough periodisation of downswings and upswings in real output growth over more than a century yields the following time intervals:

| | | Years | U.S. | U.K. | Germany | France |
|---|---|---|---|---|---|---|
| Second Cycle | A | 1846-78 | 4.2 | 2.2 | 2.5 | 1.3 |
| | B | 1878-94 | 3.7 | 1.7 | 2.3 | 0.9 |
| Third Cycle | A | 94-1914 | 3.8 | 2.1 | 2.5 | 1.5 |
| | B | 1914-38 | 2.1 | 1.1 | 2.9 | 1.0 |
| Fourth Cycle | A | 1938-70 | 4.0 | 2.4 | 3.8 | 3.7 |
| | B | 1970- | | | | |

notes : A (resp B): average annual percentage growth in real output during accelerated (resp. slower) growth period.
source: Gordon, Reich, Edwards (1982)

competitiveness. In the context of increased competition and slower growth the positive correlation seen in the past between employment and technical change may no longer hold.

Still, rates of growth of employment in OECD countries did remain rather close to those observed in the 60s; the major difference lies in the structure of employment growth, with industry suffering the major decline while employment increased in services[19].

The challenge to analysts of the relation between employment and technological change is to provide explanations that are in accord with the above stylised facts.

## SECTION II - CURRENT ISSUES IN ASSESSING THE EMPLOYMENT EFFECTS OF TECHNICAL CHANGE.

We shall distinguish three broad currents of analysis. The first enlarges the scope of Solow's growth analysis mentioned above, the second brings together some neo-Keynesian developments addressing the issue of technological change, and the third is a mix of structuralist and Schumpeterian analysis where technological change is given some precise content. The borders between these three approaches are blurred and it is useful to recall the specific assumptions at the core of each.

For the Solowian tradition, agents are basically rational and well informed and prices tend to adjust in accordance with the expectations of the marginalist school. Developments may involve some departures from these central hypotheses, with some consequences for the overall dynamic of economic growth, but notional demands and supplies derived from the assumptions are still the driving force.

By contrast the neo-Keynesian developments basically assume that agents are neither fully informed, nor fully rational, and that prices are therefore rather sticky. This leads to markets which are either demand or supply constrained. Such disequilibria may impinge upon

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19 Employment growth
Average yearly growth rates in % (1960-68 / 1979-1989)

| Civilian Employment | agriculture 60s | agriculture 80s | industry 60s | industry 80s | services 60s | services 80s | total 60s | total 80s |
|---|---|---|---|---|---|---|---|---|
| OECD seven | -4.1 | -2.5 | 1.5 | -0.2 | 2.3 | 2.2 | 1.0 | 1.2 |
| OECD smaller European | -2.2 | -0.6 | 1.4 | 0.1 | 2.6 | 2.5 | 0.5 | 1.1 |

source: Historical Statistics, OECD, Paris, June 1991 the dynamics of economic growth and the pattern of technological change (the existence of increasing returns is one example).

In both these approaches technological change is a rather abstract concept. The third approach, on the other hand, draws extensively on developments in the Economics of Technological Change, explicitly analyzing innovation and diffusion behaviour. Here we find the neo-Schumpeterian approaches.

This grouping helps to map out the various developments on technological change and employment that we review below. The classification also helps to stress some complementarity between the three approaches: the Solowian tradition focuses on learning processes in developing a new growth theory, the neo-Keynesian/Kaldorian works stress the dynamics of external and internal labour division, while the neo-Schumpeterian approach deals with the choices of innovated products or processes.

All these developments finally concur to build up an approach of a much more endogenous technological change, raising new issues that we shall confront in our concluding section.

## II 1 From Solow's model to the New Growth Theory.

Let us recall to begin with the basic neo-classical growth model as assessed by Solow (1956). In this crude formulation there is no technological change and employment is equal to the supply of labour. Unemployment is thus assumed to be inexistant and we hardly have a growth model. If the production function is of a Cobb Douglas type with constant returns to scale for instance, the only stationary path is one where capital per head, k, does not grow over time :

$$k^{1-\alpha}=s/n$$

where k is the capital per worker, n is the growth rate of labour supply and s the rate of saving [20]. As $\alpha$ is less than 1, any rise in the growth rate of labour supply, n, will simply reduce the level of capital per head, k, constant over the stationary growth path.

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[20] This result is straight forward as the growth rate of capital per head, $\dot{k}/k$, when the production technology is a Cobb Douglas with constant returns to scale can be written as $\dot{k}/k = sk^{\alpha-1} - n$. A similar result, i.e. a zero growth rate on the stationary path, is also obtained with a more general production function. The constant capital per head, k, on this path is given by the following equation:

$$k/f(k)=s/n$$

where f(k) is a general production function with constant or decreasing returns.

In order to bring the model into accordance with the observation that economic growth outpaces the growth of capital stock[21], Solow (1957) introduced an exogenous trend of technological change into the production function. The stationary growth path corresponds then with some positive growth rates :

$$g = \gamma/(1-\alpha)$$

where g is the growth rate of output on the stationary growth path and $\gamma$ the growth rate of technological change.

Critics of such a representation have been numerous, leading to the famous capital controversy between the two Cambridges. Criticism centered basically on the crude and exogenous treatment of technological change, since it obviously requires both resources and the will of economic agents to move from blue prints to effective changes in equipment and organization. This representation also blurred all the conditions which could either slow down or block the diffusion of technological change (among them the state of the labour market).

However the path from criticism to alternative propositions is fraught with difficulties[22]. In retrospect (see Dixit 1990), Solow's model seems to have been the subject of numerous developments which have only partly overcome the initial critics. As mentioned above, many of these developments tried, around the seventies and early eigthies, to account for the growth residual by detailing the various inputs in production (see Jorgenson and Griliches 1967, Denison 1985). More recent developments tend to interpret Solow's growth residual in radically new ways and fall into three categories. Let us see how they relate to employment.

The first type is close to the previous growth residual approach, except that it focuses on market structure and its disturbing effects on Solow's results. Hall (1988, 1990) is the major example, with his emphasis on monopoly power and labour market dysfunctionments, close to the neo-Keynesian analyses examined below. The second type is to be found in the

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[21] Solow estimated that capital accumulation could account for only one eigth of the growth of output in the US between 1909 and 1949, a result which was to be more than confirmed by Denison for the post war period.

[22] One of the first to experience such difficulty has been Kaldor himself with what he thought of as an alternative treatment of technological change, tying the growth of production per head with the investment/capital ratio (Kaldor 1957), a formulation which did not really get rid of the critized global production function. Only in later works (see below) did Kaldor really formulate an alternative approach, then subject to criticisms of its own.

Real Business Cycle approaches which attribute dynamics of its own to the Solowian technical shift factor, whereby random productivity shocks accumulate over time to constitute the "trend" of technological change. The third type transforms the original approach even more radically, assuming that returns may not be constant or decreasing but may in fact increase due to some Marshallian externalities whereby actions of all agents in the end benefit everyone, a buttressing effect which can be carried over into Solow's framework by an aggregate variable. Let us quickly review these three types of approach and their consequences on employment.

a) The case of non-competitive markets.

Hall (1988) has interpreted Solow's residual as an indicator of monopoly power. He stresses that, if the markets of the product or of the factors were not competitive, then the estimation of the residual was flawed. Following this line of criticsm Hall (1990) notes that, under Solow's assumptions, the productivity residual should not be correlated with any variable that is not correlated with the productivity growth rate. Estimations done for 26 U.S. industries over the period 1954-1984 showed that in most cases the invariance hypothesis failed. For Hall (1990), the most important sources of failure are the existence of market power and of increasing returns[23]. Interestingly enough, such issues as labour management and wage formation have no explanatory power for Hall (1990)[24], while two other issues, namely unmeasured work effort and monopsony power on the labour market, could have been retained but were not supported by the observations. Thus work effort should have increased during upswings whereas empirical studies tend to conclude that on the contrary work effort increases during downswings (see Fay and Medoff 1985, Bowles Gordon Weisskopf 1985)[25]. Similarly a firm in a position of monopsony in the labour market may employ too few workers, but according to Hall (1990) such a monopsonistic situation cannot last for long, as firms will tend to attract workers from more distant markets.

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[23] Hall (1990), defining a cost-based measure of the residual (versus Solow's revenue-based definition), developed a test of the two explanations of market power and increasing returns. It showed that, even accounting for monopoly power, the modified Solow residual still has the same failure of invariance as the original.

[24] Regarding overhead labour and labour hoarding Hall (1990) features them as non explanation as their effects are balancing out in its analytical formulation and therefore do not affect the residual.

[25] Underreporting of hours of work would also play contracyclically and thus could not account for the positive correlation between productivity and output.

These analyses call attention to the influence that market power and increasing returns can have on the dynamics of productivity gains. They also lead us to question the effects of labour market conditions, an issue missing in Solow's model (and subjected to early criticisms, see Heertje (1973)). Nevertheless, Hall's results suggest that most short run changes in labour market conditions have little effect on the dynamics of productivity, leaving the question open regarding more structural changes.

b) Real Business Cycles.

In contrast with the above investigation on the irrelevance of Solow's basic assumptions on competition and constant returns, the Real Business Cycle approach starts by completing Solow's assumptions in assuming that the Hicks-neutral shift factor follows a specific recursive stochastic process[26]. This makes it possible to account for fluctuations of output growth within the theoretical framework of the general equilibrium.

Let us take the following production function:

$$Y_t = A_t F(K_t, L_t)$$

where A is the technical shift factor, K capital stock and L labour. Kydland and Prescott (1982) chose a stochastic process for their technology shocks with a highly persistent first order serial correlation of 0.95 on a quaterly basis. Indeed this assumption seems in accordance with the results of a regression run by Dixit (1990) on the time series for the period 1909-1949 calculated by Solow (1957):

$$\begin{aligned} \ln A_t = \; & -0.0033 + 0.0031t + 0.8260 \ln A_{t-1} \\ & (-0.2690) \quad (2.0600) \quad (9.1695) \\ R^2 = \; & 0.973 \quad SEE = 0.033 \quad DW = 1.972 \end{aligned}$$

Such high levels of persistence in the effect of technology shocks implies, if one does not observe such persistence in output growth, that some inner mechanism helps to damp down these regressive linkages. And indeed in the RBC framework, where agents are supposed to react in a rational and optimizing way to the random shocks, the damping-down effect is accounted for by some intertemporal possibility of substitution in leisure. It follows that the

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[26] A similar extension of Solow's approach to a stochastic environment had already been initiated by Brock and Mirman (1972).

ability of technology shocks of the above type to explain movements in output depend on a substitution between leisure and work which remains largely hypothetical. This tends to attribute moves in employment to reactions regarding leisure time from workers facing sudden wage changes following productivity shocks[27]. The logical conclusion would be that most of the current unemployment is voluntary, which points to a major weakness of the initial formulation of the Real Business Cycles theory. Recent developments (surveyed in Hénin 1991) tend to get rid of this leisure substitution hypothesis, putting the stress on adjustments in capacity utilisations or, more interestingly for our purposes, on more current approaches to the labour market such as the efficiency wage theory, job search theory[28] and so on.

However there remains the problem of matching these labour market theories, which try to account for practices restraining the ups and downs of the market, with the basic hypothesis of exogenous technological productivity shocks (a hypothesis which is not supported by econometric research either). This critique led to the development of RBC models where productivty gains are endogenous, at least for the component linked to variations in work effort involved in the classic short term productivity cycle. In that respect the RBC approach comes close to the objective of the third type of analysis, which is to account for the whole endogenous nature of productivity gains.

c) <u>The New Growth Theory.</u>

The major extension of Solow's model that we are now considering has led to an impressive collection of works under the heading of the new growth theory. They depart clearly from Solow's approach in allowing for the existence of increasing returns at the level of industries or of economies. Following Arrow's seminal paper on learning by doing (Arrow 1962), these analyses (exemplified by the works of Lucas (1988) and Romer (1986)) have stressed the existence of Marshallian externalities in production. They point to the fact that the sum of individual actions impinges upon the environment of all such actions. Most of the

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[27] These shocks could a priori affect productivity upwards or downwards, this last possibility being rather doubtful as stressed by Summers (1989).

[28] such as Pissarides (1990) which studies the effect of technological growth on unemployment in a search model and concludes that increased growth reduces unemployment as it implies a higher present value for a labour-market match.

proponents of this new endogenous growth theory focus on the propitious effect of collective learning and knowledge on the efficiency of individual production processes.

There are various ways of characterising these externalities. They can constitute the equivalent of a growth factor when they consist in endogenizing the Solowian technological shift factor, or they can impinge directly on capital or labour[29]. Thus a representative firm i using capital $K_i$ and labour $L_i$ has accordingly the production function, where Z is an aggregate variable carrying the externality effect :

- a) $F(K_i, L_i, Z)$ (case of three independant factors)
- b) or $F(ZK_i, L_i)$ (the externality effect bears on capital per head)
- c) or $F(K_i, ZL_i)$ (the externality effect bears on labour)

F is increasing in all arguments. F is concave and homogenous of degree one in the first two arguments, when Z is kept constant. In Arrow (1962) all $k_i$ add up to K and $Z = K^\gamma$ in a formulation of type c (as shown in Sheshinski 1967). In Romer (1986), $Z = K = \Sigma\, k_i$ (with $k_i = K_i/L_i$) in a formulation of type a) [30], while in Romer (1990) the formulation is close to type b as the externality plays on physical inputs (with the peculiarity that it is the number of inputs employed in an economy more than the aggregate quantity that matters).

Z is endogenously produced and for its effect not to peter out after a while its production has to benefit from constant or increasing returns. Arrow's model thus fails to have a persistent effect on growth (and ends up as in Solow's initial 1956 formulation with a zero growth path), while in Romer (1986) the favoured assumption of increasing returns in producing the technology leads to an explosive growth path. Despite these theoretical drawbacks[31], these approaches gain some support from empirical evidence on the existence of returns to scale at a global level. A very telling work in that respect was given by Caballerro and Lyons (1989), showing decreasing economies of scale at a detailed industry level and increasing returns at the level of the whole manufacturing sector. Beyond these

[29] Displaying somehow the same variety of formulation as the definition of neutrality of technical change according to Hicks, Solow or Harrod.

[30] The production function has the following reduced form for a typical firm :

$$y_i = [k_i]^\alpha . K^\delta \text{ with } k_i = K_i/L_i$$

[31] On top of the above limitations one should add, following Dixit (1990), that for analytical simplicity the authors chose variants of the Cobb Douglas form which prevented them from being confronted with multiple stationary points as implied by the general form.

crude tests which can have many alternative explanations, there is no direct testing of these technological externalities carried over by quantities of equipment (Z is linked with capital stocks). A second vintage of models of endogenous growth (including Romer 1990 and Lucas 1988) has put the emphasis more on human capital. Interestingly enough both approaches differ in their treatment of human capital. In Romer (1990) a stock of human capital is given and can be utilised either in production of goods or in R&D activities, the latter enjoying increasing economies of scale in producing innovations (in the form of new intermediary inputs) which are accessible to all units of production. We still have a Marshallian externality but it occurs from the production of some specific goods carried out by a share of the human capital stock devoted to research activity. The production function can thus be summarised as follows:

$$Y = AH_1^{\alpha} L^{\beta} \bar{k}^{1-\alpha-\beta}$$

with Y output, $H_1$ human capital engaged in production, L plain labour, $\bar{k}$ average level of equipment and A the innovative content of capital goods which is itself produced with the help of the share $H_2$ of human capital:

$$\dot{A} = \delta H_2 A$$

In Lucas (1988), by contrast, human capital stock is not fixed but embedded in the work force and can be increased from one period to another according to the choice made between work and training. This intertemporal treatment of human capital is much more in line with the standard human capital theory à la Becker; it nonetheless differs from this standard human capital approach in assuming that the efficiency of the representative firm is boosted by the average level of human capital in the economy. This Marshallian externality clearly associates the model developed by Lucas (1988) with the new endogenous growth theory. The production function can thus be written:

$$Y = AK^{\beta}(uh)^{1-\beta}\bar{h}^{\gamma}$$

with Y output, K capital stock, u the fraction of time devoted to production, h the stock of human capital, $\bar{h}$ the average level of human capital, and with the following law of human capital formation:

$$\dot{h} = \delta(1-u)h$$

The externality of the average level of human capital leads to global increasing returns as is the case in all these endogenous growth models.

Both models lead to the conclusion that there is an optimal path of human capital accumulation in the case of Lucas, or of human capital utilisation in the case of Romer. Both postulate that resources should continuously be devoted to increasing the stock or the utilisation rate of human capital, even if this growth rate is decreasing.

However, the empirical tests of these theories remain rather sketchy. In most cases reduced forms of these models of endogenous growth have been used to account for growth rate differences over long periods of time for sets of countries with very different levels of development. A good example is given by Barro (1991), who found that the 1960 level of human capital was a key factor in accounting for any catching up between 1960-1985 within a set of 98 countries. By and large the endogenous growth models have clearly made a step forward in endogenising the Solowian technological shift factor. The way in which they have done so, namely by incorporating a Marshallian externality linked to a learning process, has provided some theoretical insights into the potentially key role of certain learning activities. Many alternative schemes have been developed insisting on processes and equipment, products or R&D activities (as shown in the survey by Amable and Guellec 1991), yet the empirical evidence on reduced forms of the models is mainly concentrated on broad international comparisons and therefore says little regarding technological change and employment in one country[32]. The retardation effects induced by the pressure of unemployment or the shock effect unleashed by the upsurge of a new technological system are not accounted for.

Taken as a whole, the developments of Solow's approach surveyed above convey a much more comprehensive picture than the endogenous growth models alone. However, such a synthesis is not easily manageable and would fall short of providing a theoretical framework fitting the bulk of stylised facts that we recalled. To get these complementary views one has to consider developments of the two other approaches with rather different starting points, and shortcomings, of their own.

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[32] The only exception would be the extension by Aghion and Howitt (1991) of their own previous work [Aghion Howitt (1990)] into a multisectoral model including a labour market model. Aghion and Howitt (1990) is itself an interesting extension of Romer (1990) type of approach into a modeling of a Schumpeterian destructive creation process.

**II 2 Post-Keynesian developments: in search of innovation in modelling structural change.**

By contrast with the previous approaches which gave little insight into structural changes, we find in the work of the post-Keynesians a good set of studies with a broad empirical background and/or with specifications on market structures and dynamics. We shall take a comprehensive view of the Keynesian tradition, including all those who do not take it for granted either that prices change in order to adjust to supply and demand in every market, or that agents use fully rationally their informations. In such contexts, technological change may very well lead to unemployment. Furthermore, the realistic drive of post-Keynesian theoretical developments means that these approaches lend themselves more readily to empirical investigation. Multisectoral Keynesian models are a good case in point, providing the type of assessment of detailed employment effects of technological change which were lacking. Conversely, much has been done to account for various cases of market imperfections, mainly concerned with price stickiness as in the "disequilibrium " approaches. Beyond such a static approach to market structures, somehow at odds with such a dynamic factor as technological change, some analyses have concentrated on the changes in the division of labour which go along with technological change; examples of such Smithian approaches link market expansion to all kinds of innovations in equipment, products and organisation. In all these "post-Keynesian" analyses technological change remains rather abstract, even if part of it is endogenised by composition effects in the case of multi-sectoral models, or by accounting for some inner dynamics of labour division in Kaldorian approaches. Nevertheless, some of the basic specific impulses of technological change are not recorded. This will set the border of our third category of contemporary works on technology and employment. Thus the structuralist approaches, which we shall review afterwards, aim precisely to restore (be it at the price of a less tractable formulation) a specific environment of technological change which impinges on the behaviour of every economic agent. The dividing line between the Keynesian tradition and the structuralist (i.e. Schumpeterian) one is not that clear cut. Some Hicksian analyses for instance could be considered as intermediates, as they clearly follow some of the Keynesian hypotheses on the functioning of markets and also embrace some elements of the technological environment, be it in the form of a reference to long term phases or to time spans of diffusion (diffusion clocks).

In presenting these various "post-Keynesian" analyses, which assume market imperfections, some bounded rationality and limited information[33], we shall first introduce the fixed-price approaches followed by a quick overview of recent developments in multisectoral models, before going on to look at neo-Smithian Kaldorian approaches. Throughout this section we shall address the technology/employment issue at a macro or meso-economic (sectoral) level.

a) The fixed price approaches.

In general, the final effect of any technological change on employment will depend on a set of various elasticities, leaving the door open to empirical investigations into the magnitude of these elasticities.

In the pure neo-classical case, a general technical change (i.e. applying across the board, in all sectors) will only leave total labour demand unchanged providing (a) markets and agents behave as assumed and (b) labour is the only factor employed under constant return technologies[34]. Even in this simplified context, if technical change is sector specific, total labour demand might increase or decrease in accordance with the relative position of demand elasticities, of unit labour cost and of the magnitude of the specific technical change.

If one considers a general technical change (or restricts the analysis to one sector), but in the case where wages are fixed in nominal terms, it can be shown (see for instance Neary (1981) or Sinclair (1981)) that an elasticity of demand greater than one is a necessary and sufficient condition for labour demand to be increased provided that technological change is Hicks-neutral[35].

Katsoulacos (1986) has extended this result to the case of imperfect markets by introducing a price-cost margin different from unity. He has shown that the influence of technological change on labour demand then depends on how the elasticity of demand varies with output[36]:

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[33] which are two basic components of the economics of technological change, although they are not the only ones, or necessary ones.

[34] see Katsoulacos (1986) chapter 3. The result still requires that preferences be homothetic.

[35] i.e. can be formalized as a product augmenting trend.

[36] Stoneman (1983) has established similar results (though in less general cases) using specific production functions, Cobb Douglas and CES, and constant elasticity of demand and assuming perfect market conditions. Conversely Stoneman (1983) did not simply treat technological change as a productivity shock but in a more

$$\text{E9}: \quad \overset{\circ}{L} \geq 0 \leftrightarrow q\left(\frac{\sigma}{\theta_k}\right)\left(1-\left(\frac{1}{\eta_c}\right)\right) \geq \beta$$

where $\eta_c$ is the derivative of the elasticity of output with respect to changes in the unit cost c, ( $\eta_c$ is thus a function of the price-cost margin),

$\beta$ is the Hicksian index of the bias of technological change, measuring the proportionate change in the capital/labour ratio attributable to technical change at constant factor prices,

$\theta_K$ the share of capital in total cost,

$\sigma$ the elasticity of substitution between labour and capital,

and q is the Hicksian measure of the extent of technological progress (i.e. the residual unexplained by the growth of input).

Equation E9 precisely calculates the extent to which the responsiveness of the elasticity of demand to technological change (via price changes) will lead to an increase in demand for labour.

Let us now turn to approaches making even stronger assumptions in terms of price stickiness and market imperfections.

In the disequilibrium approach, as developed in Barro Grossman (1971), Benassy (1975) and Malinvaud (1977), rigid prices and wages lead to quantity constraints in markets. The effect of technological change on employment then depends on the situation in each market. The basic disequilibrium model allowed for two markets (goods and labour) and two inputs. In this context, any productivity shock was bound to have a negative impact on the demand for labour if both goods and labour were in excess supply. Such a scheme helped to distinguish between Keynesian and classical unemployment and hinted at the relevant policies to fight it. Nonetheless, at this aggregate level its predictions remain crude regarding the relation between technological change and employment. One way to overcome this limited capacity to account for structural changes has been to consider that market

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substantive way in line with the structuralist approach.

imperfections, leading to quantity constraints, are induced more by technical rigidities than by price rigidities[37]. Sneessens (1987, 1990) thus develops a model where the representative firm in each sector has a given Leontief production technology (with given output/labour and output/capital ratios) and chooses its price and level of production so as to maximize its profits for a predetermined stock of capital. The quantity constraints bearing on these representative firms can stem either from shortages in demand (at the prices following from their optimization program they would be willing to produce more), or in capital (they would need a larger capital stock), or in labour supply (at the given wage they could employ more workers than are available). Such a model makes it possible to estimate the impact of some given technological change (in the form of a shift in either the labour output ratio or the capital output ratio, or both) on the demand for labour. It does not however lend itself to analytical solutions and furthermore such a model has to distinguish between many sectors to account comprehensively for structural changes, which leads to econometric difficulties as soon as the number of sectors is more than two[38].

At this stage we have drifted away from fixed-price approaches towards multisectoral macro models where technological change is largely exogenous, but which have the great advantage of allowing for empirical investigations in realistic cases of multisectoral specific technological changes.

b) Multisectoral models.

The sixties and seventies witnessed the development of many multisectoral macroeconomic models along with the development of computing capacities and the increasing availability of relevant statistics. We do not intend to survey all these developments, especially in light of the crisis of confidence they underwent in the early eigthies when they failed to account for some shifts in productivity and investment. We shall therefore focus on the very contemporary multisectoral models which have tried to overcome the weaknesses of standard Keynesian macro models in accounting for structural changes. The main constraint on these developments come from the fact that the empirical

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[37] There are other ways to overcome this limited capacity using various alternative assumptions on how market clear ; Stoneman (1983) points to the introduction of price expectations as in the neo-classical framework; Sneessens (1990) refers to the use of computable general equilibrium models.

[38] As assessed in Sneessens (1990) on the basis of the two sector disiquilibrium model estimated in Artus, Avouyi-Dovi Laffargue (1987).

investigations which constitute their comparative advantage cannot rely too systematically (econometrically) on past observations if the structural changes under review present a radical break with the previous periods, as Wilson (1987) concludes from a survey of estimates of the various elasticities involved in measuring the impact of technological change in a macroeconomic Keynesian model. It follows that in times when technological change is more than incremental in all fields these macro models have to resort to a large extent to expert advice and simulations in conducting their empirical investigations[39]. The main drawbacks of this method are, first, that it is open to a degree of arbitrariness which severely limits the credibility of the results and, second, that nothing guarantees that all the various hypotheses are mutually consistent. In fact we are not at the level of firms or studying the diffusion of detailed techniques where experience can be called upon; for these macro models, experts are asked to produce their own guestimates. An illustration of the misunderstandings this situation can lead to is given by the debate over the results of the study by Leontief and Duchin (1986). The authors analysed the employment effects that computer technologies (CT) may have in the US over the period 1980-2000; they used an input-output analysis with special CT branches and a dynamic modelling of investment[40]. This elaborate study, bringing together a lot of expertise in technology, showed new trends in productivity for detailed sectors which resulted in a negative overall effect on employment, everything else being equal in particular concerning the growth of final demand. Cyert and Mowery (1988) reported how some critics challenged the evidence as insufficient, showing a credibility gap regarding the assessment of the supply side transformation, while the scenarios proposed by Leontief and Duchin focused on various alternative demand effects leading to overall positive effects on employment: in two scenarios out of three the demand for labour in 2000 exceeds expected supply! The effects on demand were thus much more debatable issues, as rightly underlined in De Wit's 1990 survey.

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[39] This does not deny the interest of purely retrospective studies such as those of Young and Lawson (1986) for the US (quoted in Cyert and Mowery's 1988 survey), or Wragg and Robertson (1978) for the UK, which all tend to show that in roughly two thirds of sectors technological change reduced labour requirements per unit of output, but that in a good half of cases this detrimental effect was more than offset by employment growth induced by growth in final demand.

[40] A similar attempt but restricted to the use of industrial robots was conducted at the same time by Howell (1985).

The similar studies on the employment effect of information technologies done by Whitley and Wilson (1982, 1987) display other aspects of the same issue, namely the transformation in the various components of demand.

In Whitley and Wilson (1982), simulations run on a macro model of some forty sectors of the U.K. economy over a decade (the 80's) show that direct displacement of 342000 jobs will be compensated by a) 175000 jobs induced by price decreases, b) 142000 jobs induced by higher domestic demand and c) 106000 jobs created by improved non-price competitiveness, leaving a gain of 81000 jobs which could be turned into a loss of some 132000 jobs under an alternative assumption regarding the relative speed of diffusion of IT in the UK compared to her competitors!

Whitley and Wilson (1987), using an extended version of the previous model (49 sectors, with greater emphasis on services) and updated assumptions regarding productivity trends, run some simulations of the effect on employment of various IT diffusion patterns in the UK over the decade 1985-1995. Their conclusions point clearly to sectoral imbalances. In the baseline scenario, the rise in productivity trends does not improve the competitiveness of UK manufacturing industry sufficiently to halt the steep decline in industrial jobs, while rather reduced productivity gains in most service activities contribute to further strong increases in tertiary jobs. Simulations then show that increased IT diffusion would benefit employment in manufacturing by some 281000 jobs by 1995, while a similar boost in services would reduce the employment level by some 521000 jobs! It follows that much of the overall effect of the specific technological change under view (namely IT diffusion) depends upon our ability to follow the transformation undergone in service activities, a rather weak point in so far as supply and demand effects are particularily intricate. Taking lessons from the two examples above, the Meta-Studie research project (Matzner, Schettkat, Wagner 1988, Matzner, Wagner 1990), carried out in Germany with the cooperation of nine research institutes, developed a more comprehensive approach towards service activities and technology, taking into account all foreseable technological changes beyond IT. Special attention was also paid to the effect of technological change on external competitiveness by means of exogenous shifts in export and import elasticities assumed to be related to technological changes. This multi-dimensional project operated at all levels (micro, meso and macro), using different methodologies; simulation models were constructed, comparable with the above multisectoral models, and the results of the investigations at the micro and meso levels were fed into the macro models used[41]. Beyond all the issues addressed and the information gathered, the simulations run on various macro models (encompassing different elements of the improvements) lead to the impressionistic result that the diffusion of new technologies has a slightly detrimental effect on employment but that any lower rate of diffusion would be worse because of its detrimental effect on competitiveness and demand.

Finally, the Meta-Studie tends to reinforce some of the conclusions of the previous studies on the importance of demand effect, as well as retaining some of their shortcomings.

By and large the Multisectoral models still remain at the centre of most debates on technological change and employment, thanks to their capacity for empirical investigation. Five points seem to follow from these various empirical simulations.

First, technological change has been given some specific content, with reference being made in the first place to information technologies. However, this caracterization of technological change requires some theoretical framework on innovation and diffusion behaviour which would help to check the consistency of the various assumptions on productivity trends.

Second, the crucial rôle played by the magnitude of demand effects in the assessment of the overall effect of technological change on employment has been confirmed. The fact that technical progress may cause unemployment by pushing the growth of potential output beyond the development of demand was for instance clearly noticed in Pasinetti (1981), as nothing ensures that the two multisectoral patterns of change would coincide in the short run, leading at least to cyclical technological unemployment. However, the empirical findings on this demand issue remain sketchy (see Bosworth 1987), which prevents assessments from being empirically grounded.

Third, the effect of technological change seems to differ widely between manufacturing and service sectors, as underlined in the stylised facts recalled earlier. Much of the effort to account for demand effects is thus linked to an understanding of innovation in services.

Fourth, the slowdown in productivity gains did not feature in the above analyses. Either some lags and learning effects are not accounted for, due to the lack of a theory of

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[41] This way of putting what would have been background reports in other studies upfront is a way of overcoming partially the bias in the discussion of the results induced by the opacity of the hypotheses.

innovation and diffusion (see point 1 above), or conversely the fact that productivity gains may be endogenous is not taken into account.

Last, technical change in all cases and sectors continued to be regarded as exogenous. The causality then ran from technological change to employment, disregarding the fact that the level of economic activity itself can impinge upon the diffusion of technological change (if not upon innovation itself).

The next field of post-Keynesian studies will deal with this last issue in part by focusing on the endogenization of technological change induced by the combination of market expansion and labour division.

c) Endogenous productivity gains.

Adam Smith's law linking the division of labour to the extent of the market and Allyn Young's developments pointing to the dynamics of innovation brought by an enlarged division of labour both between and within firms are basic references for these approaches. Kaldor in particular found in this combination the elements on which he based his cumulative causation pattern (see Kaldor 1966, 1972, 1981): the expansion of markets leads to external and internal increasing returns; these productivity gains are in turn transformed into expanding markets, providing certain conditions are met regarding the formation of demand. The very simple Verdoorn law, linking medium term productivity gains to output growth, was chosen as a reduced form to account for these dynamics[42]. Most developments on these Kaldorian lines consisted in assessing and estimating extended formulations of this cumulative causation pattern beyond the reduced form initially given by Kaldor. In principle such approaches make a neat distinction between the interrelated dynamics of the obtention of productivity gains on the one hand and of the allocation of these productivity gains towards various determinants of demand on the other. However, empirical investigations on these lines have mainly been devoted to estimating equations of productivity gains, somehow neglecting once more the crucial aspects of demand formation[43]. Although such estimations

[42] After the relative failure of Kaldor, 1957 attempt to account for technical change outside the framework of a "standard aggregate" production function, this was an oversimplified way of accounting for the embedded nature of technical change: output growth led to investments which stimulated diffusion of new techniques and increased productivity gains.

[43] These estimates correspond to developed Verdoorn laws as can be seen in the Symposium on Kaldor's laws, published in a special issue of the Journal of Post Keynesian Economics, May 1983.

can lead to reasonable accounts of the productivity slowdown (see Michl 1985), they fell short of providing new perspectives for addressing the issue of technological change and employment. Attempts to estimate fully fledged cumulative causation models including both the obtention and the allocation of productivity gains can be dated back to Cornwall (1977) and Boyer Petit (1981). The latter retained a set of simultaneous equations assessing formation of demand and productvity gains, though internal demand as well as the pace of technological change, given by R&D expenditures remained exogenous. Running the model over the decades of rapid growth for six European industries suggested a negative impact of innovation on manufacturing employment which could only be overcome by assuming that the level of demand was significantly boosted in the process[44]. Further works did stress the importance of matching an analysis of demand formation with the obtention of productivity gains (see Boyer 1987, Boyer Petit 1991), but failed to produce empirical investigations of these fully fledged models[45]. Distinguishing analytically between various arrangements of institutions constituting the roots of demand formation (whether it concerns wage, price or profit formation) made it possible to define various growth regimes (wage-led, export-led, etc), all of which condition the type of effect that technological change can have on employment. Such formalization of the link established between wage formation, technological change and the growth of employment is clearly illustrated in Fagerberg (1991).

For instance, in the case of full wage-productivity indexation Fagerberg's model shows that full employment equilibrium could be attained :

$$\overset{\circ}{L}=\alpha+\frac{(1-\pi)(\sigma+\beta\tau)}{\mu}$$

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[44] If, following a switch towards a more capital intensive technology, the investment/output ratio was increased by 1% (and demand increased accordingly by an increase in investment), employment would contract by 0.2 %. A rise of one percent in the ratio of R&D to value added would lead to a reduction in employment of some 0.5% (without taking into account any alleviating effect of the corresponding rise in demand). This negative effect is not so surprising as service activities were left out of the analysis.

[45] Reasons for this failure are numerous, ranging from the simplicity of the model (with one sector and a crude approach to technological change) to econometric difficulties linked to colinearities and differences in the intrinsic stability over time of obtention and allocation of productivity gains, the latter being more volatile.

where $\dot{L}$ is the growth rate of employment,

$\alpha$ the growth rate of labour supply,

$\pi$ the elasticity of real wage to productivity,

$\mu$ the elasticity of real wages to unemployment,

$\beta$ the growth rate of capital per worker,

and $\tau$ the elasticity of productivity to capital per worker.

However, in this formulation any partial indexation ($\pi < 1$) should lead to excess demand for labour and any upwards shift in the growth of capital per head $\beta$, linked to technological change, should reinforce this tendency.

Sylos Labini (1984, 1991) has developed an alternative formalization of the Kaldorian endogeneisation of productivity gains, putting more emphasis on price differentials between capital and labour than on institutional arrangements:

$$\dot{L} = c\dot{Y} - \alpha\ \dot{UC} - \beta(\dot{W} - \dot{Pm})^{-\tau}$$

where $\dot{L}$ is the growth rate of employment,

$\dot{UC}$ the growth rate of unit labour costs,

$\dot{W}$ the growth rate of nominal wages,

$\dot{Pm}$ the growth rate of the price of equipment,

and $\gamma$ with $c = 1-\gamma$ is the elasticity of productivity to output.

The effect of innovation will then depend on how the incentives to substitute capital for labour caused by innovation are matched by a rise in output, although demand remains exogenous in this formulation. In a more comprehensive way Scott (1989) developed a new growth model insisting on the embedded nature of technological change within investments in a broad sense[46]. Biases in investments/arrangements, due to misled animal spirits of standard investors as well as misled wage-earners' expectations, explain the mismatches provoked by technological changes. This joint treatment of demand formation and of productivity gains is in accordance with the cumulative causation approach[47]. The notion of arrangement/investment also hints at some technological assessment, although it does not seem to be easily manageable in practice.

Finally, although these developments of Kaldor's work stress an important side of the endogenous nature of technological change and provide us with a coherent way of accounting for productivity slowdown (see Boyer Petit 1991), the nature of this change remains nearly as abstract as in the previous post-Keynesian analyses. Accounting for the dynamics of the division of labour between firms and the ensuing increasing returns is not the end of the story; it still leaves unexplained the pace of diffusion, the nature of change, (whether process or product oriented), and the sectoral dimension of this structural change.

**II 3 Modelling innovation and structuralist approaches.**

The last set of contemporary analyses we shall consider address the specificity of technological change more straightforwardly, borrowing from various traditions in particular Schumpeter but also Hicks and Chamberlin.

As their description of technological change mainly focuses on productivity gains, the above post-Keynesian approaches tend to be biased towards process innovations. This indirect approach to technical change limits their ability to deal with all the time lags, learning and behavioural changes which are at the core of the economics of innovation. The challenge of approaches trying to achieve a more realistic and direct appraisal of technical change is to pass beyond that stage and still be able to assess its impact on employment at the micro, meso and macro levels.

To overcome these shortcomings one has to look more closely at the production process, not only at the level of the firm where the decisions regarding innovation are taken

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[46] Scott (1989) develops an extensive notion of investment which includes all types of lasting arrangements, although in practice his empirical investigations boil down to physical capital, R&D and advertising expenditures.

[47] Scott does not however consider Kaldor's approach of static and dynamic economies of scale as persuasive and prefers to interpret the facts referred to as helping to explain why investment opportunities persist over time and why returns on investment do not appear to diminish appreciably.

but also at the inter-firm level where all kinds of organisation may combine to foster and diffuse technological change. Schumpeterian approaches follow such a structuralist perspective in insisting upon the role of innovation in market competition, i.e. in the decision-making process of entrepreneurs. These approaches have not however covered process and product innovations to the same extent and have again mainly analyzed the choices of new production techniques. For this reason we shall pay special attention to the Chamberlinian treatments of product innovation, where product innovation is regarded as product differentiation. Similarly, we shall complement the Schumpeterian approaches, which try to account for the specific time-structure of innovation, with analysis focusing on the critical linkages between decisions and time as exemplified in the works of Hicks and his followers, although their modelling of technical change itself remains rather crude. We shall begin this last part of our survey with these Hicksian developments, then review modelling of product innovation before dealing with the structuralist approaches themselves.

a) The Hicksian legacy.

One of the main shortcomings of the analyses of productivity changes was that they transformed technological change into a smooth, monotonous process, whereas experience suggests that discontinuities occur which may provoke upswings and downswings of economic activity or, conversely, be provoked by such cycles. Thus the occurrence of a major process innovation not only constitutes a break but also launches a process of capital accumulation which takes time and structures the growth pattern of the economy. Hicks (1973) focused on is problem of long run transition from one steady state growth path to another for an economy where an innovation in productive equipment occurs. He used for this purpose a neo-Austrian framework where technology is represented by a time profile of inputs and outputs. Further assumptions on distribution (wage rate is fixed, all wages are consumed), demand (gross profits accruing to capitalists, once wages are paid for, are supposed to be constant between the two technological scenarios) and on the working of the capital market (the interest rate ensures that markets clear) help to determine the transition path. The time path of output and employment will finally depend on the technical coefficients of the two technologies (and especially upon the time it takes to produce the different equipment). This transition period can alternate with phases where employment is over and under its level in the reference path and can present some risk of overshooting before it settles down on its new steady state growth path. Hicks's approach to this problem of the "traverse" thus helped to investigate the whole set of issues raised by the transition from one steady state growth path to another following a process innovation. Yet the approach is very general and implies the working of financial markets, distribution issues or factors more akin to standard analyses of the economics of technical change and diffusion. Amendola Gaffard (1988), using a multisectoral neo-Austrian model to simulate various "traverses", put the stress on the working of financial markets. The effect on employment again varies in accordance with the technical coefficients retained. Such simulations tend to underline the fact that much depends on the ability of firms to get their investments in the new techniques financed.

While the overall framework is close to the initial Ricardian question of compensation effects, the debate over the problem of the traverse makes it clear that no full compensation is certain and that the dynamics of the economy during this transition period are open. The more comprehensive view given by the Hicksian approach of the dynamics of economies submitted to "exogenous" technological change opens the way for more radical considerations, as given in the recent literature on chaos. Day (1982) has shown that slight departures from the standard Cobb-Douglas framework of Solow could lead to chaotic behaviour of the economy. Such possibilities in the course of the transition process between two states of technology raise a lot of interesting issues[48]. Either one can see such instability as a cause, preventing an economy from reaching a new path of steady growth, or one can look for the economic stabilizer (such as a propitious type of industrial relations) which has carried the economy out of the doldrums of stagnation induced by some kind of technological change (for instance being too process-oriented).

Going back to the Hicksian approach, it should be noted that it can be combined with some standard approaches in the theory of diffusion, explicitly transforming the transition time path into a diffusion path. The study of actual technological changes is thus made possible, as shown in Stoneman (1976) with the diffusion of computers in the UK. Rapid diffusion of computers is assumed, which implies significant growth in employment in the capital goods industry which overtakes for a while the labour-saving effect in the industries using computers. It clearly shows in a simplified yet realistic context how the compensation effects evolve over time. A generalization of this Hicksian application is given in Stoneman

[48] On these chaotic growth models and their implications see Lordon (1991).

(1983, appendix chapter 12) within a two sector model where the diffusion of the new technique follows a probit scheme[49]. It stresses that the speed of diffusion is itself an important determinant of the overall pattern of transition. The time path of employment thus depends upon (a) the time path of consumption (dependent in turn upon the time path of wages[50]), (b) the speed of diffusion and (c) the specific coefficients of the technologies under consideration, all of which confirms that there is no general answer concerning the effect of technological change on employment.

Despite the emphasis they quite correctly put on the overall dynamics of an economy in transition, the main flaw of these Hicksian approaches certainly remains the crudeness of their assumptions on demand (kept somehow constant whatever the technological scenario), which most often leads them to underestimate the net effect of technological change on employment. We shall quickly survey how this limit has been partly overcome in dealing with product innovation, before going on with our review of openly structuralist approaches.

b) <u>Product innovation in a Chamberlinian legacy</u>

There is widespread agreement that product innovations have a beneficial effect on employment. However, little has been done to assess precisely the necessary and sufficient conditions for such a net effect to take place. Basically most authors have emphasised that many process innovations could not cope with stagnation if internal demand in a closed economy was satiated, in which case the supply of labour could shrink following increases in productivity brought about by process innovations. Some autonomous growth in demand thus appeared to be a necessary condition of economic growth. As a matter of fact the fear of satiation (and of a shrinking labour market) is not the only issue around product innovation. Thus if the product innovation is a substitute for existing products, its diffusion may very well end up reducing economic activity and employment. There is therefore a real need to go beyond a general assessment of the general stimulus given to demand expansion by product innovation. The question is then how to establish in a given analytical framework

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[49] i.e. the heterogeneity of firms drives the diffusion process as the price of the new equipment declines over time. An epidemic scheme, where firms are similar except in their access to "information", could alternatively have been selected.

[50] If there is full flexibility of wages and prices, then by definition price changes can adjust to cope with any disequilibrium and there is no technological unemployment, as recalled earlier. With these Hicksian approaches we are therefore in an environment of relatively fixed price equilibrium.

what a "new" product is. The first solution to this problem was given by analogy with the treatment of process innovations. Clearly process innovations are also product innovation for the capital goods industry. The capacity to reduce production costs in industries using new equipment led to exceptional increases in the demand addressed to these capital goods industries. Innovation is thus revealed by a shift in the structure of demand. Such an approach is however to close to a tautology to be really of any use. It is not tractable as it does not distinguish between causes and effects; the question of whether a product innovation has positive or negative impact on employment has no meaning anymore and it also skips the case where innovation possesses a systemic nature which boosts demand for all products[51]. Another solution, much referred to in the 80's after Dixit, Stiglitz (1977) and Krugman (1979) used it, recalls the notion of product differentiation introduced by Chamberlin to account for imperfect competition. This tries to express what the "economy" of the final consumer is. Thus the consumer is supposed to balance the negative utility of work with the utility gained from n goods, partly substitutable, possibly extended by the occurrence of product innovation. Because of this partial substitutability, innovations appear as new quality of similar products, which defines a case of horizontal product differentiation. The optimization of the consumer programme mentioned above shows that an increase in the number of products does increase employment, but that this net positive effect on employment diminishes when the degree of substitutability between products rises. Such a case of horizontal product differentiation appears to be limited to a short or medium term perspective, as the list of products is not constantly increasing and some actual product innovations do eliminate old products from the market. The case of vertical product differentiation is an attempt to account for this Shumpeterian process of destructive creation. Drawing upon the work of Shaked and Sutton (1983) on "natural oligopoly", Katsoulacos (1986) develops a model where the occurrence of a new product increases the utility of the consumers and displaces an old quality good from the market. Two goods are produced in the model, one standard and one quality good for which one firm covers the whole market (the case of natural monopoly); workers have the same utility function but their efficiency at work and the negative utility of work for each of them differ and are uniformily distributed over a given range. It is shown in this context that a new product of higher quality can be

[51] as it may well be the case with a change of technological system, as some authors, referring to the present diffusion of information technologies suggest.

priced so as to capture the market, which will increase welfare and therefore employment, as the willingness to work is increased in the process. The model of creative destruction by Aghion and Howitt (1991), including labour market and employment issues, is also to be recalled at this stage.

In any case, it is clear that the above developments on product innovation only retain a fraction of what is referred to as product innovation. The context is one of general equilibrium, which rules out the question of technological unemployment, and of full information, rationality and optimization behaviour which limits its application to the cases where the partial equilibrium (or probit) model of diffusion is relevant, while models of diffusion assuming bounded rationality, incomplete information and non-optimizing behaviour would seem rather more relevant in the case of final users. The structuralist neo-Schumpeterian approaches, which we shall review next, appear in that respect all the more complementary in so far as they take these characteristics to be general when studying the process of innovation.

c) <u>The Schumpeterian structuralist tradition</u>

There has been a widespread revival among economists of Schumpeter's idea that innovation was a driving force in market competition in the 70's and 80's. As recalled in section I of this paper, part of this resurgence comes from the limited capacity of the Keynesian conceptual framework to account for the vagaries of economic growth in developed economies, and part from the coincidence of the downswing of the fourth Kondratiev cycle with the surge of a new technological system centered around technology information technology.

The return of mass unemployment, at least in European countries, which standard reflation policies seem unable to cure, is a sign which somehow combines these two aspects. Accordingly, some of the authors who constitute the neo-Schumpeterian tradition tend to insist on the microeconomics of market developments while others concentrate more on the macroeconomics of long term cycles. The works of Nelson and Winter are representative of the first current, those of Freeman and Soete of the second. Just for sake of clarity, and without underestimating their basic agreement, we shall follow this order for a rapid presentation of their approaches.

Interestingly enough Nelson and Winter (1974, 1982) start with the objective of accounting for the same data as Solow but using a conceptual framework where the driving forces of economic growth are the selection of innovations and the ensuing accumulation of capital. In this process firms are supposed to be satisfaction-oriented rather than maximization oriented and to do so by trial and error in search of a satisfying technique for instance. On this basis Nelson and Winter set up a simulation model where firms start with a set of 100 feasible techniques (each given by a capital/labour ratio) and where the initial conditions for the aggregate are those met in Solow's work. The labour supply is here exogenous as well as the depreciation rate and the expected rate of return on investments. The simulation of this Schumpeterian behaviour of firms reproduces the kind of smooth aggregate trends as analysed by Solow. It follows that looking into the structure of the productive process and allowing for the breaks that innovations represent does not necessarily lead to chaos, and can even give well ordered patterns, depending on firms' behaviour. Conversely it implies that one can find some configurations of technological change where the aggregate patterns present discontinuities or trends which cannot be accounted for by standard macroeconomic approaches. The problem is then to identify the precise configurations which hamper the growth process and the full employment of labour resources. Once it is acknowledged that there is no automatic feedback ensuring full employment, the analysis of Nelson and Winter calls into question how much room for manoeuvre is left for technology policies, all of which requires in turn a characterization of the institutional context of innovation (the national systems of innovation according to Nelson's terminology). Similar approaches simulating the behaviour of "Schumpeterian" firms have been developed either to be applied to country cases on the basis of information collected at the firm level, as done by Eliasson (1986) for the Swedish economy, or to analyze various patterns of technological competition, as done with the self-organisation model successively developed in Silverberg (1984) and in Dosi, Orsenigo and Silverberg (1988).

The difficulty with these various models of "technological competition" remains their empirical basis. Either one tends to fix the technological choices observed in detail at some point in time or one assumes a certain scheme of technologically driven market competition with little empirical grounding apart from expert advice. Technological change somehow loses part of its historical specificity regarding its very nature as well as the context of industrial relations which forges it. The approach thus seems to balance between one-to-one mapping, where it is difficult to assess the key issues of the period, and a rather abstract treatment with little reference to actual technological change. In this respect, the other half of the structuralist approach is highly complementary in insisting largely on this historical specificity.

The questions of Freeman and Soete (1982, 1987) emerge from investigations into the historical patterns of innovation and on its relationship to macroeconomic evolution. The occurrence of a new technological paradigm around information technology is presented from the start as a means of getting out of the downphase of a Kondratieff cycle. A new technological paradigm implies the diffusion of clusters of innovations which should boost a whole set of economic activities. The argument is not deterministic and allows that many things are likely to block the process of recovery, in some countries at least. The thesis developed in fact tries to account for the productivity paradox (why is economic growth so sluggish when such a new technological system is available and is being put to use?) in allowing for delays in learning and organisational difficulties[52]. There is also the idea that technological change is for a large part endogenous and that slow growth in itself is a major source of these difficulties, all of which leads the authors to advocate adjusted reflation policies which would ease the mastering of the new technologies and accurately help to restructure the supply side of the economy. The argument is not elaborated within one type of formalization, partly because the thesis is being built up, gathering material in various fields of activity and pursuing certain lines of argument, partly because it fails to capture the specificity of such a broad category as a new technological paradigm within a practicable theoretical framework [53].

In that respect some truly structuralist developments of the above thesis are worth considering here, although they are only concerned with process innovations. Changes in techniques of production do not simply shift the capital/labour ratio but also affect the skill structure of jobs. The difficulty of adjusting this skill structure in times of technological

[52] of which lack of standardization is one of the more important.

[53] It is worth recalling that the works assessing the impact of IT, which we have already surveyed with the Input/Output research, mainly based their estimations on detailed firm surveys or on expert advice and were crude in their treatment of final demand.

change can thus generate unemployment, which would account for unexpected slowdowns in productivity gains. In the present case, if one assumes that the requirements, in terms of skills, of the diffusion of information technology in various activities are known, then one can track whether or not the adjustment of the job structure keeps pace with the modernization of equipment. In the short and medium term it is indeed easier to raise physical rather than human capital, as stressed by Katsoulacos (1986, chapter 8). However, such an approach implies a certain rigidity of requirements as well as non-substitutability between workers of different skills; whereas in the sixties, for instance, the debate on structural unemployment precisely petered out as requirements adjusted and unskilled workers were used as substitutes for skilled workers. The application of this structuralist approach to the study of the diffusion of information technology thus implies a specific rigidity in skill requirements if only to take full benefit of their advantages. The works of Blackburn, Coombs and Green (1985) and others, putting in a long term perspective the various phases f the mechanization of work, go in that direction. Implying in the end a real break in work organization, they stress that IT now extend mechanization to the control functions, whereas it initially applied to transformation functions (over the first cycle), and then to transfer functions (over the second and third long wave). On the basis of such assumptions, studies on the evolution of job structures in the course of IT diffusion have mainly investigated the sectoral dimension of the productivity slowdown, stressing in different ways that the delays in adjusting the skill structure were longer in service activities than in manufacturing industries (see Baumol, Blackman and Wolff 1989, Roach 1989, De Wit 1990, Petit 1991). So far studies on the effect on unemployment of mismatches between supply and demand for skills are rare, although much of the literature linking persistant mass unemployment to a hysteresis effect (see Blanchard and Diamond 1989) could be related to such skill mismatches, as hinted at in Freeman and Soete (1985a) and stated explicitly in a simulation model of long term macroeconomic growth in Petit and Tahar (1991). These extensions do not cope with the weaknesses of the structuralist approach that were mentioned above; but despite these weaknesses (or thanks to them) this approach stimulates and frames the contemporary questioning on the issue of technological change and employment. Somehow most of the contemporary developments that we review can be of some use in developing the argument, except for those restricted to static general equilibrium and its behavioural context regarding rationality and information of agents. In that sense this approach is both at the core of the actual debate on technology and employment and in a position to insist that the answer is necessarily multidimensional in a developed and integrated world economy, as we shall stress in the following conclusion.

## SECTION III NEW PATHS AND AGENDA FOR RESEARCH.

### 1. New complementarities and complexities

In reviewing contemporary developments in the analysis of the effect of technological change on employment one is struck by the complementarities which exist between the various approaches. One first notices the complexity of the dynamics of structural change in an economy. Both the R.B.C. and the evolutionary approaches show that erratic microeconomic events either from exogenous shocks or linked to "realistic" behaviour of firms combine to produce a smooth pattern of economic growth. Conversely one has limited insights when confronted with an unusual macroeconomic evolution and in such cases a structuralist approach to the inner changes in the production process may help to figure out which are the main characteristics of the behaviour at the origin of the odd macro evolutions. On the other hand the New Growth Theory points to factors such as the accumulation of knowledge as the source of endogenous technological change but says very little which could help to understand the failures and blockages of the process, where an approach allowing for the time requirements of capital accumulation or the diversity of the various branches of economic activity is required.

This does not mean that the approaches under review all have the same relevance, nor that one approach is always able to give an insight into the shortcomings of any other. We have observed that the complex dynamics of our economies should often lead to chaotic behaviour and that we fail to account for most of the stabilizing effects. The simulation of evolutionary models shows how a given set of behaviour can lead to a smooth growth pattern but does not put an end to the question. If one agrees on the endogenous nature of technological change, the dynamics may be complex and theoretically too dependant on initial conditions. One has to take account of the fact that some reactions have a stabilizing role on the process. Two processes may be involved: the adjustment of work organization and the scrapping of old equipment, two subjects on which our current knowledge remains limited (and our past knowledge obsolete). The developments in the theory of diffusion of technological change which insist on path dependency (as in the works of Arthur and David) or on strategic behaviour do show that we have to enlarge the scope of the microeconomics on which our analyses of technological change and employment are based. The conclusion to be drawn when faced with the complexity of the dynamics of the structural change is that we cannot expect the kind of simple answer implied in the notion of compensation effect but we can feature certain aspects of it using various approaches and enlarge our understanding by developing approaches to specific processes and topics, even such classic ones as the whole set of learning processes, the treatment of product innovation or the new context of "globalization" in which technological change now occurs.

1 Developing the analysis of the adjustment/learning processes may rank first on the agenda. The insistence on the largely incorporated nature of technological change should not obscur the fact that there is a long way between the instalment of equipment and its "efficient" use even at a local level. However, the general acknowledgement that such learning processes exist should be taken further so as to understand the inner dynamics of these learning process. All kinds of learning can be called upon, although some consistency is required along with an exhaustive assessment of all the processes involved. Special attention should be paid to learning process linked to the employment function of the firm. One should distinguish between learning processes which represent some adjustments of industrial relations or of work organization and learning processes constituting more obviously an untangible asset. Some developments on incentives and strategic behaviour within the new industrial economics would be worth considering in that respect.

2 New steps have been made to account for product innovation in referring to product differentiation. It helps in particular to give some content to the notion of technological competitiveness. Nonetheless, this product-innovation side remains a weak part of the analysis, especially when it comes to empirical investigations. Horizontal differentiation seems to refer mainly to incremental innovations, while vertical differentiation remains a difficult concept to apply. It follows that crude assumptions on demand effects still play a crucial part in assessing the "compensation effects" of technological change. There is no easy way out of this black hole, although debates could be clarified. One could in particular adjust the approach of the utility of final users to the specificity of the technological side under review. Regarding the diffusion of IT, for instance, various externalities are at work

producing networking effects, all of which may help us to understand the rigidity of some learning processes on the end users' side.

3 Finally, a major break in the old employment/technology issue comes from the fact that technological change increasingly takes place at a worldwide level. Economies of scale are partially international and external demand is a major component of demand. In this interdependant world the employment issue remains national. The timing of all the learning processes we referred to cannot be synchronized at a national level. The pace of technical change is set at a worldwide level which reduces the room for manoeuvre for an economy trying to adjust in accordance with the characteristics of its labour force. It is all the more important to assess the stringent conditions for positive institutional adjustments. This would question national systems of innovation (in a very comprehensive way) and their dynamics in space and time.

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